NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF MECHATRONICS ENGINEERING

COURSE MATERIALS

MR 407 AUTOTRONICS

VISION OF THE INSTITUTION
To mould true citizens who are millennium leaders and catalysts of change through excellence in education.

MISSION OF THE INSTITUTION
NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values. We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

ABOUT DEPARTMENT

- Established in: 2013
- Course offered: B.Tech Mechatronics Engineering
- Approved by AICTE New Delhi and Accredited by NAAC
- Affiliated to the University of Dr. A P J Abdul Kalam Technological University.

DEPARTMENT VISION

To develop professionally ethical and socially responsible Mechatronics engineers to serve the humanity through quality professional education.

DEPARTMENT MISSION

1) The department is committed to impart the right blend of knowledge and quality education to create professionally ethical and socially responsible graduates.

2) The department is committed to impart the awareness to meet the current challenges in technology.

3) Establish state-of-the-art laboratories to promote practical knowledge of mechatronics to meet the needs of the society

PROGRAMME EDUCATIONAL OBJECTIVES

I. Graduates shall have the ability to work in multidisciplinary environment with good professional and commitment.

II. Graduates shall have the ability to solve the complex engineering problems by applying electrical, mechanical, electronics and computer knowledge and engage in lifelong learning in their profession.

III. Graduates shall have the ability to lead and contribute in a team with entrepreneur skills, professional, social and ethical responsibilities.

IV. Graduates shall have ability to acquire scientific and engineering fundamentals necessary for higher studies and research.

PROGRAM OUTCOME (PO'S)

Engineering Graduates will be able to:

PO 1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO 2. Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO 3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO 4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO 5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO 6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO 7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO 8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO 9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO 11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO 12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOME(PSO'S)

PSO 1: Design and develop Mechatronics systems to solve the complex engineering problem by integrating electronics, mechanical and control systems.

PSO 2: Apply the engineering knowledge to conduct investigations of complex engineering problem related to instrumentation, control, automation, robotics and provide solutions.

COURSE OUTCOME

After the completion of the course the student will be able to

C407.1	Acquire the basic knowledge in fundamentals of entrepreneurship and its process.
C407.2	Understand the various characteristics and competencies of entrepreneurs.
C407.3	Describe about the fundamentals of Business and Projects.
C407.4	Acquire knowledge in process of starting new ventures and international business.
C407.5	Interpret about time management, planning and innovation in entrepreneurship.
C407.6	Understand various funding assistance for starting new venture.

CO VS PO'S AND PSO'S MAPPING

CO	PO1	PO 2	PO3	PO 4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PS0 1	PSO 2
C407. 1	-	-	2	-	-	2	-	-	-	-	2	2	-	-
C407. 2	-	-	2	-	-	2	-	-	-	-	2	2	-	-
C407. 3	-	-	2	-	-	2	-	-	-	-	3	2	-	-
C407. 4	-	-	2	-	-	2	-	-	-	-	3	2	-	-
C407. 5	-	-	2	2	-	2	-	-	-	-	3	2	-	-
C407. 6	-	-	2	3	-	2	-	-	-	-	3	2	-	-

Note: H-Highly correlated=3, M-Medium correlated=2, L-Less correlated=1

SYLLABUS

Course code	Course Name	L-T-P - Credits	Year of Introduction
MR407	Autotronics	3-0-0-3	2016

Prerequisite : NIL

Course Objectives

- This course provides basic knowledge on the working of automobiles and the electrical and electronic systems in automobiles.

Syllabus

Automotive fundamentals: The engine-components-systems -Automotive sensors -Fuel injection and Ignition system –Electronic ignition system- Safety and comfort - Electric vehicles and hybrid vehicles - Vehicle Intelligence - mobile robot vision -object detection- collision warning and Avoidance system-low tire pressure warning system.

Expected outcome .

Students will

- acquire knowledge on the sensors used in vehicles
- be familiar with the various electronic controls used in automobiles
- become familiar with advanced comfort and safety systems used in automobiles

Text Book:

1. Tom Denton, Automobile electrical and electronic systems, BH Publication, Third edition 2004

References:

1. William B. Ribbens, Understanding Automotive Electronics - Sixth edition Elsevier Science 2003
2. Ronald K.Jurgen, Sensors and Transducers - SAE 2003
3. Jack Erjavec, Robert Scharff, Automotive Technology - Delmar publications Inc 1992
4. Ronald K.Jurgen, Electric and Hybrid-electric vehicles - SAE 2002
5. Ichiro Masaki, Vision-based Vehicle Guidance - Springer Verlag, Newyork 1992
6. Jay Webster, Class Room Manual For Automotive Service And System - Delmer Publications Inc 1995
7. Ron Hodkinson, John Fenton, Light Weight Electric/Hybrid Vehicle Design - Read Educational and Professional Publications Ltd. 2001.

Course Plan

Module	Contents	Hours	Sem. Exam Marks
I	Automotive fundamentals: The engine-components-Drive train -Starting & charging systems operation- Ignition system- Suspension systems-brakes -ABS - Steering system –Adaptive Cruise Control	7	15%
II	Automotive sensors: introduction- working principle of sensors- throttle position sensors-manifold pressure sensor-mass air flow sensor-engine coolant temperature sensors-vehicle speed sensors- crankshaft position sensors-exhaust gas oxygen sensors	7	15%
FIRST INTERNAL EXAMINATION			

III	Fuel injection and Ignition system: Introduction -fuel system components-electronic fuel system-fuel injection-types-throttle body versus port injection-electronic control fuel injection-operation-different types-fuel injectors-idle speed control-continuous injection system-high pressure diesel fuel injection – multi point fuel injection system –Electronic ignition system-operation-types-Electronic spark timing control.	7	15%
IV	Safety and comfort : antilock braking system-traction control system-electric seats- mirrors and sun roofs- central locking and electric windows-cruise control-electric power steering-electronic clutch-electronic suspension system-airbags	7	15%
SECOND INTERNAL EXAMINATION			
V	Electric vehicles and hybrid vehicles: Introduction-Electric Vehicle development- system layout- basic system components-fuel cell Electric vehicle. Hybrid vehicle: series Hybrid Vehicle - parallel Hybrid Vehicle-CNG Electric hybrid vehicle.	7	20%
VI	Vehicle Intelligence: Introduction -basic structure-vision based autonomous road vehicles-architecture for dynamic vision system -features-applications. An application of mobile robot vision to a vehicle information system-object detection-collision warning and Avoidance system-low tire pressure warning system.	7	20%
END SEMESTER EXAM			

QUESTION PAPER PATTERN

Maximum Marks : 100 Exam Duration:3 hours

PART A: FIVE MARK QUESTIONS

8 compulsory questions –1 question each from first four modules and 2 questions each from last two modules (8 x 5= 40 marks)

PART B: 10 MARK QUESTIONS

5 questions uniformly covering the first four modules. Each question can have maximum of three sub questions, if needed. Student has to answer any 3 questions

(3 x10 = 30 marks)

PART C: 15 MARK QUESTIONS

4 questions uniformly covering the last two modules. Each question can have maximum of four sub questions, if needed. Student has to answer any two questions

(2 x15 = 30 marks)

QUESTION BANK

MODULE I

Q:NO:	QUESTIONS	CO	KL	PAGE NO:
1	Discuss the various components in the battery ignition system	CO1	K2	54
2	List the various components in ABS of a car and mention its working	CO1	K1	67
3	Discuss in the technology behind the ACC.	CO1	K2	100
4	Sketch the spark plug used in automobiles and elucidate its working.	CO1	K3	64
5	List the various components in charging system of a car and mention its working	CO1	K1	41
6	Discuss in the technology behind the ACC.	CO1	K2	100
7	Discuss the various types of brakes.	CO1	K2	71
8	Sketch the connecting rod used in engine and elucidate its working	CO1	K3	25
9	Discuss in detail about the working of ABS	CO1	K2	66
10	Compare magneto ignition and coil operated ignition with suitable description and sketches.	CO1	K4	49
11	Investigate the adaptive cruise control technology in automobiles.	CO1	K6	100
12	Explain in detail about the various components of engine with neat figure.	CO1	K2	23
13	Investigate the various suspension systems in automobiles.	CO1	K6	79

14	List the various types of engines used in automotive industry	CO1	K1	16
15	Investigate the various braking systems in automobiles.	CO1	K6	71
16	Investigate the various steering systems in automobiles.	CO1	K6	90
17	List the various types of drive trains used in automotive industry.	CO1	K1	36
MODULE II				
1	Define Sensors and list the various sensors used in automobiles	CO2	K1	105
2	Judge the impact of sensors in modern automobile industries	CO2	K5	106
3	Discuss the working of vehicle speed sensor with neat figure.	CO2	K2	112
4	Judge the impact of sensors in modern automobile industries	CO2	K5	104
5	Demonstrate the working of MAF sensors with suitable sketch.	CO2	K3	107
6	Demonstrate the working of Manifold pressure sensors with suitable sketch.	CO2	K3	108
7	Demonstrate the working of voltage sensors with suitable sketch.	CO2	K3	110
8	Demonstrate the working of exhaust gas oxygen sensors with suitable sketch.	CO2	K3	108
9	Define Sensors and list the various sensors used in automobiles	CO2	K1	104
10	With neat sketch elucidate the working of vehicle speed sensor and exhaust gas oxygen sensor.	CO2	K3	112

11	With neat sketch elucidate the working of coolant temperature and crank shaft position sensor.	CO2	K3	116
12	Investigate the need for sensors in modern automobiles and specify some examples.	CO2	K6	105
13	With neat sketch elucidate the working of Manifold pressure sensor and MAF sensor.	CO2	K3	107
MODULE III				
1	Demonstrate the various fuel systems in automobile industries	CO3	K3	130
2	Discuss the types of fuel injectors	CO3	K2	133
3	With neat sketch discuss the working carburetor system	CO3	K3	129
4	With neat sketch discuss the working mechanical fuel injector.	CO3	K3	135
5	With neat sketch discuss the working electronic fuel injector.	CO3	K3	136
6	Compare mechanical fuel injectors with electrical fuel injectors system.	CO3	K4	135
7	Investigate the various types of fuel injection systems with suitable figures	CO3	K6	131
8	With neat sketch discuss the working throttle body fuel injection system.	CO3	K3	138
9	Discuss the working single point fuel injection system.	CO3	K2	137
10	With neat sketch discuss the working multi point fuel injection system.	CO3	K3	138
11	Discuss the working port fuel injection system.	CO3	K2	138
12	Compare throttle body and port fuel injection system	CO3	K4	138

13	List the basic components in an electronics fuel injection system.	CO3	K1	141
14	Investigate the working of electronically controlled ignition system	CO3	K6	146
15	List the various components of electronic ignition systems	CO3	K2	148
16	Discuss the working and applications of electronically controlled ignition system with suitable figure	CO3	K2	147
17	Discuss in detailed about the working of electronically control for spark timing.	CO3	K2	150
MODULE IV				
1	Discuss the need for ABS in modern vehicles with suitable justification.	CO4	K2	172
2	List the various components in ABS of a car and mention its working	CO4	K1	172
3	Discuss in the technology behind the traction control in automotives	CO4	K2	176
4	Sketch the circuit for electrically operated sunroof and discuss its working.	CO4	K3	181
5	List the various components in electric seat adjustment of a car and mention its working	CO4	K1	179
6	Discuss in the technology behind the central locking in automotives.	CO4	K2	186
7	List the various components in central locking system of a car and mention its working.	CO4	K1	188
8	Discuss in detail about the working of power windows	CO4	K2	186

9	Discuss in detail about the working of electric windows	CO4	K2	186
10	Investigate the cruise control technology in automobiles.	CO4	K6	191
11	Explain in detail about the acceleration and deceleration process in cruise control technology.	CO4	K2	193
12	Investigate the various components to dis engaged the cruise control system.	CO4	K6	192
13	List the various types of power steering systems used in automotive industry	CO4	K1	199
14	Investigate the various power steering mechanisms in automobiles.	CO4	K6	196
15	Compare the various steering systems with suitable description and sketches.	CO4	K4	197
16	Sketch the electric power steering system and elucidate its working	CO4	K3	199
17	Investigate the electric clutch mechanism in automotive	CO4	K6	200
18	With neat sketch explain the working of electric clutch in automotives	CO4	K3	200
19	Compare the working of electrically engaging and electrically releasing of clutches with neat figure.	CO4	K4	201
20	Discuss in detail about electronic suspension system in modern vehicles	CO4	K2	201
21	Discuss the types of electronic suspension systems	CO4	K2	202
22	Investigate the working of airbag system in auto motive’s while get crash.	CO4	K6	203
23	List the various components in airbag system and mention its working.	CO4	K1	204

MODULE V				
1	Relate the various types of EV’s and HEV’s	CO5	K4	209
2	Discuss about the characteristics of electric vehicles.	CO5	K2	208
3	List the key components of electric vehicle	CO5	K1	209
4	Investigate the working of electric vehicles.	CO5	K6	212
5	Investigate the working of electric vehicles fuel cells.	CO5	K6	234
6	List the main components of fuel cell electric vehicle	CO5	K1	235
7	Examine the advantages and disadvantages of the fuel cell electric vehicles.	CO5	K4	237
8	Investigate the working of hybrid vehicles.	CO5	K6	237
9	With neat sketch explain the working of hybrid vehicles.	CO5	K3	239
10	With neat sketch explain the working of series hybrid vehicles.	CO5	K3	240
11	With neat sketch explain the working of parallel hybrid vehicles.	CO5	K3	241
12	Compare series and parallel HV’s	CO5	K4	244
13	Discuss the types of hybridization.	CO5	K2	248
14	Examine the advantages and disadvantages of the hybrid vehicles.	CO5	K4	252
15	Discuss the working and benefits of CNG hybrid vehicles	CO5	K2	253
MODULE VI				
1	Judge the impact of intelligence in modern automobile industries	CO6	K5	261

2	Discuss briefly about the vehicle intelligence in modern vehicles.	CO6	K2	262
3	Sketch the architecture of vision based autonomous vehicle and explain its working	CO6	K3	263
4	Define about dynamic vision	CO6	K1	277
5	Define vehicle intelligence	CO6	K1	261
6	Sketch the architecture for dynamic vision in vehicle and explain its working	CO6	K3	277
7	Investigate the working of dynamic vision in intelligent vehicles	CO6	K6	280
8	Investigate the collision warning and awareness system in intelligent vehicles	CO6	K6	322
9	Discuss in detail about tire pressure monitoring system	CO6	K2	327
10	Compare direct and indirect TPMS	CO6	K4	329
11	Investigate the working of TPMS	CO6	K6	327

APPENDIX 1

CONTENT BEYOND THE SYLLABUS

MODULE 1

FUNDAMENTAL OF AUTOMOTIVE ELECTRONICS

INTRODUCTION

Automotive electronics are electronic systems used in road vehicles, such as: engine management, ignition, radio, carputers, telematics, in-car entertainment systems and others. Electronic systems have become an increasingly large component of the cost of an automobile, from only around 1% of its value in 1950 to around 30% in 2010.

The earliest electronics systems available as factory installations were vacuum tube car radios, starting in the early 1930s. The development of semiconductors after WWII greatly expanded the use of electronics in automobiles, with solid-state diodes making the automotive alternator the standard after about 1960, and the first transistorized ignition systems appearing about 1955.

The availability of microprocessors after about 1974 made another range of automotive applications economically feasible. In 1978 the Cadillac Seville introduced a "trip computer" based on a 6802 microprocessor. Electronically-controlled ignition and fuel injection systems allowed automotive designers to achieve vehicles meeting requirements for fuel economy and lower emissions, while still maintaining high levels of performance and convenience for drivers. Today's automobiles contain a dozen or more processors, in functions such as engine management, transmission control, climate control, antilock braking, passive safety systems, navigation, and other functions.

Modern electric cars rely on power electronics for the main propulsion motor control, as well as managing the battery system. Future autonomous cars will rely on powerful computer systems, an array of sensors, networking, and satellite navigation, all of which will require electronics.

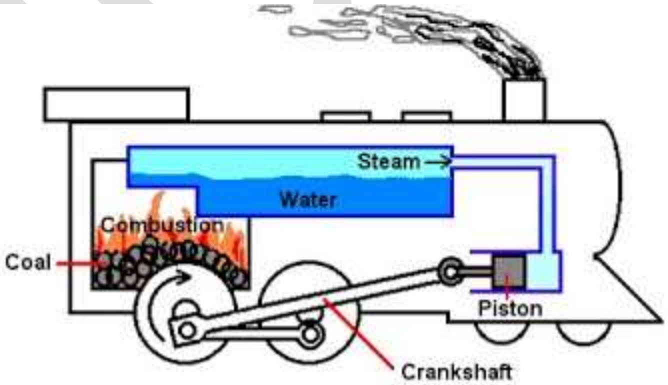
WHAT IS ENGINE? WHAT ARE MAIN TYPES OF ENGINE?

Today we will discuss about engine and types of engine used in automobile. Any device which can convert heat energy of fuel into mechanical energy is known as engine or heat engine. Engine is widely used in automobile industries or we can say that engine is the heart of an automobile. Basically engine may be classified into two types.

Types of Engine:

EXTERNAL COMBUSTION (E.C.) ENGINE

An engine in which combustion of fuel take place outside of the cylinder is known as EC engine. In this type of engine heat, which is generated by burning of fuel is used to convert the water or other low boiling temperature fluid into steam. This high pressure steam used to rotate a turbine. In this engine we can use all solid, liquid and gases fuel. These engines are generally used in driving locomotive, ships, generation of electric power etc.



Advantages of E.C. engine-

- In these engines starting torque is generally high.
- Because of external combustion we can use cheaper fuels as well as solid fuel.
- They are more flexible compare to internal combustion engines.

INTERNAL COMBUSTION (I.C.) ENGINE

It is an engine in which combustion of fuel take place inside the engine. When the fuel burns inside the engine cylinder, it generates a high temperature and pressure. This high pressure force is exerted on the piston (A device which free to moves inside the cylinder and transmit the pressure force to crank by use of connecting rod), which used to rotate the wheels of vehicle. In these engines we can use only gases and high volatile fuel like petrol, diesel. These engines are generally used in automobile industries, generation of electric power etc.

Advantages of I.C. engine-

- It has overall high efficiency over E.C. engine.
- These engines are compact and required less space.
- Initial cost of I.C. engine is lower than E.C. engine.
- This engine easily starts in cold because of it uses high volatile fuel.

TYPES OF I.C. ENGINE

I.C. engine is widely used in automobile industries so it is also known as automobile engine. An automobile engine may be classified in many manners. Today I am going to tell you some important classification of an automobile engine.

According to number of stroke:

1. Two stroke engine

In a two stroke engine a piston moves one time up and down inside the cylinder and complete one crankshaft revolution during single time of fuel injection. This type of engine has high torque compare to four stroke engine. These are generally used in scooters, pumping sets etc.

2. Four stroke engine

In a four stroke engine piston moves two times up and down inside the cylinder and complete two crankshaft revolutions during single time of fuel burn. This type of engines has high average compare to two stroke engine. These are generally used in bikes, cars, truck etc.

According to design of engine:

1. Reciprocating engine (piston engine)

In reciprocating engine the pressure force generate by combustion of fuel exerted on a piston (A device which free to move in reciprocation inside the cylinder). The piston starts reciprocating motion (too and fro motion). This reciprocating motion converts into rotary motion by use of crank shaft. So the crank shaft starts to rotate and make rotate the wheels of the vehicle. These are generally used in all automobile.

2. Rotary engine (Wankel engine)

In rotary engine there is a rotor which frees to rotate. The pressure force generated by burning of fuel is exerted on this rotor so the rotor rotate and starts to rotate the wheels of vehicle. This engine is developed by Wankel in 1957. This engine is not used in automobile in present days.

According to fuel used:

1. Diesel engine

These engines use diesel as the fuel. These are used in trucks, buses, cars etc.

2. Petrol engine

These engines use petrol as the fuel. These are used in bikes, sport cars, luxury cars etc.

3. Gas engine

These engines use CNG and LPG as the fuel. These are used in some light motor vehicles.

4. Electric engine

It is eco-friendly engine. It doesn't use any fuel to burn. It uses electric energy to rotate wheel.

According to method of ignition:

1. Compression ignition engine

In these types of engines, there is no extra equipment to ignite the fuel. In these engines burning of fuel starts due to temperature rise during compression of air. So it is known as compression ignition engine.

2. Spark ignition engine

In these types of engines, ignition of fuel start by a spark, generated inside the cylinder by some extra equipment (Spark Plug). So it is known as spark ignition engine.

According to number of cylinder:

1. Single cylinder engine

In this type of engines have only one cylinder and one piston connected to the crank shaft.

Single Cylinder Engine

2. Multi-cylinder engine

In this type of engines have more than one cylinder and piston connected to the crank shaft.

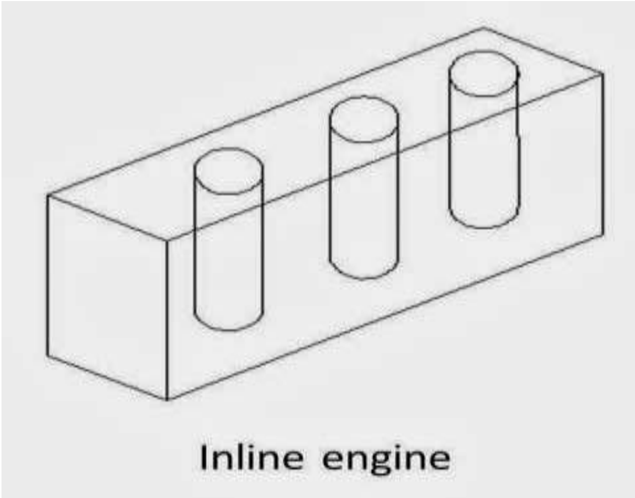
Double Cylinder Engine

Multi Cylinder Engine

According to arrangement of cylinder:

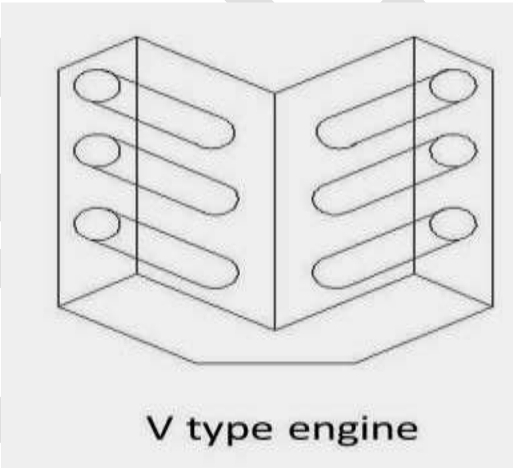
1. In-line engine

In this type of engines, cylinders are positioned in a straight line one behind the other along the length of the crankshaft.



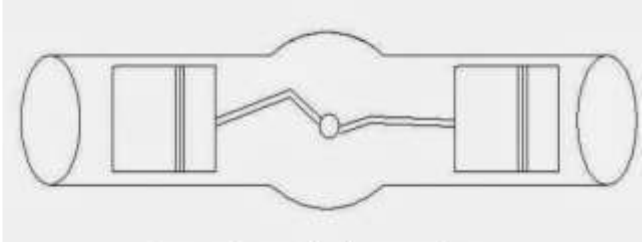
2. V-type engine

An engine with two cylinder banks inclined at an angle to each other and with one crankshaft known as V-type engine.



3. Opposed cylinder engine

An engine with two cylinders banks opposite to each other on a single crankshaft (V-type engine with 180o angle between banks).



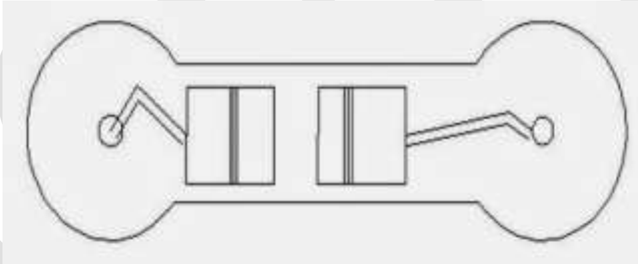
Opposite cylinder engine

4. W-type engine

An engine same as V-type engine except with three banks of cylinders on the same crankshaft known as W-type engine.

5. Opposite piston engine

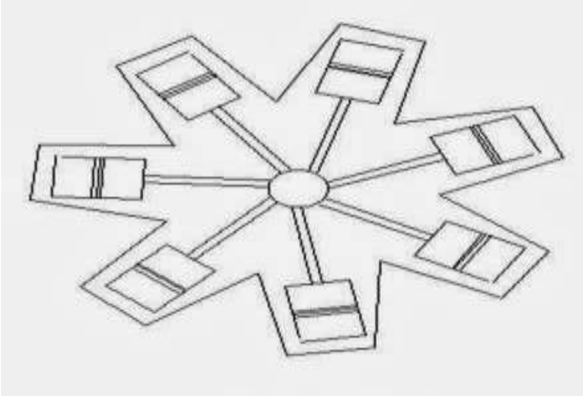
In this type of engine there are two pistons in each cylinder with the combustion chamber in the center between the pistons. In this engine, a single combustion process causes two power strokes, at the same time.



Opposite piston engine

6. Radial engine

It is an engine with pistons positioned in circular plane around the central crankshaft. The connecting rods of pistons are connected to a master rod which, in turn, connected to the crankshaft.



Redial engine

According to air intake process:

1. Naturally aspirated

In this types of engine intake of air into cylinder occur by the atmospheric pressure.

2. Supercharged engine

In this type of engine air intake pressure is increased by the compressor driven by the engine crankshaft.

3. Turbocharged engine

In this type of engine intake air pressure is increase by use of a turbine compressor driven by the exhaust gases of burning fuel.

COMPONENTS OF IC ENGINES

The burning heart of our fast cars, yeah you are right, I am talking about engine. It's the power unit we have to spin our car wheels. The entire thrill we have got while driving depends on the capacity of this power unit, and the limits up-to which we can push its components to operate safely. It is the combination of all parts of an engine that makes a car to move faster and faster.

So let's just dig out what it's components are, and how precisely they must be engineered to get the maximum power out of an engine.

Main Parts of an Engine are;

1) Camshaft:

Camshaft is a type of rotating device or apparatus used in piston engines for propelling or operating poppet valves. Camshaft comprises of series of cams that regulates the opening and closing of valves in the piston engines. The camshaft works with the help of a belt, chain and gears.

2) Crankshaft:

Crankshaft is a device, which converts the up and down movement of the piston into rotatory motion. This shaft is presented at the bottom of an engine and its main function is to rotate the pistons in a circular motion. Crankshaft is further connected to flywheel, clutch, main shaft of the transmission, torque converter and belt pulley.

To convert Reciprocating motion of the Piston into Rotary motion, the Crankshaft and Connecting Rod combination is used. The Crankshaft which is made by Steel Forging or Casting is held on the Axis around which it rotates, by the Main Bearings, which is fit round the main Journals provided.

There are always at least two such bearings, one at the rare end and other at front end. the increase in number of Main Bearings for a given size of the Crankshaft means less possibility of Vibration and Distortion.

But it will also increase the difficulty of correct alignment in addition to increased production cost. The Main Bearings are mounted on the Crankcase of the Engine. The Balance weight or Counter weight keep the system in perfect balance.

The Crank Webs are extended and enlarged on the side of Journal opposite the Crank Throw so as to from balance weights. The Crankshaft may be made from Carbon Steel, Nickel Chrome or other Alloy Steel.

3) Connecting Rod:

Connecting rods are made of metals, which are used, for joining a rotating wheel to a reciprocating shaft. More precisely, connecting rods also referred to as con rod are used for conjoining the piston to the crankshaft.

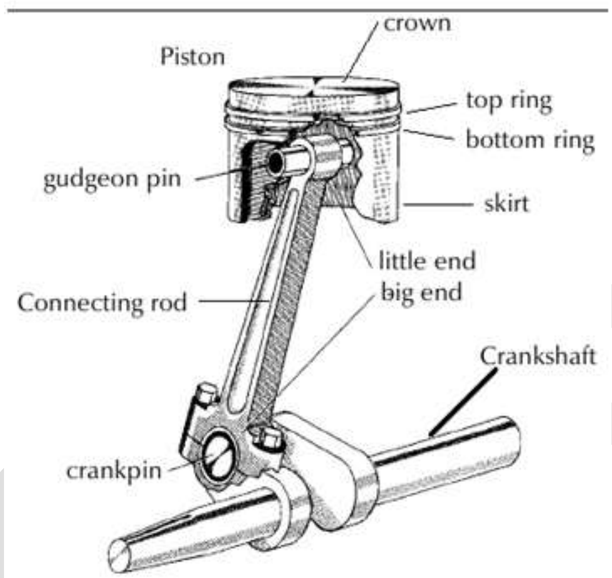
The load on the piston due to combustion of fuel in the combustion chamber is transmitted to crankshaft through the connecting rod. One end of connecting rod known as small end and is connected to the piston through gudgeon pin while the other end known as big end and is connected to crankshaft through crank pin.

Connecting rods are usually made up of drop forged I section. In large size internal combustion engine, the connecting rods of rectangular section have been employed. In such cases, the larger dimensions are kept in the plane of rotation.

In petrol engine, the connecting rod's big end is generally split to enable its clamping around the crankshaft. Suitable diameter holes are provided to accommodate connecting rod bolts for clamping. The big end of connecting rod is clamped with crankshaft with the help of connecting rod bolt, nut and split pin or cotter pin.

Generally, plain carbon steel is used as material to manufacture connecting rod but where low weight is most important factor, aluminum alloys are most suitable. Nickel alloy steel are also used for heavy duty engine's connecting rod.

Connecting rods can be made of steel, aluminum, titanium, iron and other types of metals.

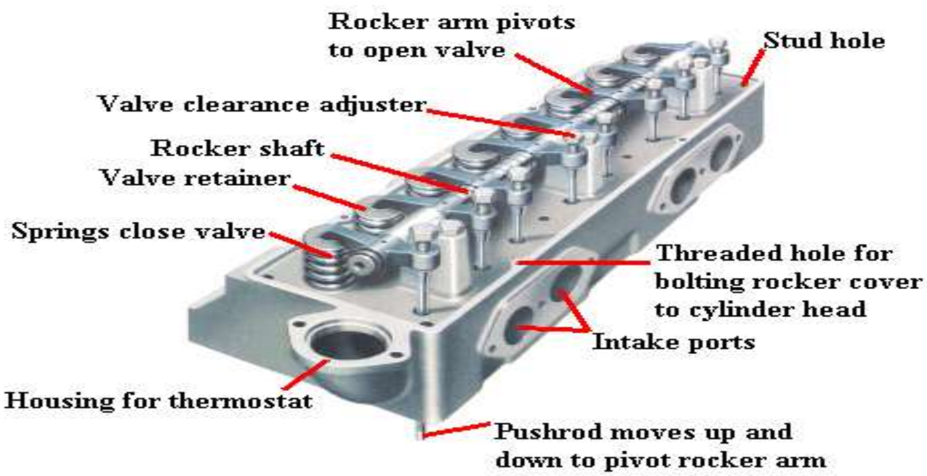


4) Crank Case:

A crankcase is a metallic cover that holds together the crankshaft and its attachments. It is the largest cavity within an engine that protects the crankshaft, connecting rods and other components from foreign objects. Automotive crankcases are filled with air and oil, while Magnesium, Cast Iron, Aluminum and alloys are some common materials used to make crankcases.

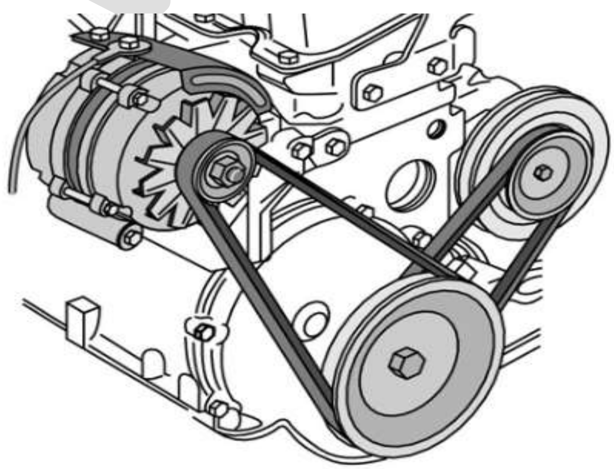
5) Cylinder Heads:

Cylinder heads refers to a detachable plate, which is used for covering the closed end of a cylinder assembled in an automotive engine. It comprises of combustion chamber valve train and spark plugs. Different types of automobiles have different engine configurations such as Straight engine has only one cylinder head while a engine has two cylinder heads.



6) Engine Belts:

Engine belts are the bands made of flexible material used for connecting or joining two rotating shafts or pulleys together. These belts work in coordination with wheels and axles for transferring energy. When the wheels or shafts are positioned at extremely different angles, then the engine belts have the ability to change the direction of a force. Engine pulley is a type of machine or a wheel having either a broad rim or groomed rim attached to a rope or chain for lifting heavy objects.



7) Engine Oil System:

Oil is one of the necessities of an automobile engine. Oil is distributed under strong pressure to all other moving parts of an engine with the help of an oil pump. This oil pump is placed at the bottom of an engine in the oil pan and is joined by a gear to either the crankshaft or the camshaft. Near the oil pump, there is an oil pressure sensor, which sends information about the status of oil to a warning light or meter gauge.

The different parts of engine oil systems include:

a) Engine Oil

b) Engine Oil Cooler

c) Engine Oil Filter

d) Engine Oil Gaskets

e) Engine Oil Pan

f) Engine Oil Pipe

8) Engine Valve:

Automobile engine valves are devices that regulate the flow of air and fuel mixture into the cylinder and assist in expelling exhaust gases after fuel combustion. They are indispensable to the system of coordinated opening and closing of valves, known as valve train. Engine valves are made from varied materials such as Structural Ceramics, Steels, Superalloys and Titanium alloys. Valve materials are selected based on the temperatures and pressures the valves are to endure.

The primary components of engine valve are:

a) Inlet Valve

b) Exhaust Valve

c) Combination Valve

d) Check Valve

e) EGR Valve

f) Thermostat Valve

g) Overhead Valve

h) Valve Guide

i) Schrader Valve

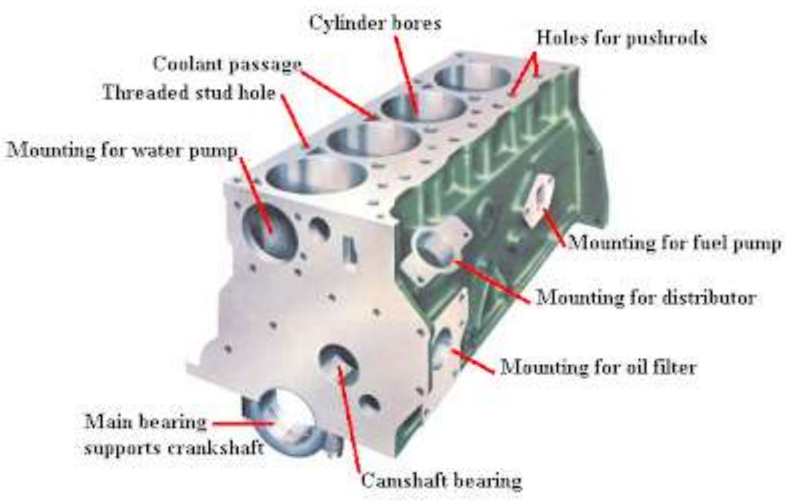
j) Vaccum Delay Parts

Inlet Valve & Exhaust Valve-

Function-Inlet valve allow the fresh charge of air-fuel mixture to enter the cylinder bore.Exhaust valve permits the burnt gases to escape from the cylinder bore at proper timing.

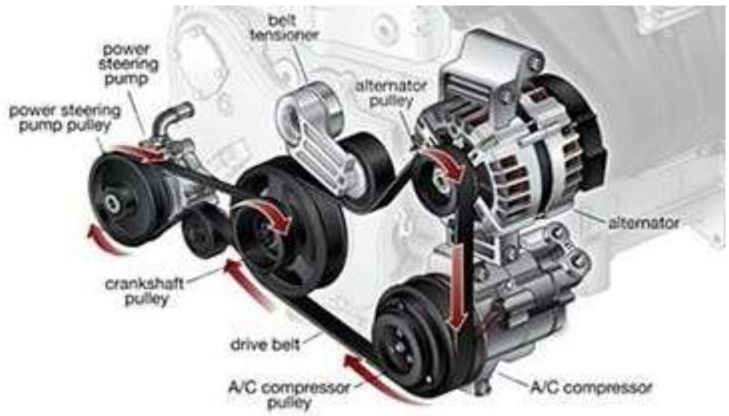
9) Engine Block:

An engine block is a metal casting that serves as a basic structure on which other engine parts are installed. A typical block contains bores for pistons, pumps or other devices to be attached to it. Even engines are sometimes classified as small-block or big-block based on the distance between cylinder bores of engine blocks. Engine blocks are made from different materials including Aluminum alloys, gray cast iron, ferrous alloys, white iron, gray iron, ductile iron, malleable iron, etc.



10) Engine Pulley:

An engine pulley is a wheel with a groove around its circumference, upon which engine belts run and transmit mechanical power, torque and speed across different shafts of an engine. An engine houses pulley units of different sizes for cam shaft drive, accessory drive and timing belts. Molded plastics, iron and steel are normally used to make engine pulleys.



11) Engine Brackets:

An engine bracket is a metallic part used to join an engine mount to the power unit or the body of a vehicle. These auto parts are installed between a vehicle's body and power unit to dampen the vibrations generated by the engine, thus preventing a vehicle's body from shaking due to the vibrations. Engine brackets are made from Ductile Iron Cast, Aluminum, Polypropylene, Fiberglass and alloys.

12) Engine Mounting Bolts:

Automotive mounting bolts secure different automobile components viz. air bags, brake fittings, etc. on to a supporting structure. Likewise, engine mounting bolts help secure an automobile's engine in place. Based on usage, a number of materials such as alloys, silicon bronze, bronze, ceramic, carbon, aluminum, nylon, phosphor bronze, nickel silver, plastic, titanium, zirconium and stainless steel are utilized to produce these bolts.

13) Piston:

Piston is a cylindrical plug which is used for moving up and down the cylinder according to the position of the crankshaft in its rotation. Piston has multiple uses and functions. In the case of four-stroke engine the piston is pulled or pushed with the help of crankshaft while in the case of compression stroke, piston is pushed with the powerful explosion of mixture of air and fuel.

Piston comprises of several components namely:

a) Piston Pins

b) Piston Floor Mat

c) Piston Rings

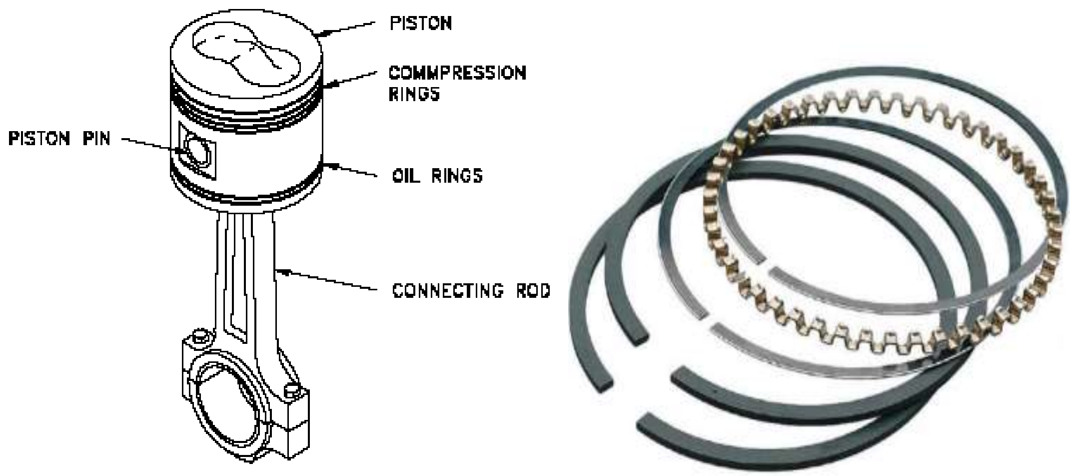
d) Piston Valve

14) Piston rings:

Piston rings provide a sliding seal between the outer edge of the piston and the inner edge of the cylinder. The rings serve two purposes:

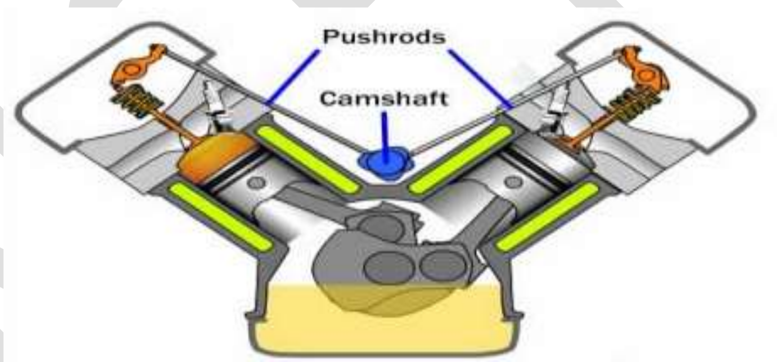
· They prevent the fuel/air mixture and exhaust in the combustion chamber from leaking into the sump during compression and combustion.

· They keep oil in the sump from leaking into the combustion area, where it would be burned and lost.



15) [Push Rods]:

Push rods are thin metallic tubes with rounded ends that move through the holes within a cylinder block and head, to actuate the rocker arms. Pushrods are found in valve-in-head type engines and are essential for the motion of engine valves. Some commonly used materials for manufacturing pushrods are Titanium, Aluminum, Chrome Moly and Tempered Chrome Moly.



16) Valve train:

Valve train consists of various components and parts, which enables valves to operate and function smoothly. Valve train comprises of three main components: camshafts, several components which are used for turning the camshaft's rotating movement into reciprocating movement, and lastly valves and its various parts.

The primary components of valve train are:

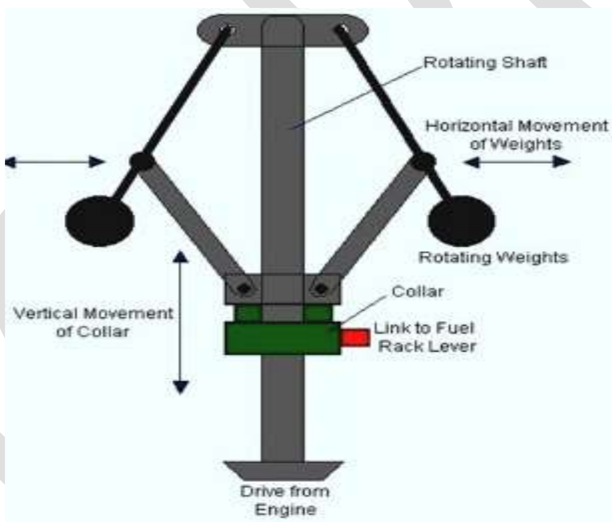
a) Tappet

b) Rocker Arms

c) Valve Timing System

17) Governor

It controls the speed of engine at a different load by regulating fuel supply in diesel engine. In petrol engine, supplying the mixture of air-petrol and controlling the speed at various load condition.



18) Carburettor

It converts petrol in fine spray and mixes with air in proper ratio as per requirement of the engine.

19) Fuel Pump

This device supplies the petrol to the carburettor sucking from the fuel tank.

20) Spark Plug

This device is used in petrol engine only and ignite the charge of fuel for combustion.

21) Fuel Injector

This device is used in diesel engine only and delivers fuel in fine spray under pressure.

22) Gudgeon Pin

Connects the piston with small end of connecting rod.

This pin connects the piston with small end of the connecting rod, and also known as piston pin. It is made up of case hardened steel and accurately ground to the required diameters. Gudgeon pins are made hollow to reduce its weight, B resulting low inertia effect of reciprocating parts.

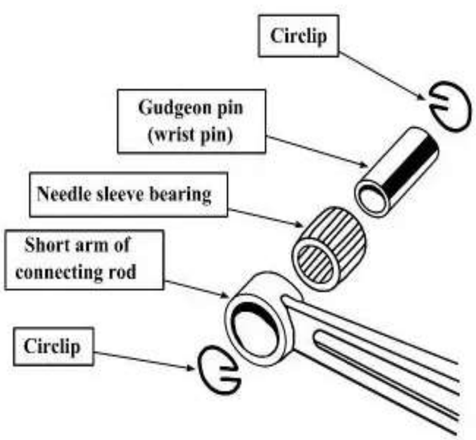
This pin is also known as "Fully Floating" as this is free to turn or oscillate both in the piston bosses as well as the small end of the connecting rod. There are very less chances of seizure in this case but the end movement of the pin must be restricted to score the cylinder walls. This can be achieved by using any one of the following three methods,

A) One spring circlip at each end is fitted into the groove in the piston bosses.

B) On spring circlip is provided in the middle.

C) Bronze or Aluminium pads are fitted at both ends of the pin, which prevents the cylinder walls from being damaged.

The gudgeon pin may also be semi-floating type, in which either the pin is free to turn or oscillate in the small end bearing but secured in the piston bosses or it may secured in the small end bearing and allowed a free oscillating movement in the piston bosses. This method provides more bearing area at the bosses and hence no need for providing bushes there in, is preferred.

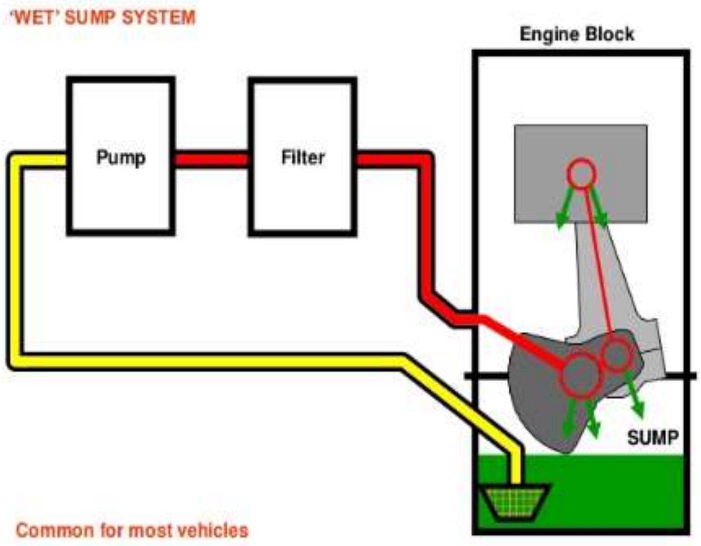


23) Crank Pin

Hand over the power and motion to the crank shaft which come from piston through connecting rod.

24) Sump

The sump surrounds the crankshaft. It contains some amount of oil, which collects in the bottom of the sump (the oil pan).



25) Distributor –

It operates the ignition coil making it spark at exactly the right moment. It also distributes the spark to the right cylinder and at the right time. If the timing is off by a fraction then the engine won't run properly.

26) Gasket

A wide variety of materials are used in making gaskets like Teflon, glass-fiber, silicon etc. It is generally a paper like sheet which is placed between engine block and engine head. As we have already discussed that we have both water and oil vents in engine block, so gasket gives insulation from water or oil leaking into engine cylinder or air-fuel mixture from engine cylinder leaking out from joint of engine block and engine head. Aluminum engine blocks are preferred over cast iron because it expends more on heating thus compressing the gasket more, increases the workability of gasket, thus reducing the chances of leakage.

DRIVE TRAINS

The drive train serves two functions: it transmits power from the engine to the drive wheels, and it varies the amount of torque. 'Power' is the rate or speed at which work is performed. 'Torque' is turning or twisting force. Multiple ratio gearboxes are necessary because the engine delivers its maximum power at certain speeds, or RPM (Rotations Per Minute). In order to use the same engine RPM's at different road speeds, it is necessary to change the 'Gear Ratio' between the engine and the drive wheels. Just like a bicycle, the car has to switch gears in order to move at a wide range of speeds. Unlike your bicycle, the car's drivetrain also has to allow you to back up. (Well, you could push it backwards if you ate your Wheaties) There are actually two sets of gears in the drive train; the transmission and the differential. The transmission allows the gear ratio to be adjusted, and the differential lets the drive wheels turn at different speeds. Manual transmissions usually have four or five speeds, and often have overdrive, which means that the output shaft can turn faster than the input shaft for fuel economy on the highway. Some use an electric clutch and a switch that controls whether the overdrive is engaged or not. An interesting development on a few cars is the clutch less manual transmission, which uses a stick shift and an automatic electric clutch. Speed and position sensors, mini computers, and throttle controls keep the engine from over-revving when the driver shifts gears. As with many automotive inventions, this is an old idea which may now reach feasibility due to the computer revolution. Automatic transmissions commonly use three forward gears to blend speed and torque. In the case of a three-speed transmission, first gear delivers maximum torque and minimum speed for starting. Second gear offers medium torque and speed for acceleration and hill climbing.

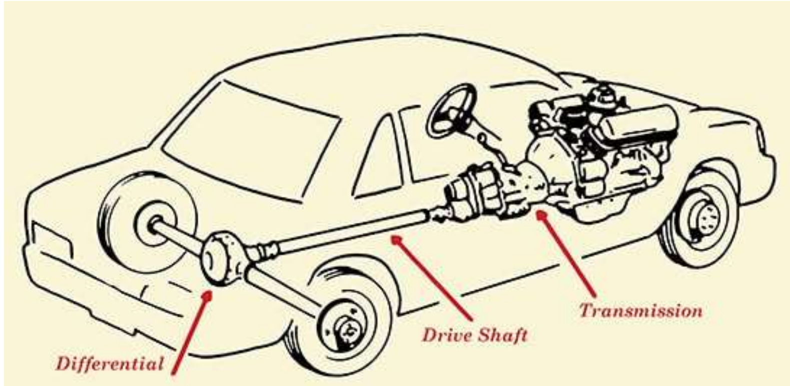
Third gear allows maximum speed with minimum torque for highway travel. A reverse gear permits backward movement. A transmission is a speed and power changing device installed at some point between the engine and driving wheels of a vehicle. It provides a means for changing the ratio between engine RPM (Revolutions Per Minute) and driving wheel RPM to best meet each particular driving situation. Some types of drive train layouts use a Transaxle, which is simply a combination of the transmission and the differential. These are usually found on front wheel drive cars, but are also used on mid- and rear-engine cars. Some exotic cars have their engine in the front, and a transaxle in the rear of the car for better weight balance. Torque is derived from power. The amount of torque obtainable from a source of power is proportional to the distance from the center of rotation at which it is applied. It is logical, then, that if we have a shaft (in this case, the crankshaft) rotating at any given speed, we can put gears of different sizes on the shaft and obtain different results. If we put a large gear on the shaft, we will get more speed and less power at the rim than with a small gear. If we place another shaft parallel to our driving shaft and install gears on it in line with those on the driving shaft, we can obtain almost any desired combination of speed or power within the limits of the engine's ability. That is exactly what an automobile transmission does by means of gears and other devices.There are two types of transmissions; manual and automatic. If you have a manual transmission, you have to shift the gears yourself, usually with a stick located on your console and the clutch pedal. If you have an automatic transmission, the mechanism changes without any help from you. This is accomplished through a system that works by oil pressure. Each shift of the gears is controlled by a shift valve; the gears shift change depending on speed, the road, and load conditions. Another basic component of all drive trains is some form of a clutch. it allows the engine to continue rotating while the gears and wheels are stationary. Automatic transmission cars use a 'torque converter' in lieu of a clutch. From the back of the engine to where the rubber meets the road, the drivetrain encompasses one of the most complicated systems of your car. Some people say looking at a transmission 'makes their brain hurt'.

What the Drivetrain Is…?

The drivetrain isn't a single part in your car, but rather a series of parts that work together to transfer the rotational power produced in your engine to your wheels so your car can move.

You may have come across the word "powertrain" before. While it's often used interchangeably with drivetrain, they're not the same thing. The powertrain encompasses everything that makes the car go, including the engine. The drivetrain encompasses the things that make the car go, *not* including the engine. It's these engine-exclusive parts that we'll be focusing on below.

Rear-Wheel Drivetrain



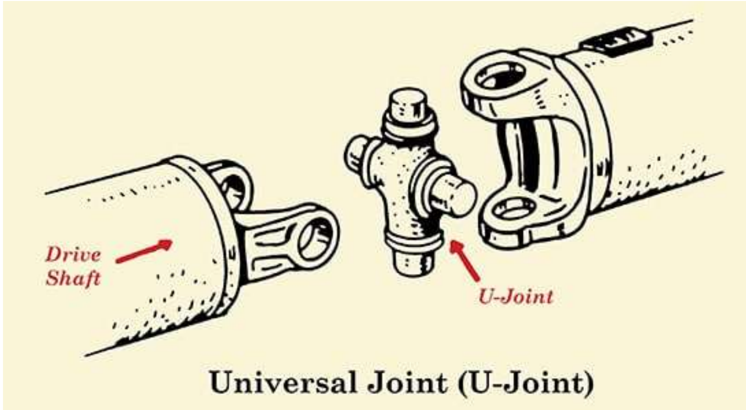
In rear-wheel drivetrain arrangements, power is transferred to the rear wheels to move the car. It's the drivetrain arrangement that's been around the longest and is still used today on many cars and trucks.

This arrangement provides myriad benefits over the front-wheel variety. First, it distributes weight more equally to each tire, which in turn provides better steering and handling. Second, rear-wheel drive can offer superior braking compared to front-wheel drive vehicles. Finally, and probably most importantly, rear-wheel drivetrain arrangements split the jobs of steering and driving the vehicle, which can lead to better handling and acceleration. With rear-wheel drive vehicles, the back wheels only have to move the car. In front-wheel drive cars, the wheels have to both move the car forwards or backwards *and* steer it left or right. We'll talk more about this when we discuss front-wheel drivetrain arrangements below.

Rear-wheel drivetrains consist of the following main parts:

Transmission controls the amount of power that goes from your engine to your wheels. In rear-wheel drive cars, the transmission is attached to the rear of the engine by way of a flywheel. The transmission takes the spinning movement — the torque — from the engine's crankshaft and passes it along to the…

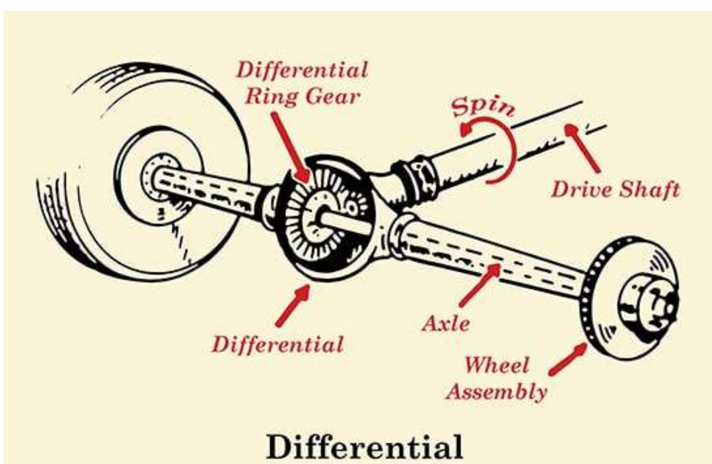
Drive Shaft is a spinning tube that connects to the rear of the transmission and transmits the spinning power that began in the engine to the back of the vehicle at the differential (more on that in a bit). Drive shaft designs come in two types: torque tube and Hotchkiss.



Torque tube drive shafts were used on older vehicles and are still used on some trucks and SUVs today. The driveshaft itself is *enclosed* in a tube. Torque tubes connect the transmission and differential via a single universal joint, or U-joint for short.

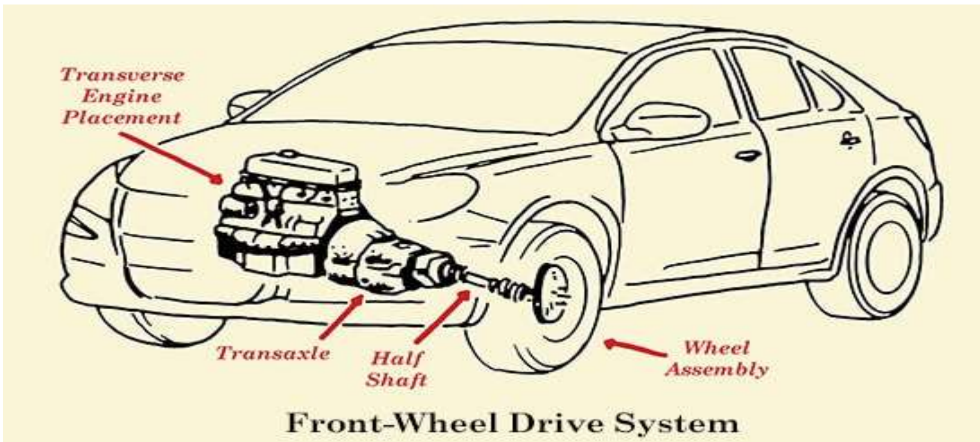
Hotchkiss drive shafts are the more common drive shaft design. Unlike torque tube drive shafts, Hotchkiss drive shafts have an open design, meaning you can actually see the drive shaft spin beneath your car when it's moving. Also, instead of just using one U-joint to connect the transmission and the differential, Hotchkiss drive shafts use two U-joints.

Differential is the melon-sized part that sits between the two rear wheels. It's the last stop along the drivetrain before torque is transferred to the rear wheels. The differential transfers torque, causing them to spin, which in turn moves the car.



It's called a "differential" because it allows the two rear wheels on the same axle to move at *different* speeds. You're probably thinking, "When would my rear wheels move at different speeds?" Well, a common instance is whenever you go around a corner. When you make a right turn, your inside wheel (the right wheel) travels less of a distance than your outside wheel (left wheel). To keep up with the inside wheel, the outside wheel must spin slightly faster. The differential makes this possible. If there was a solid connection between both wheels, one of the wheels would need to skid in order for the axle to keep moving.

Front-Wheel Drivetrain



Front-Wheel Drive System

Many cars today use front-wheel drive. Instead of the rear wheels powering movement, the front wheels do. Consequently, you don't need a long drive shaft that runs the length of the car to transfer torque to move the wheels. All the components of the drive train — transmission, differential, and drive shafts — are in the front of the car. To fit all these components in the front, cars with a front-wheel drivetrain arrangement place the engine sideways in the car. This is called a "transverse engine placement." Open up the hood of your car — if the engine runs horizontally and not vertically, you've probably got a front-wheel drive car.

Because all the parts of a forward-wheel drivetrain are positioned at the front of a vehicle, you can make them smaller and lighter. Or you can make the cars bigger, but just have more room for passengers. Consequently, most minivans use front-wheel drive.

Another benefit of front-wheel drive vehicles is that because there's more weight at the front of the vehicle due to all the components of the drivetrain being in the front, it provides more traction on slippery surfaces, like snow. You only get this traction benefit at lower speeds, though. When you're traveling at higher speeds, rear-wheel drive actually provides better traction.

Front-wheel drivetrains have the same basic set-up as rear-wheel drivetrains, but the parts are a bit different:

Transaxle. Instead of a transmission, most front-wheel drivetrains have a transaxle. A transaxle combines the transmission and differential into one single unit. If you have a front-wheel drive car and you want to earn Car Guy bonus points, don't refer to your transmission as a transmission, but as a transaxle.

While most cars that use transaxles mount them right next to the engine, some sports cars use transaxles on rear-wheel drive trains for even weight distribution.

Half-shaft. Because all the components of the drivetrain are in the front of the car, front-wheel drive vehicles don't need long drive shafts to transfer torque to the wheels. Instead, a half-shaft connects from the transaxle to the wheel assembly.

In place of U-joints, half-shafts connect the transaxle and the wheel assembly with constant velocity joints, or CV-joints. CV-joints use a ball bearing mechanism to reduce friction and allow for the more complex wheel movements used in front-wheel drive cars — remember, front-wheel drive cars not only have to move the car forward, but also steer it left and right.

CHARGING SYSTEMS

What is a Charging System?

The modern charging system hasn't changed much in over 40 years. It consists of the alternator, regulator (which is usually mounted inside the alternator) and the interconnecting wiring.

The purpose of the charging system is to maintain the charge in the vehicle's battery, and to provide the main source of electrical energy while the engine is running.

If the charging system stopped working, the battery's charge would soon be depleted, leaving the car with a "dead battery." If the battery is weak and the alternator is not working, the engine may not have enough electrical current to fire the spark plugs, so the engine will stop running.

If the battery is "dead", it does not necessarily mean that there is anything wrong with it. It is just depleted of its charge. It can be brought back to life by recharging it with a battery charger, or by running the engine so that the alternator can charge it

.The main component in the charging system is the **ALTERNATOR**. The alternator is a generator that produces Alternating Current (AC), similar to the electrical current in your home. This current is immediately converted to Direct Current (DC) inside the alternator. This is because all modern automobiles have a 12 volt, DC electrical system.

A **VOLTAGE REGULATOR** regulates the charging voltage that the alternator produces, keeping it between 13.5 and 14.5 volts to protect the electrical components throughout the vehicle.

There is also a system to warn the driver if something is not right with the charging system. This could be a dash mounted voltmeter, an ammeter, or more commonly, a warning lamp. This lamp is variously labeled "Gen" Bat" and "Alt.". If this warning lamp lights up while the engine is running, it means that there is a problem in the charging system, usually an alternator that has stopped working. The most common cause is a broken alternator drive belt.

The alternator is driven by a belt that is powered by the rotation of the engine. This belt goes around a pulley connected to the front of the engine's crankshaft and is usually responsible for driving a number of other components including the water pump, power steering pump and air conditioning compressor. On some engines, there is more than one belt and the task of driving these components is divided between them. These belts are usually referred to as: Fan Belt, Alternator Belt, Drive Belt, Power Steering Belt, A/C Belt, etc. More common

Courtesy General Motors

on late model engines, one belt, called a Serpentine Belt will snake around the front of the engine and drive all the components by itself.

On engines with separate belts for each component, the belts will require periodic adjustments to maintain the proper belt tension. On engines that use a serpentine belt, there is usually a spring loaded belt tensioner that maintains the tension of the belt, so no periodic adjustments are required. A serpentine belt is designed to last around 30,000 miles. Check your owner's manual to see how often yours should be replaced.

Alternator output is measured in both voltage and amperage. To understand voltage and amperage, you must also know about resistance, which is measured in ohms. An easy way to picture this is to compare the movement of electricity to that of running water. Water flows through a pipe with a certain amount of pressure. The size (diameter) of the pipe dictates how much resistance there will be to the flowing water. The smaller the pipe, the more resistance. You can increase the pressure to get more water to flow through, or you can increase the size of the pipe to allow more water to flow using less pressure. Since too much pressure can burst the pipe, we should probably restrict the amount of pressure being used. You get the idea, but how is this related to the flow of electricity?

Well, voltage is the same as water pressure. Amperage is like the amount or volume of water flowing through, while resistance is the size of the wire transmitting the current. Since too much voltage will damage the electrical components such as light bulbs and computer circuits, we must limit the amount of voltage. This is the job of the voltage regulator. Too much water pressure and things could start breaking. Too much voltage and things could start burning out.

Let's get technical

Now, let's go a little deeper and see how these charging system components actually work to produce the electrical power that a modern automobile requires.

The Alternator

The alternator uses the principle of electromagnetism to produce current. The way this works is simple. If you take a strong magnet and pass it across a wire, that wire will generate a small voltage. Take that same wire and loop it many times, than if you pass the same magnet across the bundle of loops, you create a more sizable voltage in that wire.

Alternator Stator

There are two main components that make up an alternator. They are the rotor and the stator. The rotor is connected directly to the alternator pulley. The drive belt spins the pulley, which in turn spins the rotor. The stator is mounted to the body of the alternator and remains stationary. There is just enough room in the center of the stator for the rotor to fit and be able to spin without making any contact.

The stator contains 3 sets of wires that have many loops each and are evenly distributed to form a three phase system. On some systems, the wires are connected to each other at one end and are connected to a rectifier assembly on the other end. On other systems, the wires are connected to each other end to end, and at each of the three connection points, there is also a connection to the rectifier. More on what a rectifier is later.

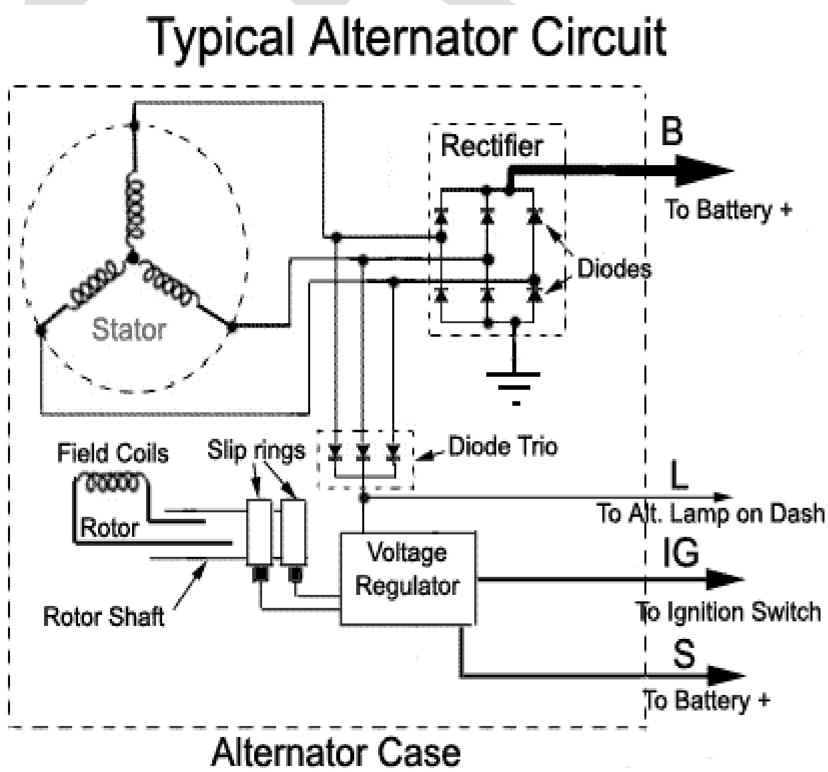
Alternator Rotor

The rotor contains the powerful magnet that passes close to the many wire loops that make up the stator. The magnets in the rotor are actually electro magnets, not a permanent magnets. This is done so that we can control how much voltage the alternator produces by regulating the amount of current that creates the magnetic field in the rotor. In this way, we can control the output of the alternator to suit our needs, and protect the circuits in the automobile from excessive voltage.

Now we know that every magnet has a north and a south pole and electro magnets are no exception. Our rotor has two interlocking sections of electro magnets that are arranged so that there are fingers of alternating north and south poles. that are evenly distributed on the outside of the rotor.

When we spin the rotor inside the stator and apply current to the rotor through a pair of brushes that make constant contact with two slip rings on the rotor shaft. This causes the rotor to become magnetized. The alternating north and south pole magnets spin past the three sets of wire loops in the stator and produce a constantly reversing voltage in the three wires. In other words, we are producing alternating current in the stator.

Now, we have to convert this alternating current to direct current current. This is done by using a series of 6 diodes that are mounted in a rectifier assembly. A diode allows current to flow only in one direction. If voltage tries to flow in the other direction, it is blocked. The six diodes are arranged so that all the voltage coming from the alternator is aligned in one direction thereby converting AC current into DC current.



There are 2 diodes for each of the three sets of windings in the stator. The two diodes are facing in opposite directions, one with its north pole facing the windings and the other with its south pole facing the windings. This arrangement causes the AC current coming out of the windings to be converted to DC current before it leaves the alternator through the B terminal. Connected to the B terminal of the alternator is a fairly heavy wire that runs straight to the battery.

Current to generate the magnetic field in the rotor comes from the ignition switch and passes through the voltage regulator. Since the rotor is spinning, we need a way to connect this current from the regulator to the spinning rotor. This is accomplished by wires connected to two spring loaded brushes that rub against two slip rings on the rotor's shaft. The voltage regulator monitors the voltage coming out of the alternator and, when it reaches a threshold of about 14.5 volts, the regulator reduces the current in the rotor to weaken the magnetic field. When the voltage drops below this threshold, the current to the rotor is increased.

There is another circuit in the alternator to control the charging system warning lamp that is on the dash. Part of that circuit is another set of diodes mounted inside the alternator called the diode trio. The diode trio takes current coming from the three stator windings and passes a small amount through three diodes so that only the positive voltage comes through. After the diodes, the wires are joined into one wire and sent out of the alternator at the L connection. It then goes to one side of the dash warning lamp that is used to tell you when there is a problem with the charging system. The other side of the lamp is connected to the run side of the ignition switch. If both sides of the warning lamp have equal positive voltage, the lamp will not light. Remove voltage from one side and the lamp comes on to let you know there is a problem.

This system is not very efficient. There are many types of malfunctions of the charging system that it cannot detect, so just because the lamp is not lit does not mean everything is ok. A volt meter is probably the best method of determining whether the charging system is working properly

The Voltage Regulator

The voltage regulator can be mounted inside or outside of the alternator housing. If the regulator is mounted outside (common on some Ford products) there will be a wiring harness connecting it to the alternator.

The voltage regulator controls the field current applied to the spinning rotor inside the alternator. When there is no current applied to the field, there is no voltage produced from the alternator. When voltage drops below 13.5 volts, the regulator will apply current to the field and the alternator will start charging. When the voltage exceeds 14.5 volts, the regulator will stop supplying voltage to the field and the alternator will stop charging. This is how voltage output from the alternator is regulated. Amperage or current is regulated by the state of charge of the battery. When the battery is weak, the electromotive force (voltage) is not strong enough to hold back the current from the alternator trying to recharge the battery. As the battery reaches a state of full charge, the electromotive force becomes strong enough to oppose the current flow from the alternator, the amperage output from the alternator will drop to close to zero, while the voltage will remain at 13.5 to 14.5. When more electrical power is used, the electromotive force will reduce and alternator amperage will increase. It is extremely important that when alternator efficiency is checked, both voltage and amperage outputs are checked. Each alternator has a rated amperage output depending on the electrical requirements of the vehicle.

IGNITION SYSTEM

The purpose of the ignition system is to create a spark that will ignite the fuel-air mixture in the cylinder of an engine. It must do this at exactly the right instant and do it at the rate of up to several thousand times per minute for each cylinder in the engine. If the timing of that spark is off by a small fraction of a second, the engine will run poorly or not run at all.

The ignition system sends an extremely high voltage to the spark plug in each cylinder when the piston is at the top of its compression stroke. The tip of each spark plug contains a gap that the voltage must jump across in order to reach ground. That is where the spark occurs.

The voltage that is available to the spark plug is somewhere between 20,000 volts and 50,000 volts or better. The job of the ignition system is to produce that high voltage from a 12 volt source and get it to each cylinder in a specific order, at exactly the right time.

Let's see how this is done.

The ignition system has two tasks to perform. First, it must create a voltage high enough (20,000+) to arc across the gap of a spark plug, thus creating a spark strong enough to ignite the air/fuel mixture for combustion. Second, it must control the timing of that the spark so it occurs at the exact right time and send it to the correct cylinder.

The ignition system is divided into two sections, the primary circuit and the secondary circuit. The low voltage primary circuit operates at battery voltage (12 to 14.5 volts) and is responsible for generating the signal to fire the spark plug at the exact right time and sending that signal to the ignition coil. The ignition coil is the component that converts the 12 volt signal into the high 20,000+ volt charge. Once the voltage is stepped up, it goes to the secondary circuit which then directs the charge to the correct spark plug at the right time.

The Basics

Before we begin this discussion, let's talk a bit about electricity in general. I know that this is basic stuff, but there was a time that you didn't know about this and there are people who need to know the basics so that they could make sense of what follows.

All automobiles work on DC, or Direct Current. This means that current moves in one direction, from the positive battery terminal to the negative battery terminal. In the case of the automobile, the negative battery terminal is connected by a heavy cable directly to the body and the engine block of the vehicle. The body and any metal component in contact with it is called the Ground. This means that a circuit that needs to send current back to the negative side of the battery can be connected to any part of the vehicle's metal body or the metal engine block.

A good example to see how this works is the headlight circuit. The headlight circuit consists of a wire that goes from the positive battery terminal to the headlight switch. Another wire goes from the headlight switch to one of two terminals on the headlamp bulb. Finally, a third wire goes from a second terminal on the bulb to the metal body of the car. When you switch the headlights on, you are connecting the wire from the battery with the wire to the headlamps allowing battery current to go directly to the headlamp bulbs. Electricity passes through the filaments inside the bulb, then out the other wire to the metal body. From there, the current goes back to the negative terminal of the battery completing the circuit. Once the current is flowing through this circuit, the filament inside the headlamp gets hot and glows brightly. Let there be light.

Now, back to the ignition system. The basic principle of the electrical spark ignition system has not changed for over 75 years. What has changed is the method by which the spark is created and how it is distributed.

Currently, there are three distinct types of ignition systems, The **Mechanical Ignition System** was used prior to 1975. It was mechanical and electrical and used no electronics. By understanding these early systems, it will be easier to understand the new electronic and computer controlled ignition systems, so don't skip over it. The **Electronic Ignition System** started finding its way to production vehicles during the early '70s and became popular when better control and improved reliability became important with the advent of emission controls. Finally, the **Distributor less Ignition System** became available in the mid '80s. This system was always computer controlled and contained no moving parts, so reliability was greatly improved. Most of these systems required no maintenance except replacing the spark plugs at intervals from 60,000 to over 100,000 miles.

Let's take a detailed look at each system and see how they work.

MAGNETO IGNITION SYSTEM

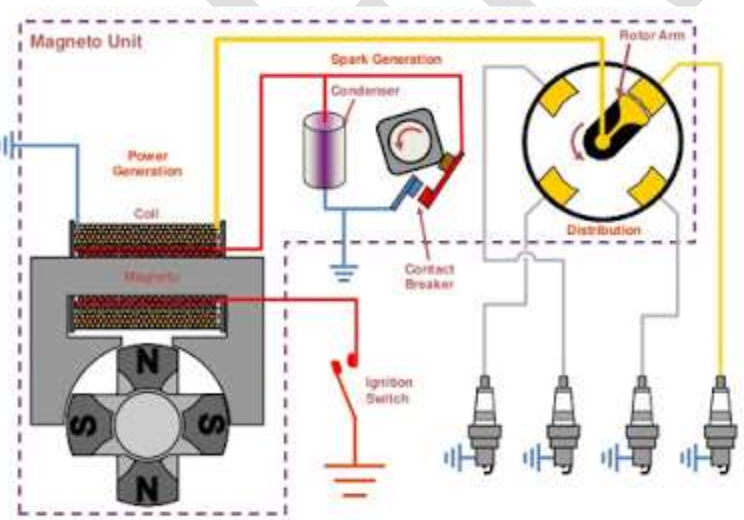
A combustion engine which has some vivid characteristic like high speed and high internal compression requires a system that produces very high ignition from the spark plug which is used as the source. The ignition system is the system which uses the spark plug as their source where electrical energy is input given to the spark plug.

There are three types of ignition system

1. Battery Ignition System
2. Magneto Ignition System
3. Electronic Ignition System

The Magneto Ignition System is a unique kind of Ignition System which has its own source to generate the necessary amount of energy for an automobile or a vehicle to work.

Main Parts



IGNITION SYSTEM – Magneto System

Here is the list of parts that are used in it

1. Magneto
2. Distributor

3. Spark Plug
4. Capacitor

1. MAGNETO

The source that generates energy in the Magneto Ignition System is the Magneto. Generally, a magneto is a small generator that works on electricity. When magneto is rotated by the engine, it produces the voltage. The higher the rotation, the greater will be the amount of voltage produced by the system. The magneto does not need any external power source such as a battery to kick start it as it itself is a source for generating the energy. There are two types of winding in it. It has a primary binding and a secondary binding.

In addition to this, magneto has 3 types based on its engine rotation

1. Armature rotating type
2. Magnet rotating type
3. Polar inductor type

In the armature rotating type, armature rotates between the stationary magnet whereas in the magnet rotating type, the armature is stationary and the magnets are rotating around the armature. In the polar inductor type, both the magnet and the windings remain stationary but the voltage is generated by reversing the flux field with the help of soft iron polar projections, called inductors.

2. DISTRIBUTOR

The distributor that is used in the Magneto Ignition System is also used in the multi-cylinder engine. The multi-cylinder engine is used for regulation of spark in a correct sequence in the spark plug. The surge of the ignition is distributed uniformly among the spark plugs. There are two types of distributors

1. Carbon brush type distributor
2. Gap type distributor

In carbon brush type, the rotor arm sliding over the metallic segment carry the carbon brush which is embedded inside the distributor cap or molded insulating material. This help to provide an electric connection with the spark plug. In gap type, the distributor electrode of rotor arm is close to the distributor cap, but no contact is made leading no wear for the electrode.

3. SPARK PLUG

The spark plug used in the this Ignition System has two electrodes that are parted from each other. A high voltage flows through it which causes the generation of the spark and used to ignite cylinders combustion mixture like oil. The electrode used in it is a steel shell and an insulator. The central electrode is connected to the supply of ignition coil and outer steel shell which is grounded insulating both of them. There is a small air gap that is left between the central electrode and the steel shell where the spark is generated. The central electrode is close when the spark is generated and hence it is made of a high nickel alloy that can withstand high temperature and resistances.

4. CAPACITOR

The capacitor used in the Magneto Ignition System is a simple electrical capacitor in which two metal plates are separated by an insulating material with a distance. Commonly, air is used as insulating material, but for a particular technical requirement, some high-quality insulating material is used.

Working Principle Of Magneto Ignition System

The working principle of the this ignition System is similar to the working principle of coil or battery ignition system except that in it magneto is used to produce energy but not the battery. Here are the following scenarios that occur in it.

1. When engine in the system starts it help magneto to rotate and thereby producing the energy in the form of high voltage.
2. The one end of the magneto is grounded through contact breaker and ignition capacitor is connected to it parallel.
3. The contact breaker is regulated by the cam and when the breaker is open, current flows through the condenser and charges it.
4. As the condenser is acting like a charger now, the primary current flow is reduced thereby reducing the overall magnetic field generated in the system. This increases the voltage in the condenser.
5. This increased high voltage in the condenser will act as an EMF thereby producing the spark at the right spark plug through the distributor.
6. At the initial stage, the speed of the engine is low and hence the voltage generated by the magneto is low but as the rotating speed of the engine increases, it also increases the voltage generated by the magneto and flow of the current is also increased. To kick start the engine, we can use an external source such as the battery to avoid the slow start of the engine.

Advantages and Disadvantages

Advantages

- It is more useful at medium and high speed.
- It is more useful because no battery is used.
- It requires less maintenance.

The main advantage of the magneto ignition system over other ignition system is it doesn't require any external source to generate energy. It was managed at low tension and high tension. In the high tension, a huge amount of voltage is generated using a step-up transformer which can be used for engines like the airplane engine and low tension can manage this voltage letting it flow in the smallest part of the wiring and this avoid the leakage too.

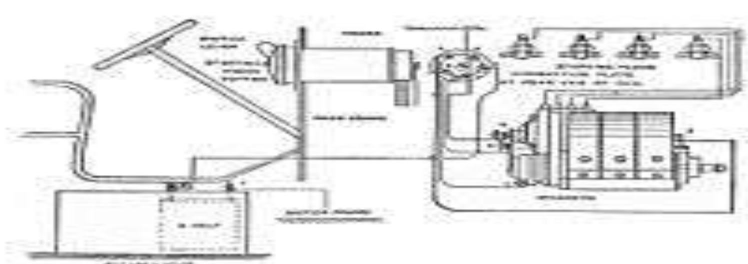
Disadvantages

- It has starting problem due to the low rotating speed at starting of the engine.
- It is more expensive when compared to battery ignition system.
- There is a possibility of misfire due to leakage because the variation of voltage in the wiring can occur.

Application

1. Here is the partial list of the applications of engines equipped with magneto ignition system.
2. Tractors, Oil Burners, and Outboard Motors
3. Washing Machines
4. Trucks and Cement Mixers
5. Buses
6. Airplane Engines
7. Power Units, Marine Engines and Natural Gas Engines

Switchable systems



Switchable magneto ignition circuit, with starting battery.

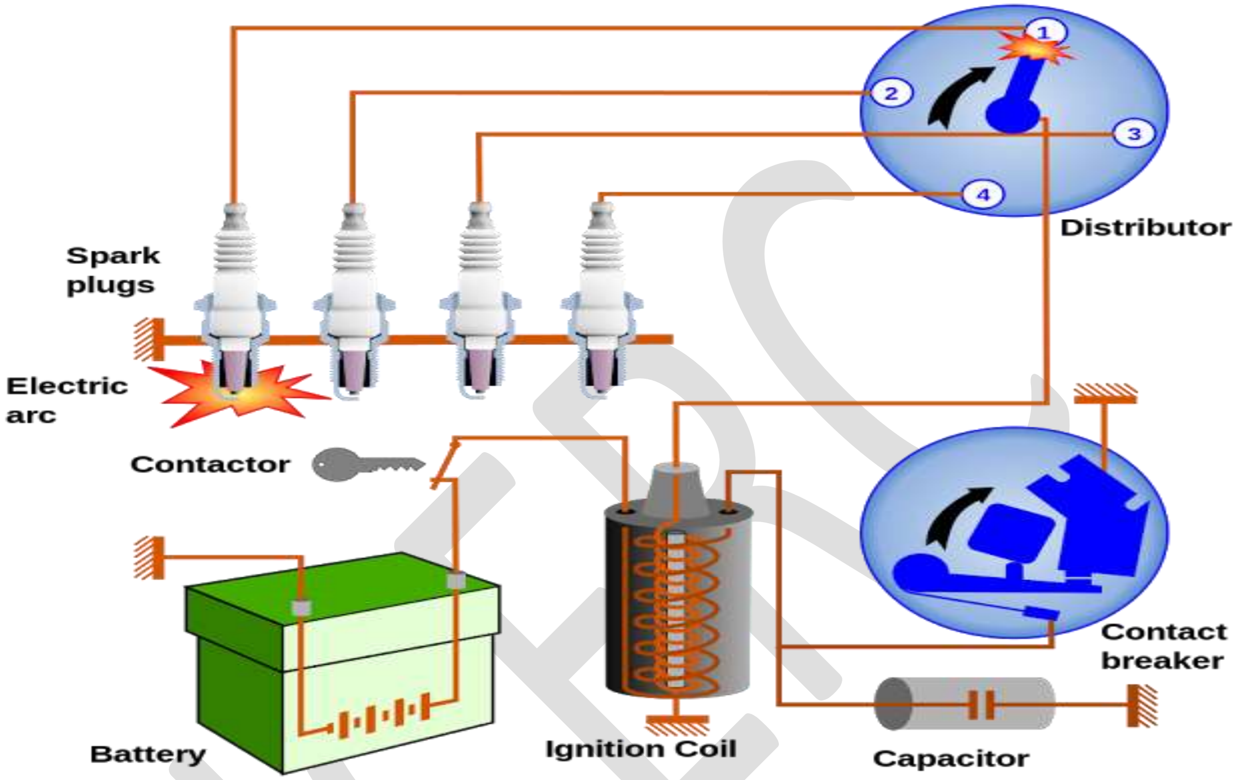
The output of a magneto depends on the speed of the engine, and therefore starting can be problematic. Some magnetos include an impulse system, which spins the magnet quickly at the proper moment, making easier starting at slow cranking speeds. Some engines, such as aircraft but also the Ford Model T, used a system which relied on non rechargeable dry cells, (similar to a large flashlight battery, and which was not maintained by a charging system as on modern automobiles) to start the engine or for starting and running at low speed. The operator would manually switch the ignition over to magneto operation for high speed operation.

To provide high voltage for the spark from the low voltage batteries, a 'tickler' was used, which was essentially a larger version of the once widespread electric buzzer. With this apparatus, the direct current passes through an electromagnetic coil which pulls open a pair of contact points, interrupting the current; the magnetic field collapses, the spring-loaded points close again, the circuit is reestablished, and the cycle repeats rapidly. The rapidly collapsing magnetic field, however, induces a high voltage across the coil which can only relieve itself by arcing across the contact points; while in the case of the buzzer this is a problem as it causes the points to oxidize and/or weld together, in the case of the ignition system this becomes the source of the high voltage to operate the spark plugs.

In this mode of operation, the coil would "buzz" continuously, producing a constant train of sparks. The entire apparatus was known as the 'Model T spark coil' (in contrast to the modern ignition coil which is *only* the actual coil component of the system). Long after the demise of the Model T as transportation they remained a popular self-contained source of high voltage for electrical home experimenters, appearing in articles in magazines such as *Popular Mechanics* and projects for school science fairs as late as the early 1960s. In the UK these devices were commonly known as trembler coils and were popular in cars pre-1910, and also in commercial vehicles with large engines until around 1925 to ease starting.

The Model T (built into the flywheel) differed from modern implementations by not providing high voltage directly at the output; the maximum voltage produced was about 30 volts, and therefore also had to be run through the spark coil to provide high enough voltage for ignition, as described above, although the coil would not "buzz" continuously in this case, only going through one cycle per spark. In either case, the low voltage was switched to the appropriate spark plug by the *'timer'* mounted on the front of the engine. This performed the equivalent function to the modern distributor, although by directing the low voltage, not the high voltage as for the distributor. The timing of the spark was adjustable by rotating this mechanism through a lever mounted on the steering column. As the precise timing of the spark depends on *both* the 'timer' and the trembler contacts within the coil, this is less consistent than the breaker points of the later distributor. However, for the low speed and the low compression of such early engines, this imprecise timing was acceptable.

BATTERY IGNITION OR COIL OPERATED IGNITION SYSTEM



Main Parts of battery ignition system:

Battery

A battery is used to provide energy for ignition. It is work as storage of energy and charged by dynamo, which is driven by engine. It converts chemical energy to electric energy. Two types of battery used in spark ignition system, lead acid battery and alkaline battery. The first one is used in light duty commercial vehicle and the other one is used in heavy duty commercial vehicle. It is housed in primary side of ignition coil.

Ignition switch

It is used to turn on and off the ignition system. Battery is connected to the primary winding of ignition coil by ignition switch and ballast resistor.

Ballast resistor

It is connected in series with primary winding to regulate current in primary winding. It is used to prevent injury due to overheating of ignition coil. It controls the current passes through primary winding. It is made by iron. Iron has property of increase electrical resistance rapidly by increase in temperature at certain limit. This additional resistance resists flowing current which control the temperature of ignition coil.

Ignition coil

Ignition coil is the main body of battery ignition system. The purpose of ignition coil to step up the battery voltage (6 or 12) to a high voltage, which is sufficient to produce spark at spark plug. It consist a magnetic core or soft wire or sheet, and two electrical winding called primary winding and secondary winding. The primary winding has generally 200-300 turn and the end are connected to exterior terminal. The secondary has almost 21000 turns of copper wire which is insulated to withstand with high voltage. It is located inside the primary winding and its one end connected to secondary winding and other end is grounded either to primary winding or to the metal case. This entire unit is enclosed in a metal container which makes it a compact unit.

Contact breaker

This is a mechanical device making and braking the primary circuit to ignition coil. When the points are closed current flow in ignition coil and when it open, flow of current stopped.

Capacitor

It is a simple electrical capacitor in which two metal plate are separated by an insulating material with a distance. Commonly air is used as insulating material but for particular technical requirement some high quality insulating material is used.

Distributor

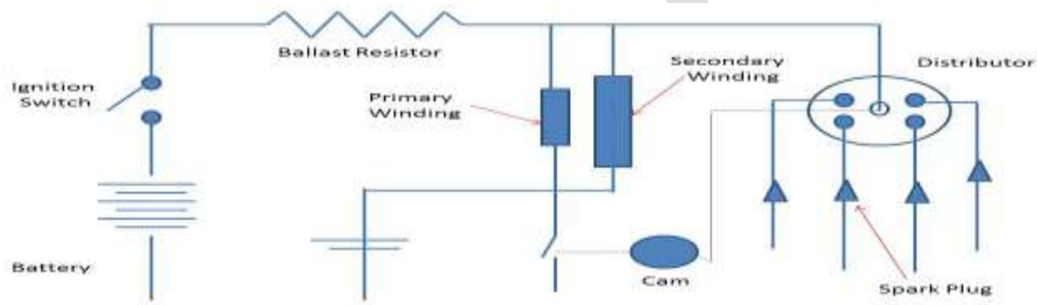
Distributor is used in multi cylinder engine to regulate spark in each spark plug at correct sequence. It distribute ignition surge in individual spark plug in correct sequence. There are two types of distributor. One is known as carbon brush type and the other one is gap type. In carbon brush type carbon brush carried by the rotor arm sliding over the metallic segment embedded into the distributor cap or molded insulating material. This makes electric connection or secondary winding with spark plug. In gap type distributor electrode of rotor arm pass close to but does not make contact with the distributor cap. So there is no wear of electrode.

Spark Plug

A spark plug generally has two electrodes which are separated with each other. A high potential discharge flow through it which generate spark and ignite the combustion mixture in cylinder. It mainly consist two electrodes a steel shell and an insulator. The central electrode connected with the supply of ignition coil. It is well insulated with the outer steel shell which is grounded. There is a small air gap between steel shell and central electrode, between which spark is generated. The electrode usually made by high nickel alloy so it can withstand with high temperature and corrosion resistance.

Working of Battery Ignition System:

In the battery ignition system ignition coil stores the energy in form of magnetic field and deliver it at the instant of ignition, in form of high voltage current with high tension wire to correct spark plug. The diagram of four cylinder battery ignition system is as follow.



Battery Ignition System for Four Cylinder SI Engine

- First low voltage current flow form battery to the primary coil through ignition switch and ballast resistor.
- Ballast resistor regulates the temperature of ignition coil by regulating current passing form it.
- The ignition capacitor connected in parallel with contact breaker. One end of secondary winding is also grounded through contact breaker.
- When the ignition switch is closed, the primary winding of the coil is connected to the positive terminal, and current flow through it known as primary current.
- The current flows form primary coil produces a magnetic field which induces an EMF in secondary coil.
- The cam regulate the contact breaker. Wherever the breaker open, current flows into condenser, which charged the condenser.
- As the condenser become charger the primary current falls and the magnetic field

collapses. This will induces a much higher voltage in condenser.

- Now the condenser discharge into the battery which reverse the direction of both primary current and magnetic field. This will induce a very high EMF in secondary winding.
- Now this high voltage EMF produce spark at correct spark plug through distributor.

Advantages and Disadvantages:

Advantages:

1. At the time of starting or at low speed good spark is available.

2. The battery which is used to generate spark can be used to light other auxiliary like headlight, tell light etc.

3. Initial expenditure is less and it has low maintenance cost.

4. Ignition system is not affected by adjusting spark timing in battery ignition system.

Disadvantages:

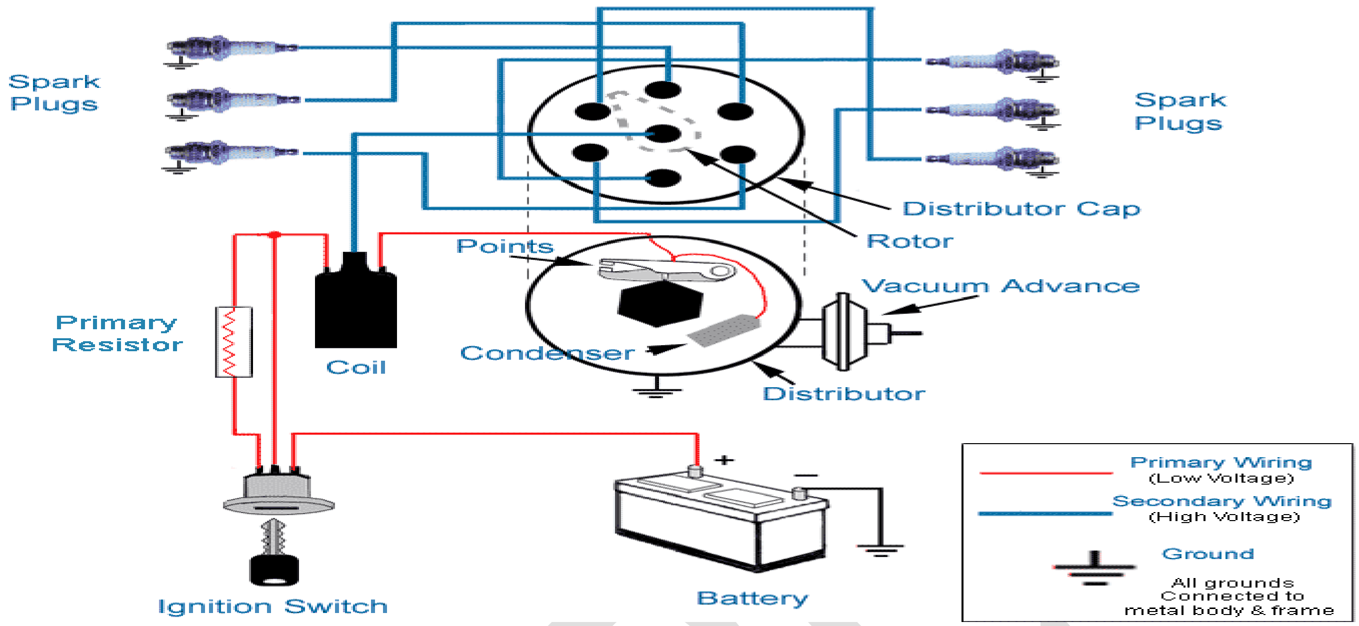
1. Time available of built up the current and stored energy is decrease as speed of engine increases.

2. Contact breaker subjected to both electrical and mechanical wear which results short maintenance interval.

3. The primary voltage decreases as the engine speed increase. So it is not fully reliable of high speed engine.

Modern ignition systems

The Mechanical Ignition System (from the dawn of the automobile to 1974)



The distributor is the nerve center of the mechanical ignition system and has two tasks to perform. First, it is responsible for triggering the ignition coil to generate a spark at the precise instant that it is required (which varies depending how fast the engine is turning and how much load it is under). Second, the distributor is responsible for directing that spark to the proper cylinder (which is why it is called a distributor)

The circuit that powers the ignition system is simple and straight forward. (see above) When you insert the key in the ignition switch and turn the key to the Run position, you are sending current from the battery through a wire directly to the positive (+) side of the ignition coil. Inside the coil is a series of copper windings that loop around the coil over a hundred times before exiting out the negative (-) side of the coil. From there, a wire takes this current over to the distributor and is connected to a special on/off switch, called the points. When the points are closed, this current goes directly to ground. When current flows from the ignition switch, through the windings in the coil, then to ground, it builds a strong magnetic field inside the coil.

The points are made up of a fixed contact point that is fastened to a plate inside the distributor, and a movable contact point mounted on the end of a spring loaded arm.. The movable point rides on a 4,6, or 8 lobe cam (depending on the number of cylinders in the engine) that is mounted on a rotating shaft inside the distributor. This distributor cam rotates in time with the engine, making one complete revolution for every two revolutions of the engine. As it rotates, the cam pushes the points open and closed. Every time the points open, the flow of current is interrupted through the coil, thereby collapsing the magnetic field and releasing a high voltage surge through the secondary coil windings. This voltage surge goes out the top of the coil and through the high-tension coil wire.

Now, we have the voltage necessary to fire the spark plug, but we still have to get it to the correct cylinder. The coil wire goes from the coil directly to the center of the distributor cap. Under the cap is a rotor that is mounted on top of the rotating shaft. The rotor has a metal strip on the top that is in constant contact with the center terminal of the distributor cap. It receives the high voltage surge from the coil wire and sends it to the other end of the rotor which rotates past each spark plug terminal inside the cap. As the rotor turns on the shaft, it sends the voltage to the correct spark plug wire, which in turn sends it to the spark plug. The voltage enters the spark plug at the terminal at the top and travels down the core until it reaches the tip. It then jumps across the gap at the tip of the spark plug, creating a spark suitable to ignite the fuel-air mixture inside that cylinder.

The description I just provided is the simplified version, but should be helpful to visualize the process, but we left out a few things that make up this type of ignition system. For instance, we didn't talk about the condenser that is connected to the points, nor did we talk about the system to advance the timing. Let's take a look at each section and explore it in more detail.

The ignition switch.

There are two separate circuits that go from the ignition switch to the coil. One circuit runs through a resistor in order to step down the voltage about 15% in order to protect the points from premature wear. The other circuit sends full battery voltage to the coil. The only time this circuit is used is during cranking. Since the starter draws a considerable amount of current to crank the engine, additional voltage is needed to power the coil. So when the key is turned to the spring-loaded start position, full battery voltage is used. As soon as the engine is running, the driver releases the key to the run position which directs current through the primary resistor to the coil.

On some vehicles, the primary resistor is mounted on the firewall and is easy to replace if it fails. On other vehicles, most notably vehicles manufactured by GM, the primary resistor is a special resistor wire and is bundled in the wiring harness with other wires, making it more difficult to replace, but also more durable.

The Distributor

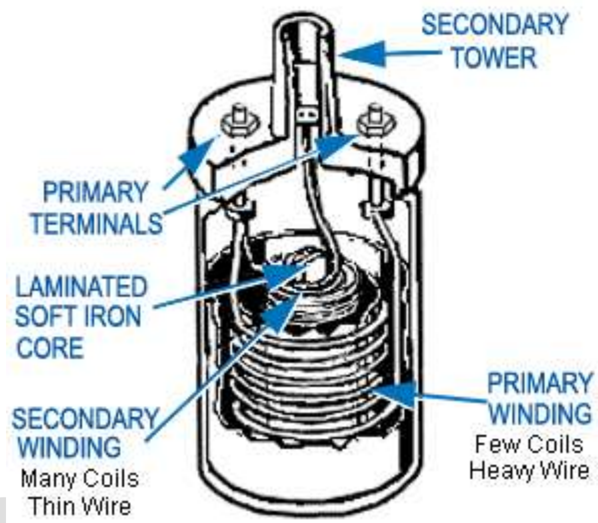
When you remove the distributor cap from the top of the distributor, you will see the points and condenser. The condenser is a simple capacitor that can store a small amount of current. When the points begin to open, the current flowing through the points looks for an alternative path to ground. If the condenser were not there, it would try to jump across the gap of the points as they begin to open. If this were allowed to happen, the points would quickly burn up and you would hear heavy static on the car radio. To prevent this, the condenser acts like a path to ground. It really is not, but by the time the condenser is saturated, the points are too far apart for the small amount of voltage to jump across the wide point gap. Since the arcing across the opening points is eliminated, the points last longer and there is no static on the radio from point arcing.

The points require periodic adjustments in order to keep the engine running at peek efficiency. This is because there is a rubbing block on the points that is in contact with the cam and this rubbing block wears out over time changing the point gap. There are two ways that the points can be measured to see if they need an adjustment. One way is by measuring the gap between the open points when the rubbing block is on the high point of the cam. The other way is by measuring the dwell electrically. The dwell is the amount, in degrees of cam rotation, that the points stay closed.

On some vehicles, points are adjusted with the engine off and the distributor cap removed. A mechanic will loosen the fixed point and move it slightly, then retighten it in the correct position using a feeler gauge to measure the gap. On other vehicles, most notably GM cars, there is a window in the distributor where a mechanic can insert a tool and adjust the points using a dwell meter while the engine is running. Measuring dwell is much more accurate than setting the points with a feeler gauge.

Points have a life expectancy of about 10,000 miles at which time they have to be replaced. This is done during a routine major tune up. During the tune up, points, condenser, and the spark plugs are replaced, the timing is set and the carburetor is adjusted. In some cases, to keep the engine running efficiently, a minor tune up would be performed at 5,000 mile increments to adjust the points and reset the timing.

Ignition Coil



The ignition coil is nothing more that an electrical transformer. It contains both primary and secondary winding circuits. The coil primary winding contains 100 to 150 turns of heavy copper wire. This wire must be insulated so that the voltage does not jump from loop to loop, shorting it out. If this happened, it could not create the primary magnetic field that is required. The primary circuit wire goes into the coil through the positive terminal, loops around the primary windings, then exits through the negative terminal.

The coil secondary winding circuit contains 15,000 to 30,000 turns of fine copper wire, which also must be insulated from each other. The secondary windings sit inside the loops of the primary windings. To further increase the coils magnetic field the windings are wrapped around a soft iron core. To withstand the heat of the current flow, the coil is filled with oil which helps keep it cool.

The ignition coil is the heart of the ignition system. As current flows through the coil a strong magnetic field is built up. When the current is shut off, the collapse of this magnetic field to the secondary windings induces a high voltage which is released through the large center terminal. This voltage is then directed to the spark plugs through the distributor.

Ignition Timing

The timing is set by loosening a hold-down screw and rotating the body of the distributor. Since the spark is triggered at the exact instant that the points begin to open, rotating the distributor body (which the points are mounted on) will change the relationship between the position of the points and the position of the distributor cam, which is on the shaft that is geared to the engine rotation.

While setting the initial, or base timing is important, for an engine to run properly, the timing needs to change depending on the speed of the engine and the load that it is under. If we can move the plate that the points are mounted on, or we could change the position of the distributor cam in relation to the gear that drives it, we can alter the timing dynamically to suit the needs of the engine.

Why do we need the timing to advance when the engine runs faster?

When the spark plug fires in the combustion chamber, it ignites whatever fuel and air mixture is present at the tip of the spark plug. The fuel that surrounds the tip is ignited by the burning that was started by the spark plug, not by the spark itself. That flame front continues to expand outward at a specific speed that is always the same, regardless of engine speed. It does not begin to push the piston down until it fills the combustion chamber and has no where else to go. In order to maximize the amount of power generated, the spark plug must fire before the piston reaches the top of the cylinder so that the burning fuel is ready to push the piston down as soon as it is at the top of its travel. The faster the engine is spinning, the earlier we have to fire the plug to produce maximum power.

There are two mechanisms that allow the timing to change: Centrifugal Advance and Vacuum Advance.

Centrifugal Advance changes the timing in relation to the speed (RPM) of the engine. It uses a pair of weights that are connected to the spinning distributor shaft. These weights are hinged on one side to the lower part of the shaft and connected by a linkage to the upper shaft where the distributor cam is. The weights are held close to the shaft be a pair of springs. As the shaft spins faster, the weights are pulled out by centrifugal force against the spring pressure. The faster the shaft spins, the more they are pulled out. When the weights move out, it changes the alignment between the lower and upper shaft, causing the timing to advance.

Vacuum Advance works by changing the position of the points in relationship to the distributor body. An engine produces vacuum while it is running with the throttle closed. In other words, your foot is off the gas pedal. In this configuration, there is very little fuel and air in the combustion chamber.

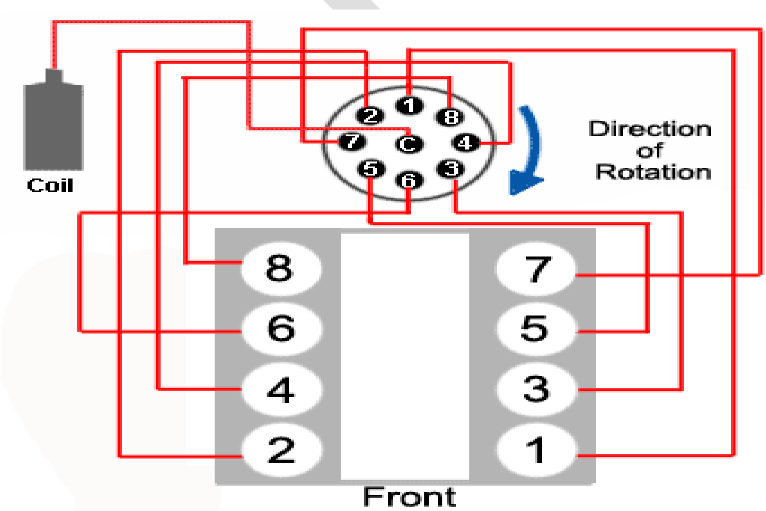
Vacuum advance uses a vacuum diaphragm connected to a link that can move the plate that the points are mounted on. By sending engine vacuum to the vacuum advance diaphragm, timing is advanced. On older cars, the vacuum that is used is port vacuum, which is just above the throttle plate. With this setup, there is no vacuum present at the vacuum advance diaphragm while the throttle is closed. When the throttle is cracked opened, vacuum is sent to the vacuum advance, advancing the timing.

On early emission controlled vehicles, manifold vacuum was used so that vacuum was present at the vacuum advance at idle in order to provide a longer burn time for the lean fuel mixtures on those engines. When the throttle was opened, vacuum was reduced causing the timing to retard slightly. This was necessary because as the throttle opened, more fuel was added to the mixture reducing the need for excessive advance. Many of these early emission controlled cars had a vacuum advance with electrical components built into the advance unit to modify the timing under certain conditions.

Both Vacuum and Centrifugal advance systems worked together to extract the maximum efficiency from the engine. If either system was not functioning properly, both performance and fuel economy would suffer. Once computer controls were able to directly control the engine's timing, vacuum and centrifugal advance mechanisms were no longer necessary and were eliminated.

Ignition Wires

These cables are designed to handle 20,000 to more than 50,000 volts, enough voltage to toss you across the room if you were to be exposed to it. The job of the spark plug wires is to get that enormous power to the spark plug without leaking out. Spark plug wires have to endure the heat of a running engine as well as the extreme changes in the weather. In order to do their job, spark plug wires are fairly thick, with most of that thickness devoted to insulation with a very thin conductor running down the center. Eventually, the insulation will succumb to the elements and the heat of the engine and begins to harden, crack, dry out, or otherwise break down. When that happens, they will not be able to deliver the necessary voltage to the spark plug and a misfire will occur. That is what is meant by "Not running on all cylinders". To correct this problem, the spark plug wires would have to be replaced.



Typical V8 Firing Order
1, 8, 4, 3, 6, 5, 7, 2

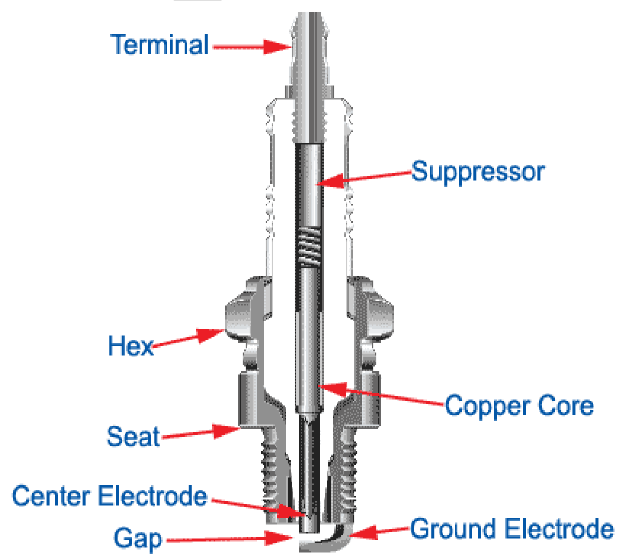
Spark plug wires are routed around the engine very carefully. Plastic clips are often used to keep the wires separated so that they do not touch together. This is not always necessary, especially when the wires are new, but as they age, they can begin to leak and crossfire on damp days causing hard starting or a rough running engine.

Spark plug wires go from the distributor cap to the spark plugs in a very specific order. This is called the "firing order" and is part of the engine design. Each spark plug must only fire at the end of the compression stroke. Each cylinder has a compression stroke at a different time, so it is important for the individual spark plug wire to be routed to the correct cylinder.

For instance, a popular V8 engine firing order is 1, 8, 4, 3, 6, 5, 7, 2. The cylinders are numbered from the front to the rear with cylinder #1 on the front-left of the engine. So the cylinders on the left side of the engine are numbered 1, 3, 5, 7 while the right side are numbered 2, 4, 6, 8. On some engines, the right bank is 1, 2, 3, 4 while the left bank is 5, 6, 7, 8. A repair manual will tell you the correct firing order and cylinder layout for a particular engine.

The next thing we need to know is what direction the distributor is rotating in, clockwise or counter-clockwise, and which terminal on the distributor cap that #1 cylinder is located. Once we have this information, we can begin routing the spark plug wires.

If the wires are installed incorrectly, the engine may backfire, or at the very least, not run on all cylinders. It is very important that the wires are installed correctly.



Spark Plugs

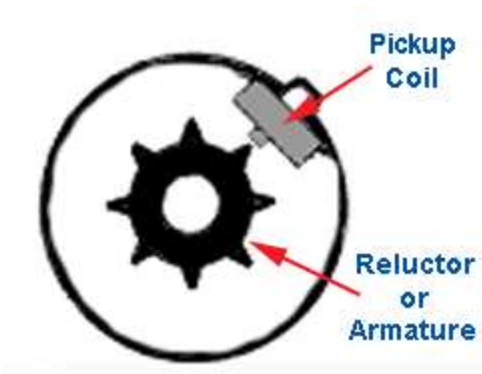
The ignition system's sole reason for being is to service the spark plug. It must provide sufficient voltage to jump the gap at the tip of the spark plug and do it at the exact right time, reliably on the order of thousands of times per minute for each spark plug in the engine.

The modern spark plug is designed to last many thousands of miles before it requires replacement. These electrical wonders come in many configurations and heat ranges to work properly in a given engine.

The heat range of a spark plug dictates whether it will be hot enough to burn off any residue that collects on the tip, but not so hot that it will cause pre-ignition in the engine. Pre-ignition is caused when a spark plug is so hot, that it begins to glow and ignite the fuel-air mixture prematurely, before the spark. Most spark plugs contain a resistor to suppress radio interference. The gap on a spark plug is also important and must be set before the spark plug is installed in the engine. If the gap is too wide, there may not be enough voltage to jump the gap, causing a misfire. If the gap is too small, the spark may be inadequate to ignite a lean fuel-air mixture, also causing a misfire.

The Electronic Ignition System (from 1970's to today)

This section will describe the main differences between the early point & condenser systems and the newer electronic systems. If you are not familiar with the way an ignition system works in



general, In the electronic ignition system, the points and condenser were replaced by electronics. On these systems, there were several methods used to replace the points and condenser in order to trigger the coil to fire. One method used a metal wheel with teeth, usually one for each cylinder. This is called an armature or reluctor. A magnetic pickup coil senses when a tooth passes and sends a signal to the control module to fire the coil.

Other systems used an electric eye with a shutter wheel to send a signal to the electronics that it was time to trigger the coil to fire. These systems still need to have the initial timing adjusted by rotating the distributor housing.

The advantage of this system, aside from the fact that it is maintenance free, is that the control module can handle much higher primary voltage than the mechanical points. Voltage can even be stepped up before sending it to the coil, so the coil can create a much hotter spark, on the order of 50,000 volts instead of 20,000 volts that is common with the mechanical systems. These systems only have a single wire from the ignition switch to the coil since a primary resistor is no longer needed.

On some vehicles, this control module was mounted inside the distributor where the points used to be mounted. On other designs, the control module was mounted outside the distributor with external wiring to connect it to the pickup coil. On many General Motors engines, the control module was inside the distributor and the coil was mounted on top of the distributor for a one piece unitized ignition system. GM called it High Energy Ignition or HEI for short.

The higher voltage that these systems provided allow the use of a much wider gap on the spark plugs for a longer, fatter spark. This larger spark also allowed a leaner mixture for better fuel economy and still insure a smooth running engine.

The early electronic systems had limited or no computing power, so timing still had to be set manually and there was still a centrifugal and vacuum advance built into the distributor.

On some of the later systems, the inside of the distributor is empty and all triggering is performed by a sensor that watches a notched wheel connected to either the crankshaft or the camshaft. These devices are called Crankshaft Position Sensor or Camshaft Position Sensor. In these systems, the job of the distributor is solely to distribute the spark to the correct cylinder through the distributor cap and rotor. The computer handles the timing and any timing advance necessary for the smooth running of the engine.

The Distributor less Ignition system (from 1980's to today)

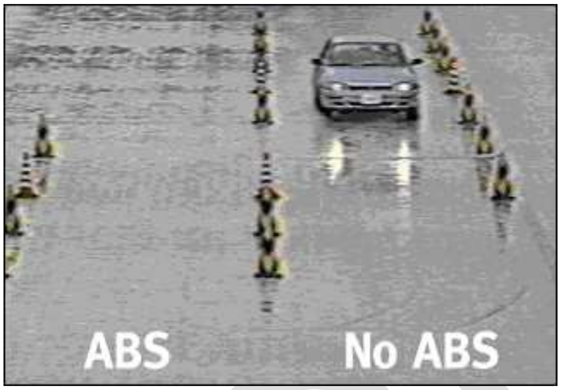
Newer automobiles have evolved from a mechanical system (distributor) to a completely solid state electronic system with no moving parts. These systems are completely controlled by the on-board computer. In place of the distributor, there are multiple coils that each serve one or two spark plugs. A typical 6 cylinder engine has 3 coils that are mounted together in a coil "pack". A spark plug wire comes out of each side of the individual coil and goes to the appropriate spark plug. The coil fires both spark plugs at the same time. One spark plug fires on the compression stroke igniting the fuel-air mixture to produce power, while the other spark plug fires on the exhaust stroke and does nothing. On some vehicles, there is an individual coil for each cylinder mounted directly on top of the spark plug. This design completely eliminates the high tension spark plug wires for even better reliability. Most of these systems use spark plugs that are designed to last over 100,000 miles, which cuts down on maintenance costs.

ANTILOCKING BRAKING SYSTEM (ABS)

ABS prevents the wheels from locking up, thus avoiding uncontrolled skidding of the vehicle and decreases the distance travelled without slipping.

Driving on expressways can be fun and thrill-inducing, as many of you surely know. One gets to unleash a car’s full potential. The city roads keep us grounded, but as soon as you hit the highway, there’s no looking back. You’ll almost never see a car going below 100 km/hr.

The situation gets particularly tricky during monsoons, as cruising in a car at such high speeds is a perfect recipe for a disaster if the roads are slick. Even so, it does happen, so what do you do in a situation on a slippery road when you have to suddenly apply the brakes of your car? Without an anti-lock brake system, the wheels of your car stop spinning and the car will begin to skid. You'll completely lose control over the car and the results can be deadly.



Anti-lock braking systems (ABS) take a lot of the challenge out of this sometimes nerve-wrecking event. In fact, on slippery surfaces, even professional drivers can't stop as quickly without ABS as an average driver can with ABS.

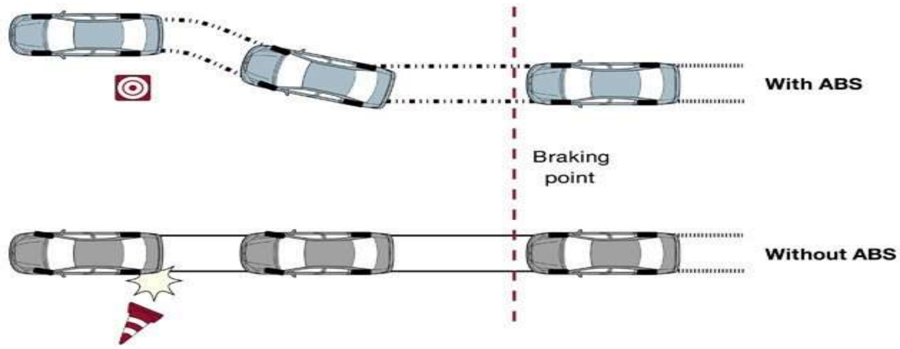
What is Anti-lock braking system (ABS) in cars?

As the name signifies, the anti-lock braking system is a safety system in cars and other automobiles that keeps their wheels from locking up and helps their drivers to maintain steering control. Also referred to as anti-skid braking system sometimes, it enables the wheels of a vehicle to maintain tractive contact with the ground so that they don't go into an uncontrolled skid.

With ABS, you have more control on your car during situations such as sudden braking. Basically, it is designed to help the driver maintain some steering ability and avoid skidding while braking.

ABS Working principle

The basic theory behind anti-lock brakes is simple. It prevents the wheels from locking up, thus avoiding uncontrolled skidding. ABS generally offers improved vehicle control and decreases stopping distances on dry and slippery surfaces.



With ABS, you get better stability and control over a car while braking

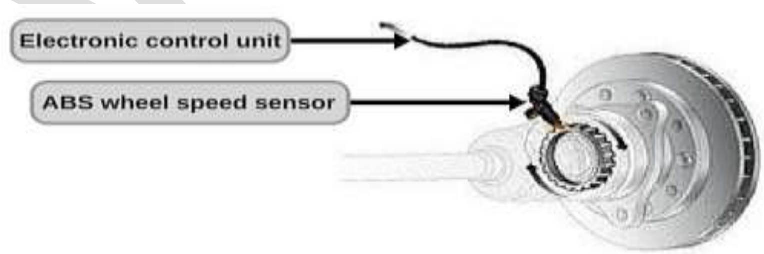
A skidding wheel (where the tire contact patch is sliding relative to the road) has less traction (grip of the tire on the road) than a non-skidding wheel. For example, if your car drives over a road covered in ice, it is unable to move forward and the wheels will keep spinning, since no traction is present. This is because the contact point of the wheel is sliding relative to the ice.

ABS modifies the brake fluid pressure, independent of the amount of pressure being applied on the brakes, to bring the speed of the wheel back to the minimum slip level that is mandatory for optimal braking performance.

ABS has four major components:

1) Speed Sensor

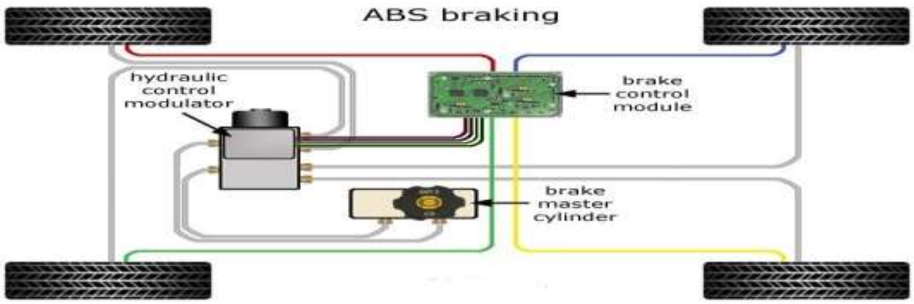
This sensor monitors the speed of each wheel and determines the necessary acceleration and deceleration of the wheels. It consists of an exciter (a ring with V-shaped teeth) and a wire coil/magnet assembly, which generates the pulses of electricity as the teeth of the exciter pass in front of it.



The speed sensor

2) Valves

The valves regulate the air pressure to the brakes during the ABS action. There is a valve in the brake line of each brake that is controlled by the ABS. In the first position, the brake valve is open and it allows the pressure from the master cylinder to be transferred to the brakes. In the second position, the brake valve remains closed and pressure from the master cylinder to the brakes is constrained. In the third position, the valve releases some of the pressure on the brakes. The third step is repeated until the car comes to a halt. The resistance that you feel when braking suddenly at high speeds is actually the brake valves controlling the pressure that is being transferred to the brakes from the master cylinder.



Components of ABS braking

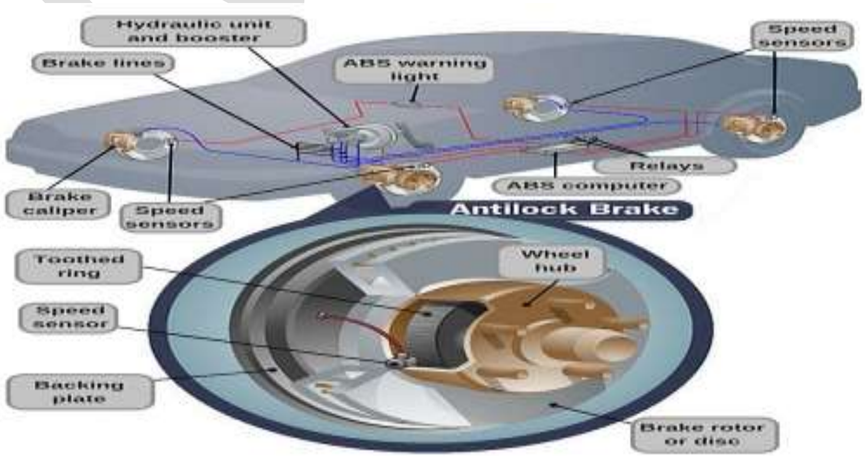
3) Electronic Control Unit (ECU)

The ECU is an electronic control unit that receives, amplifies and filters the sensor signals for calculating the wheel rotational speed and acceleration. The ECU receives a signal from the sensors in the circuit and controls the brake pressure, according to the data that is analyzed by the unit.

4) Hydraulic Control Unit

The Hydraulic Control Unit receives signals from the ECU to apply or release the brakes under the anti-lock conditions. The Hydraulic Control Unit controls the brakes by increasing the hydraulic pressure or bypassing the pedal force to reduce the braking power.

ABS in operation



Working components of an ABS.

While braking, if a wheel-locking situation is detected or anticipated, the ECU alerts the HCU by sending a current and commands it to release the brake pressure, allowing the wheel velocity to increase and the wheel slip to decrease. When the wheel velocity increases, the ECU reapplies the brake pressure and restricts the wheel slip to a certain degree (*Note:* When the braking action is initiated, a slippage between the tire and the road surface in contact will occur, which makes the speed of the vehicle different from that of the tire). The Hydraulic Control Unit controls the brake pressure in each wheel cylinder based on the inputs from the system sensor. As a result, this controls the wheel speed. This process is repeated for the next braking operation.

ABS is classified based on the number of sensors and the types of brakes used. Brakes can also be differentiated by the number of channels, i.e how many valves are individually controlled and the number of speed sensors.

Four-channel, four-sensor ABS

This is the best combination for an effective ABS system. There is a speed sensor on all four wheels and a separate valve for all four wheels. With this setup, the controller monitors each wheel individually to ensure that it is achieving maximum braking force.

Three-channel, three-sensor ABS

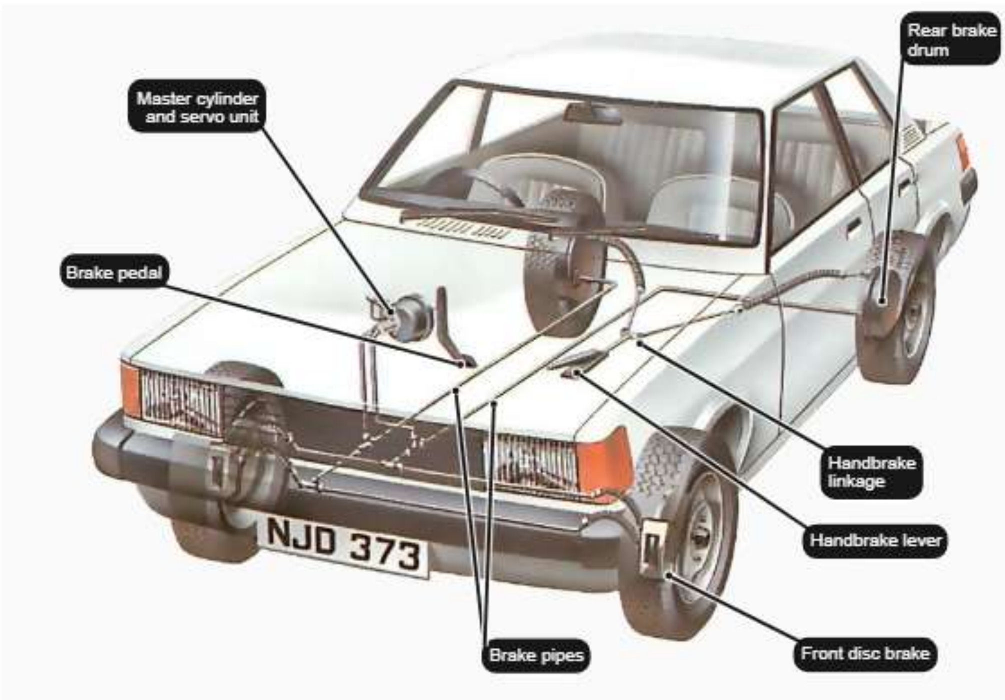
This combination, which is commonly found on pickup trucks with four-wheel ABS, has a speed sensor and a valve for each of the front wheels, along with one valve and one sensor for both rear wheels. The speed sensor for the rear wheels is located in the rear axle.

Similarly, there are also two-channel and one-channel ABS. The one-channel variant is the least effective, as you might expect.

Most new cars come equipped with ABS, as it is considered one of the most important safety features in cars. Current research shows that cars equipped with ABS are far less likely to be involved in multi-car accidents, because they still have access to steering capabilities. ABS has completely revolutionized the automobile industry to the point where a car without ABS is like a coffee mug without a handle!

BRAKES

Modern cars have brakes on all four wheels, operated by a hydraulic system. The brakes may be disc type or drum type. The front brakes play a greater part in stopping the car than the rear ones, because braking throws the car weight forward on to the front wheels. Many cars therefore have disc brakes, which are generally more efficient, at the front and drum brakes at the rear.All-disc braking systems are used on some expensive or high-performance cars, and all-drum systems on some older or smaller cars.



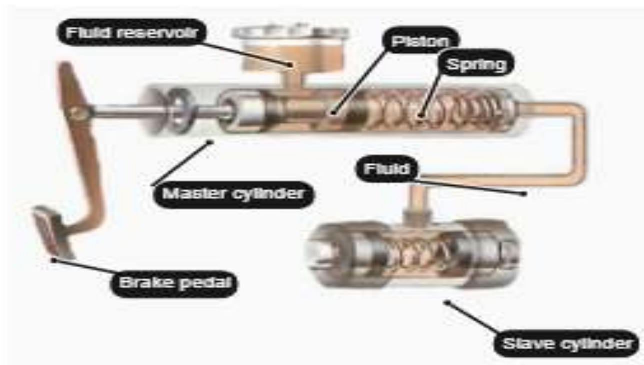
Dual-circuit braking system A typical dual-circuit braking system in which each circuit acts on both front wheels and one rear wheel. Pressing the brake pedal forces fluid out of the master cylinder along the brake pipes to the slave cylinders at the wheels; the master cylinder has a reservoir that keeps it full.

Brake hydraulics

A hydraulic brake circuit has fluid-filled master and slave cylinders connected by pipes. When you push the brake pedal it depresses a piston in the master cylinder, forcing fluid along the pipe.

The fluid travels to slave cylinders at each wheel and fills them, forcing pistons out to apply the brakes. Fluid pressure distributes itself evenly around the system. The combined surface 'pushing' area of all the slave pistons is much greater than that of the piston in the master cylinder. Consequently, the master piston has to travel several inches to move the slave pistons the fraction of an inch it takes to apply the brakes.

This arrangement allows great force to be exerted by the brakes, in the same way that a long-handled lever can easily lift a heavy object a short distance. Most modern cars are fitted with twin hydraulic circuits, with two master cylinders in tandem, in case one should fail. Sometimes one circuit works the front brakes and one the rear brakes; or each circuit works both front brakes and one of the rear brakes; or one circuit works all four brakes and the other the front ones only.



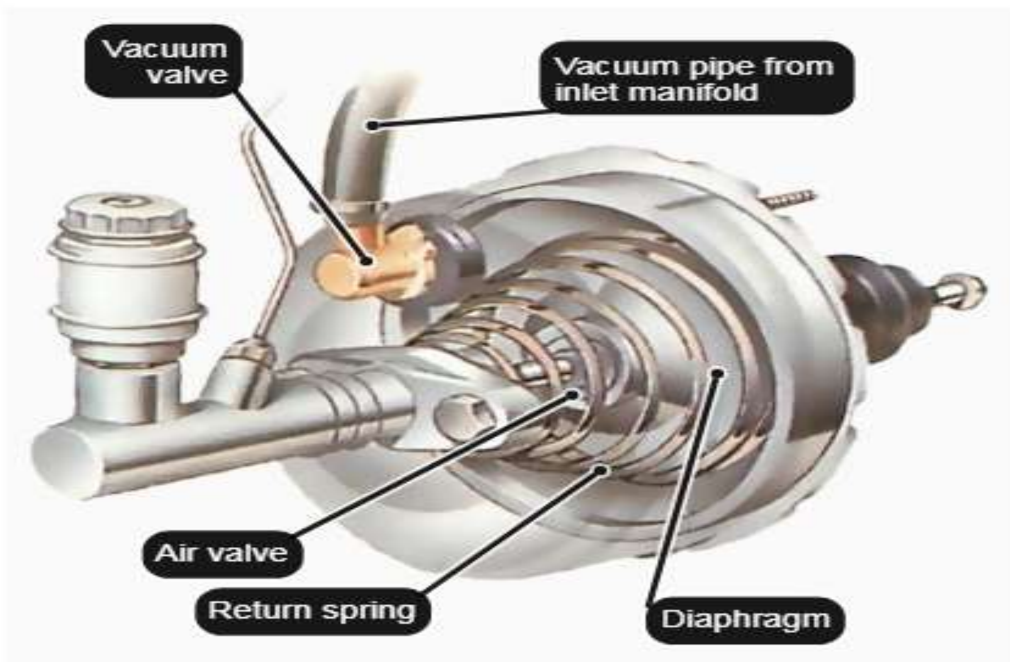
Master and slave cylinders
The master cylinder transmits hydraulic pressure to the slave cylinder when the pedal is pressed.

Under heavy braking, so much weight may come off the rear wheels that they lock, possibly causing a dangerous skid. For this reason, the rear brakes are deliberately made less powerful than the front. Most cars now also have a load-sensitive pressure-limiting valve. It closes when heavy braking raises hydraulic pressure to a level that might cause the rear brakes to lock, and prevents any further movement of fluid to them. Advanced cars may even have complex anti-lock systems that sense in various ways how the car is decelerating and whether any wheels are locking. Such systems apply and release the brakes in rapid succession to stop them locking.

Power-assisted brakes

Many cars also have power assistance to reduce the effort needed to apply the brakes. Usually the source of power is the pressure difference between the partial vacuum in the inlet manifold and the outside air.

The servo unit that provides the assistance has a pipe connection to the inlet manifold. A direct-acting servo is fitted between the brake pedal and the master cylinder. The brake pedal pushes a rod that in turn pushes the master-cylinder piston. But the brake pedal also works on a set of air valves, and there is a large rubber diaphragm connected to the master-cylinder piston. When the brakes are off, both sides of the diaphragm are exposed to the vacuum from the manifold. Pressing the brake pedal closes the valve linking the rear side of the diaphragm to the manifold, and opens a valve that lets in air from outside. The higher pressure of the outside air forces the diaphragm forward to push on the master-cylinder piston, and thereby assists the braking effort.



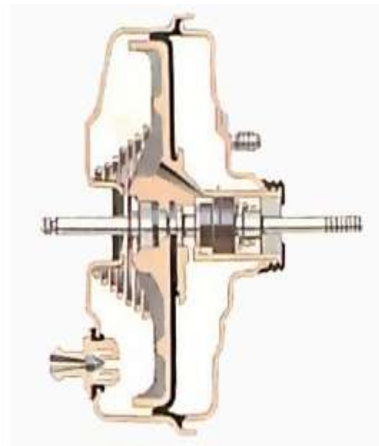
A direct-acting servo is fitted between the brake pedal and the master cylinder. The pedal can work the master cylinder directly if the servo fails or if the engine is not running.

If the pedal is then held, and pressed no further, the air valve admits no more air from outside, so the pressure on the brakes remains the same. When the pedal is released, the space behind the diaphragm is reopened to the manifold, so the pressure drops and the diaphragm falls back.

If the vacuum fails because the engine stops, for example the brakes still work because there is a normal mechanical link between the pedal and the master cylinder. But much more force must be exerted on the brake pedal to apply them.

How the brake servo works

Brake off - both sides of the diaphragm are under vacuum.

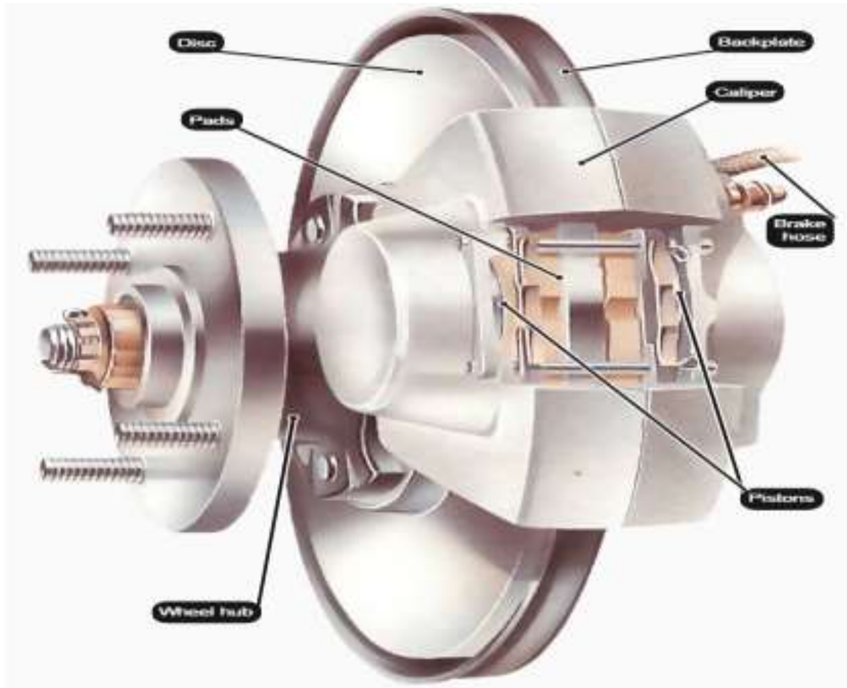


Applying the brake lets air in behind the diaphragm, forcing it against the cylinder.

Some cars have an indirect-acting servo fitted in the hydraulic lines between the master cylinder and the brakes. Such a unit can be mounted anywhere in the engine compartment instead of having to be directly in front of the pedal. It, too, relies on manifold vacuum to provide the boost. Pressing the brake pedal causes hydraulic pressure build up from the master cylinder, a valve opens and that triggers the vacuum servo.

Disc brakes

A disc brake has a disc that turns with the wheel. The disc is straddled by a caliper, in which there are small hydraulic pistons worked by pressure from the master cylinder. The pistons press on friction pads that clamp against the disc from each side to slow or stop it. The pads are shaped to cover a broad sector of the disc. There may be more than a single pair of pistons, especially in dual-circuit brakes. The pistons move only a tiny distance to apply the brakes, and the pads barely clear the disc when the brakes are released. They have no return springs.



Disc brake
The basic type of disc brake, with a single pair of pistons. There may be more than one pair, or a single piston operating both pads, like a scissor mechanism, through different types of calipers - a swinging or a sliding caliper.

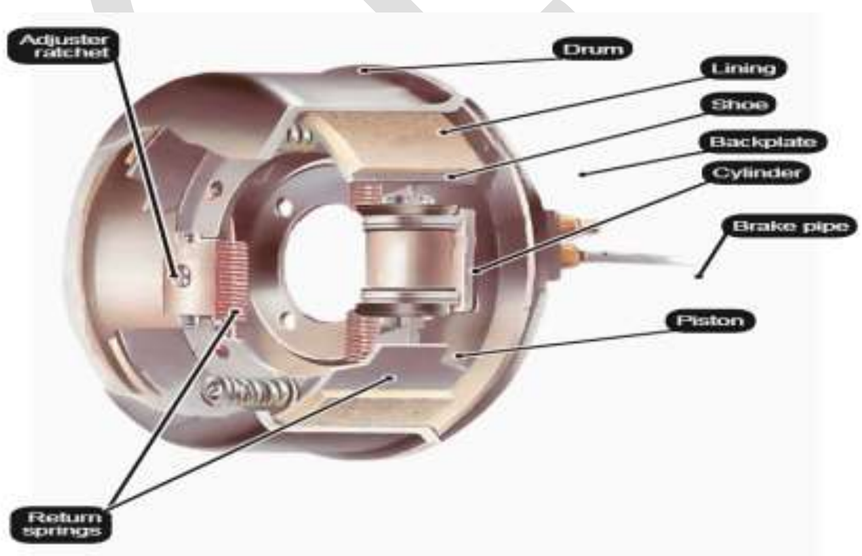
Rubber sealing rings round the pistons are designed to let the pistons slip forward gradually as the pads wear down, so that the tiny gap remains constant and the brakes do not need adjustment.

Many later cars have wear sensors leads embedded in the pads. When the pads are nearly worn out, the leads are exposed and short-circuited by the metal disc, illuminating a warning light on the instrument panel.

When the brake is applied, fluid pressure forces the pads against the disc. With the brake off, both pads barely clear the disc.

Drum brakes

A drum brake has a hollow drum that turns with the wheel. Its open back is covered by a stationary backplate on which there are two curved shoes carrying friction linings. The shoes are forced outwards by hydraulic pressure moving pistons in the brake's wheel cylinders, so pressing the linings against the inside of the drum to slow or stop it.



Drum brake
A drum brake with a leading and a trailing shoe, which has only one hydraulic cylinder; brakes with two leading shoes have a cylinder for each shoe and are fitted to the front wheels on an all-drum system.

Each brake shoe has a pivot at one end and a piston at the other. A leading shoe has the piston at the leading edge relative to the direction in which the drum turns. The rotation of the drum tends to pull the leading shoe firmly against it when it makes contact, improving the braking effect.

Some drums have twin leading shoes, each with its own hydraulic cylinder; others have one leading and one trailing shoe - with the pivot at the front. This design allows the two shoes to be forced apart from each other by a single cylinder with a piston in each end.

It is simpler but less powerful than the two-leading-shoe system, and is usually restricted to rear brakes. In either type, return springs pull the shoes back a short way when the brakes are released. Shoe travel is kept as short as possible by an adjuster. Older systems have manual adjusters that need to be turned from time to time as the friction linings wear. Later brakes have automatic adjustment by means of a ratchet.

Drum brakes may fade if they are applied repeatedly within a short time - they heat up and lose their efficiency until they cool down again. Discs, with their more open construction, are much less prone to fading.

Hand Brake

Apart from the hydraulic braking system, all cars have a mechanical handbrake acting on two wheels - usually the rear ones. The handbrake gives limited braking if the hydraulic system fails completely, but its main purpose is as a parking brake.

The handbrake lever pulls a cable or pair of cables linked to the brakes by a set of smaller levers, pulleys and guides whose details vary greatly from car to car.A ratchet on the handbrake lever keeps the brake on once it is applied. A push button disengages the ratchet and frees the lever. On drum brakes, the handbrake system presses the brake linings against the drums. Disc brakes sometimes have a comparable handbrake arrangement, but because it is difficult to place the linkage on a compact caliper, there may be a completely separate set of handbrake pads for each disc

The handbrake mechanism
The handbrake acts on the shoes by means of a mechanical system, separate from the hydraulic cylinder, consisting of a lever and arm in the brake drum; they are operated by a cable from the handbrake lever inside the car.

CAR SUSPENSION SYSTEM

One thing every body wants from a car is comfort. In any automobile, the comfort it can delivery is greatly tied to its suspension system. Without a suspension system no body will opt for a ride in any car, no matter how luxurious it may appear. How is that so? In this article we shall look at the function of the suspension of any car and the basic component of the suspension system.

History of suspension systems

1903 – Mors from Germany fixed a car using shock absorbers.

1920 – Leyland used torsion bars in their suspension system.

1922 – Unitary constructions and independent front suspension were initiated on the Lancia Lambda.

1932 – By this year ,the independent front suspension became common in standard cars.

1948 – Triumph Mayflower presented the combined coil spring/damper unit.

1950 – Ford implemented the McPherson strut independent front suspension on MK 1 consul.

1959 – Usage of independent rubber suspension started.

1962 – Introduction of the hydrostatic suspension.

FUNCTION OF SUSPENSION

Apart from your car's tyres and seats, the suspension is the prime mechanism that separates your bum (seated back side) from the road. It also prevents your car from shaking itself to pieces. No matter how smooth you *think* the road is, it's a bad, bad place to propel over a ton of metal at high speed. So we rely upon suspension. People who travel on underground trains *wish* that those vehicles relied on suspension too, but they don't and that's why the ride is so harsh. Actually it's harsh because underground trains have no lateral suspension to speak of. So as the rails deviate side-to-side slightly, so does the entire train, and it's passengers. In a car, the rubber in your tyre helps with this little problem, while all the other suspension parts do the rest.

COMPONENT OF THE SUSPENSION

The suspension of a car is actually part of the chassis, which comprises all of the important systems located beneath the car's body.

These systems include:

- The **frame** - structural, load-carrying component that supports the car's engine and body, which are in turn supported by the suspension

- The **suspension system** - setup that supports weight, absorbs and dampens shock and helps maintain tire contact
- The **steering system** - mechanism that enables the driver to guide and direct the vehicle
- The **tires and wheels** - components that make vehicle motion possible by way of grip and/or friction with the road

So the suspension is just one of the major systems in any vehicle.

With this big-picture overview in mind, it's time to look at the three fundamental components of any suspension: springs, dampers and anti-sway bars.

Springs

Today's springing systems are based on one of four basic designs:

- **Coil springs** - This is the most common type of spring and is, in essence, a heavy-duty torsion bar coiled around an axis. Coil springs compress and expand to absorb the motion of the wheels.

Coil spring

Leaf springs

- **Leaf springs** - This type of spring consists of several layers of metal (called "leaves") bound together to act as a single unit. Leaf springs were first used on horse-drawn carriages and were found on most American automobiles until 1985. They are still used today on most trucks and heavy-duty vehicles.
- **Torsion bars** - Torsion bars use the twisting properties of a steel bar to provide coil-spring-like performance. This is how they work: One end of a bar is anchored to the vehicle frame. The other end is attached to a wishbone, which acts like a lever that moves perpendicular to the torsion bar. When the wheel hits a bump, vertical motion is transferred to the wishbone and then, through the levering action, to the torsion bar. The torsion bar then twists along its axis to provide the spring force. European carmakers used this system extensively, as did Packard and Chrysler in the United States, through the 1950s and 1960s.

Torsion bar

- **Air springs** - Air springs, which consist of a cylindrical chamber of air positioned between the wheel and the car's body, use the compressive qualities of air to absorb wheel vibrations. The concept is actually more than a century old and could be found on horse-drawn buggies. Air springs from this era were made from air-filled, leather diaphragms, much like a bellows; they were replaced with molded-rubber air springs in the 1930s.

Air springs

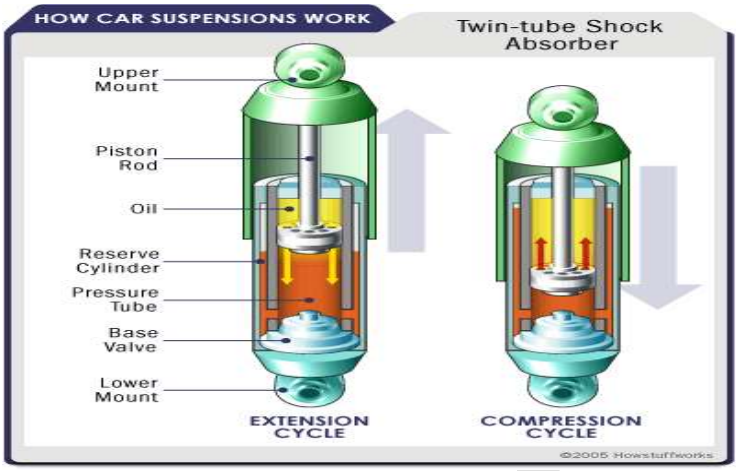
Based on where springs are located on a car -- i.e., between the wheels and the frame -- engineers often find it convenient to talk about the **sprung mass** and the **unsprung mass**.

Springs:

Sprung and Unsprung Mass: The **sprung mass** is the mass of the vehicle supported on the springs, while the **unsprung mass** is loosely defined as the mass between the road and the suspension springs. The stiffness of the springs affects how the sprung mass responds while the car is being driven. Loosely sprung cars, such as luxury cars (think Lincoln Town Car), can swallow bumps and provide a super-smooth ride; however, such a car is prone to dive and squat during braking and acceleration and tends to experience body sway or roll during cornering. Tightly sprung cars, such as sports cars (think Mazda Miata), are less forgiving on bumpy roads, but they minimize body motion well, which means they can be driven aggressively, even around corners.

So, while springs by themselves seem like simple devices, designing and implementing them on a car to balance passenger comfort with handling is a complex task. And to make matters more complex, springs alone can't provide a perfectly smooth ride. Why? Because springs are great at absorbing energy, but not so good at **dissipating** it. Other structures, known as **dampers**, are required to do this.

DAMPERS: SHOCK ABSORBERS



Unless a dampening structure is present, a car spring will extend and release the energy it absorbs from a bump at an uncontrolled rate. The spring will continue to bounce at its natural frequency until all of the energy originally put into it is used up. A suspension built on springs alone would make for an extremely bouncy ride and, depending on the terrain, an uncontrollable car.

Enter the shock absorber, or snubber, a device that controls unwanted spring motion through a process known as dampening. Shock absorbers slow down and reduce the magnitude of vibratory motions by turning the kinetic energy of suspension movement into heat energy that can be dissipated through hydraulic fluid. To understand how this works, it's best to look inside a shock absorber to see its structure and function.

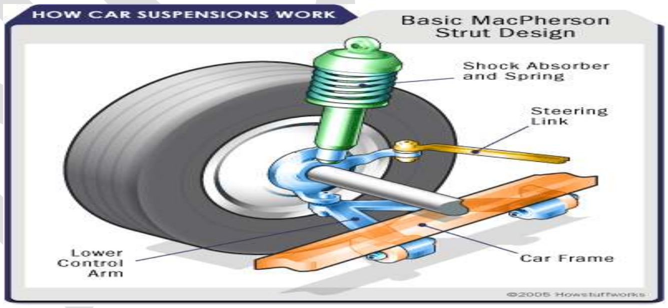
A shock absorber is basically an oil pump placed between the frame of the car and the wheels. The upper mount of the shock connects to the frame (i.e., the sprung weight), while the lower mount connects to the axle, near the wheel (i.e., the un sprung weight). In a twin-tube design, one of the most common types of shock absorbers, the upper mount is connected to a piston rod, which in turn is connected to a piston, which in turn sits in a tube filled with hydraulic fluid. The inner tube is known as the pressure tube, and the outer tube is known as the reserve tube. The reserve tube stores excess hydraulic fluid.

When the car wheel encounters a bump in the road and causes the spring to coil and uncoil, the energy of the spring is transferred to the shock absorber through the upper mount, down through the piston rod and into the piston. Orifices perforate the piston and allow fluid to leak through as the piston moves up and down in the pressure tube. Because the orifices are relatively tiny, only a small amount of fluid, under great pressure, passes through. This slows down the piston, which in turn slows down the spring.

Shock absorbers work in two cycles -- the compression cycle and the extension cycle. The compression cycle occurs as the piston moves downward, compressing the hydraulic fluid in the chamber below the piston. The extension cycle occurs as the piston moves toward the top of the pressure tube, compressing the fluid in the chamber above the piston. A typical car or light truck will have more resistance during its extension cycle than its compression cycle. With that in mind, the compression cycle controls the motion of the vehicle's unsprung weight, while extension controls the heavier, sprung weight.

All modern shock absorbers are velocity-sensitive -- the faster the suspension moves, the more resistance the shock absorber provides. This enables shocks to adjust to road conditions and to control all of the unwanted motions that can occur in a moving vehicle, including bounce, sway, brake dive and acceleration squat.

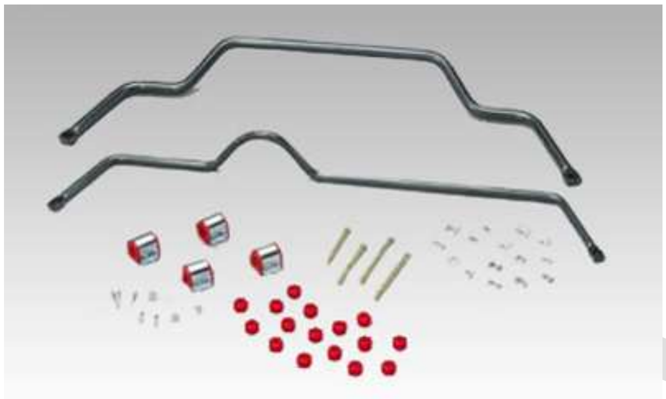
Dampers: Struts and Anti-sway Bars



Common strut design

Another common dampening structure is the strut -- basically a shock absorber mounted inside a coil spring. Struts perform two jobs: They provide a dampeningfunction like shock absorbers, and they provide structural support for the vehicle suspension. That means struts deliver a bit more than shock absorbers, which don't support vehicle weight -- they only control the speed at which weight is transferred in a car, not the weight itself.

Because shocks and struts have so much to do with the handling of a car, they can be considered critical safety features. Worn shocks and struts can allow excessive vehicle-weight transfer from side to side and front to back. This reduces the tire's ability to grip the road, as well as handling and braking performance.



Anti-sway bars

Anti-swayBars

Anti-sway bars (also known as anti-roll bars) are used along with shock absorbers or struts to give a moving automobile additional stability. An anti-sway bar is a metal rod that spans the entire axle and effectively joins each side of the suspension together.

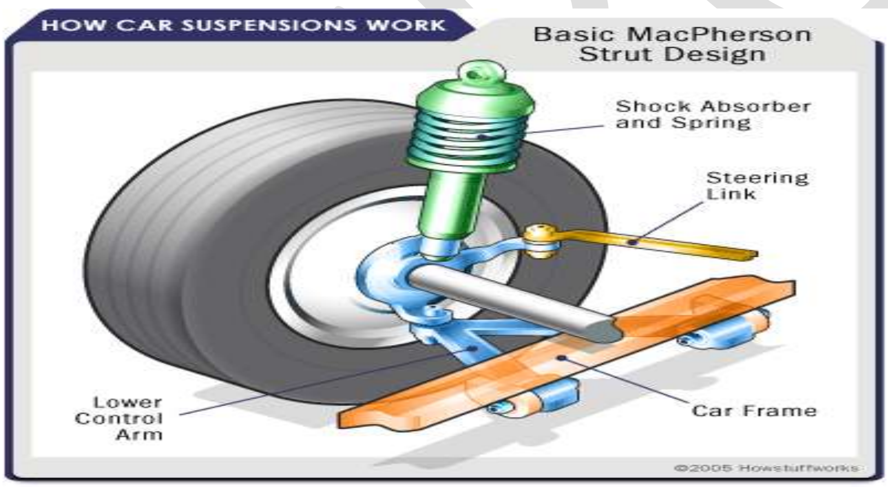
When the suspension at one wheel moves up and down, the anti-sway bar transfers movement to the other wheel. This creates a more level ride and reduces vehicle sway. In particular, it combats the roll of a car on its suspension as it corners. For this reason, almost all cars today are fitted with anti-sway bars as standard equipment, although if they're not, kits make it easy to install the bars at any time.

The suspension system used in vehicles are of various types:-

1. Independent type- Easy way to put them will be movement of one tyre doesn't affect the other one. These are also of many types like McPherson strut- used in mid level cars, double wishbone suspensions - now mostly used in 4-wheelers, leaf springs- used in heavy vehicles.

2. Dependent type- If one tyre moves, other shows movement corresponding to that. These are not in much use nowadays but being cheaper compared to independent, they can be used.

So far, our discussions have focused on how springs and dampers function on any given wheel. But the four wheels of a car work together in two independent systems -- the two wheels connected by the front axle and the two wheels connected by the rear axle. That means that a car can and usually does have a different type of suspension on the front and back. Much is determined by whether a rigid axle binds the wheels or if the wheels are permitted to move independently. The former arrangement is known as a **dependent system**, while the latter arrangement is known as an **independent system**. In the following sections, we'll look at some of the common types of front and back suspensions typically used on mainstream cars.



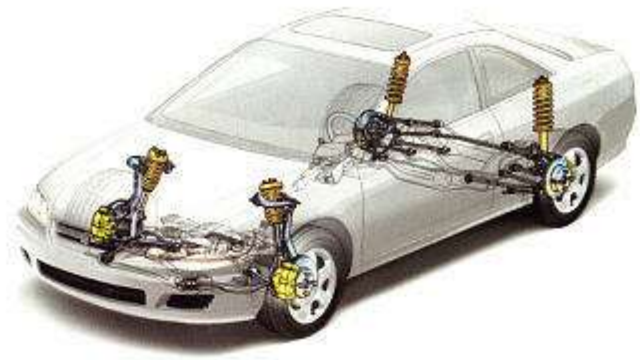
Dependent Front Suspensions

Dependent front suspensions have a rigid front axle that connects the front wheels. Basically, this looks like a solid bar under the front of the car, kept in place by leaf springs and shock absorbers. Common on trucks, dependent front suspensions haven't been used in mainstream cars for years.

Independent Front Suspensions

In this setup, the front wheels are allowed to move independently. The **MacPherson strut**, developed by Earle S. MacPherson of General Motors in 1947, is the most widely used front suspension system, especially in cars of European origin.

The MacPherson strut combines a shock absorber and a coil spring into a single unit. This provides a more compact and lighter suspension system that can be used for front-wheel drive vehicles.



Double-wishbone suspension on Honda Accord 2005 Coupe

The **double-wishbone suspension**, also known as an A-arm suspension, is another common type of front independent suspension.

While there are several different possible configurations, this design typically uses two wishbone-shaped arms to locate the wheel. Each wishbone, which has two mounting positions to the frame and one at the wheel, bears a shock absorber and a coil spring to absorb vibrations. Double-wishbone suspensions allow for more control over the camber angle of the wheel, which describes the degree to which the wheels tilt in and out. They also help minimize roll or sway and provide for a more consistent steering feel. Because of these characteristics, the double-wishbone suspension is common on the front wheels of larger cars.

Suspension Types: Rear

Historical Suspensions

Sixteenth-century wagons and carriages tried to solve the problem of "feeling every bump in the road" by slinging the carriage body from leather straps attached to four posts of a chassis that looked like an upturned table. Because the carriage body was suspended from the chassis, the system came to be known as a "suspension" -- a term still used today to describe the entire class of solutions. The slung-body suspension was not a true springing system, but it did enable the body and the wheels of the carriage to move independently.

Semi-elliptical spring designs, also known as cart springs, quickly replaced the leather-strap suspension. Popular on wagons, buggies and carriages, the semi-elliptical springs were often used on both the front and rear axles. They did, however, tend to allow forward and backward sway and had a high center of gravity.

By the time powered vehicles hit the road, other, more efficient springing systems were being developed to smooth out rides for passengers.

Dependent Rear Suspensions

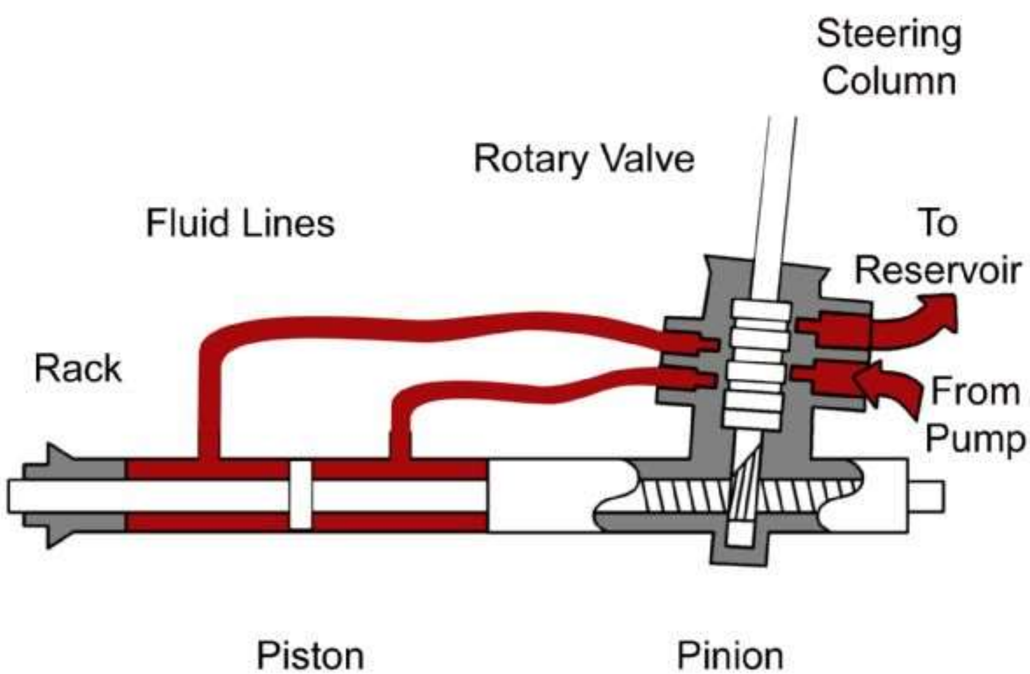
If a solid axle connects the rear wheels of a car, then the suspension is usually quite simple -- based either on a leaf spring or a coil spring. In the former design, the leaf springs clamp directly to the drive axle. The ends of the leaf springs attach directly to the frame, and the shock absorber is attached at the clamp that holds the spring to the axle. For many years, American car manufacturers preferred this design because of its simplicity.

The same basic design can be achieved with coil springs replacing the leaves. In this case, the spring and shock absorber can be mounted as a single unit or as separate components. When they're separate, the springs can be much smaller, which reduces the amount of space the suspension takes up.

Independent Rear Suspensions

If both the front and back suspensions are independent, then all of the wheels are mounted and sprung individually, resulting in what car advertisements tout as "four-wheel independent suspension." Any suspension that can be used on the front of the car can be used on the rear, and versions of the front independent systems described in the previous section can be found on the rear axles. Of course, in the rear of the car, the steering rack -- the assembly that includes the pinion gear wheel and enables the wheels to turn from side to side -- is absent. This means that rear independent suspensions can be simplified versions of front ones, although the basic principles remain the same.

STEERING SYSTEM



One of the main reasons for owning a g-Machine over a stock or Pro Street car is to be able to go fast around corners and curves in addition to straight-line performance. While much attention gets paid to fancy coilover shocks and three-link suspensions, the steering system is often overlooked. With the growth of this build segment, the choices for our cars' steering systems have never been so vast… or so confusing. What ratio is best? Does it affect bumpsteer? Power or manual? Rack or box? The choices are endless, and they can lead to a mental version of vaporlock where you just don't know which way to go.

In this story we will look at some of the more popular systems out there, along with their pros and cons.

Follow along and learn how to keep your g-Machine project pointed in the right direction.

Power or Manual Steering

No matter what system you choose, you'll need to decide whether you want it to be a manual or power-assisted system. Manual steering has long been popular with the drag racing and Pro Street crowd for one simple reason: weight. Getting 20 or 30 pounds off the front of the car is a big deal for a straight-line car and, besides, getting those front skinnies to turn doesn't take a ton of effort. By ditching the power steering you also gain a few horsepower since the engine no longer has to turn the pump. Again, the small gain is not worth the extra effort every time you have to turn the wheels. With a car that handles, those skinny front tires have now been replaced with wide swaths of rubber that have a significant footprint in contact with the asphalt. All this resistance, especially at low speeds, makes the weight savings of ditching the power steering not worth the hassles of living with the car. Could you do it? Sure. Should you do it? Not in our opinion. Besides, driving a car on a road course is tiring enough without the added effort needed to manhandle your steering wheel back and forth. Drivers of cars defined as Pro Touring or g-Machine worry about weight too, but not at the detriment of overall driving performance.

Power-assisted steering systems have a high- and a low-pressure circuit. A power steering pump is turned by a drive belt and pressurizes the fluid going to the gearbox to somewhere between 1,200 and 1,600 psi. The low-pressure line sends fluid back to the power steering reservoir where it is pumped out and sent at high pressure back to the gearbox. It is very important that you keep this in mind when choosing the lines for your system. The low-pressure side is pretty forgiving, but you want to make sure to use the right parts for the high-pressure line. Another good idea is to incorporate some sort of cooler for your power steering fluid. During track use, fluid temps can get well over 200 degrees, and this will affect the performance of your system. In fact, if you are using an older style pump where the reservoir tank is soldered to the pump body, this type of high heat has been known to cause the parts to separate, throwing fluid all over your hot engine bay and onto the track. Not good at all. Remote reservoirs are one way around this problem, or you could use a modern unit with an integrated non-soldered or plastic tank.

Here is an example of an early GM power steering pump. While OK for cruising around, it is not going to hold up to track use. Some other versions of this pump have upper sections of the tank that are soldered to the lower section, and at high temps they can separate; not a good thing.

Flaming River and many other companies offer a variable-rate pump that will hold up to even the toughest use. Fluid is pumped faster at low rpm to make maneuvering easy, and it's pumped slower at high rpm to give a better feel. This type of pump can use either an integrated or remote reservoir. In this case, this one is set up for the remote version.

This modern GM Type-II pump from Eddie Motorsports has an integral fluid reservoir that will not be affected by heat. It also has better internals than the old factory pumps. Since the tank is attached to the pump, you have less fluid lines to worry about.

Many companies offer reworked recirculating gearboxes. Several of these companies, like Detroit Speed Inc., will help you pick the box that will best fit your needs. Companies like Flaming River and CPP offer a wide array of gearbox choices to fit whatever project you have in the works. This one from Detroit Speed can be ordered with a ceramic coating to help mitigate heat coming off the headers.

Recirculating-Ball Steering Box

From about 1950 until sometime in the ’80s, recirculating-ball was the standard in steering technology. Since we have already discussed the merits of power-assisted steering, we will assume that is what you are going to run. Steering gearboxes are set up with different ratios that affect how many times you have to turn the steering wheel to get the front wheels to turn lock-to-lock. For example, in a wide-ratio box you may have to turn the steering wheel 4.5 revolutions to get the front wheels to turn lock-to-lock. For a close-ratio steering box with a ratio of 12.7:1 it will only take 3 revolutions of the steering wheel to go lock-to-lock. So, what difference does 1.5

revolutions make? The answer is a lot. You may not notice it that much driving to the grocery store, but on a road or autocross track where you're constantly throwing your car back and forth through the turns, the wide-ratio box makes you work much harder than the close-ratio box. More work will tire you out sooner and affect your performance. The close-ratio box will also make your car feel more responsive since it will require less driver input to cause your car to maneuver.

In addition to the ratio steering, gearboxes can also be adjusted for the amount of effort, or resistance, you feel when turning the steering wheel. In a car set up with low or no effort, you will have very little feedback through your steering wheel and the car will feel like it is floating around on the road. You need to find a happy medium between low effort when you are moving slow or sitting still and a higher effort setup that would be good at speed. Keep in mind that the diameter of the steering wheel also affects this ratio, or at least how it's perceived. A smaller wheel will make the ratio seem even quicker, so a small wheel coupled with a fast 12.7:1 steering box might not be the best choice.

There are many companies that offer rebuilt Saginaw 600 gearboxes for your GM application. They have generally been reworked to the close-ratio 12.7:1 and the efforts have been tweaked to a good performance compromise. If you are on a budget you can sometimes find factory close-ratio boxes used in performance models at salvage yards. For example, if you can find a used gearbox from a later-model (late '70s) Z28 it would bolt directly to your first-gen Camaro and provide a significant improvement for very little cash. Companies like Detroit Speed Inc., CPP, and Flaming River sell brand-new gearboxes in a wide array of choices to fit your Chevy. One company often looked to by racers for their box rebuilds is AGR. AGR completely goes through the box and beefs up the internal parts and seals. They even go so far as to add an additional bearing for extra support. Many of the larger rebuilders also dyno check each gearbox for pressure and balance, as well as being tested for leaks. With all the choices out there it is easy to see why this steering system is so popular.

How does a recirculating gearbox work? The recirculating-ball steering box contains a worm gear. You can imagine the gear in two sections. The first section is a block of metal with a threaded hole in it. This block has gear teeth cut into the outside of it that engage a gear that moves the pitman arm back and forth. The steering wheel connects to a threaded rod, similar to a bolt, which sticks into a hole in the block, and when the steering wheel spins, it turns this bolt. Instead of the rod twisting farther into the block the way a regular bolt would, this rod is held fixed so that when it spins it moves the block, which moves the gear that turns the wheels. Rather than have the bolt directly engage the threads in the block, all of the threads are filled with ball bearings that recirculate through the gear as it turns and acts as rolling threads. The balls actually serve two purposes. First, they reduce friction and wear in the gear, and second, they reduce play in the gear. If it wasn't for this ball bearing design, slop would be felt whenever you changed the direction of the steering wheel. This is because without the bearings in the steering gear, the teeth would come out of contact with each other for a moment, making the steering feel loose and floaty.

There are several advantages to recirculating-ball systems. First, by varying pitman arm length you can easily offer more or less steering travel than a rack-and-pinion system. Second, it is typically less expensive than converting to a rack-and-pinion system, perfect for someone on a budget. This time-tested steering system is very rugged and it is still preferred in racing organizations like NASCAR. Third, this is a very easy-to-install upgrade to your car and is generally a bolt-in deal that will keep your car with a factory look.

There are also several disadvantages to traditional gear boxes. First, since the box consists of many moving parts, there is quite a bit of friction and many wear points. The design also makes it less efficient than a rack-and-pinion system and it requires more effort. You also need to consider that a gearbox steering system has quite a few more linkage wear points including the inner and outer tie rods, the pitman arm, and the idler arm. Lastly would be weight, even when using the lighter 600 gearbox, the recirculating gearbox-based steering system is quite a bit heavier than the more compact rack-and-pinion system.

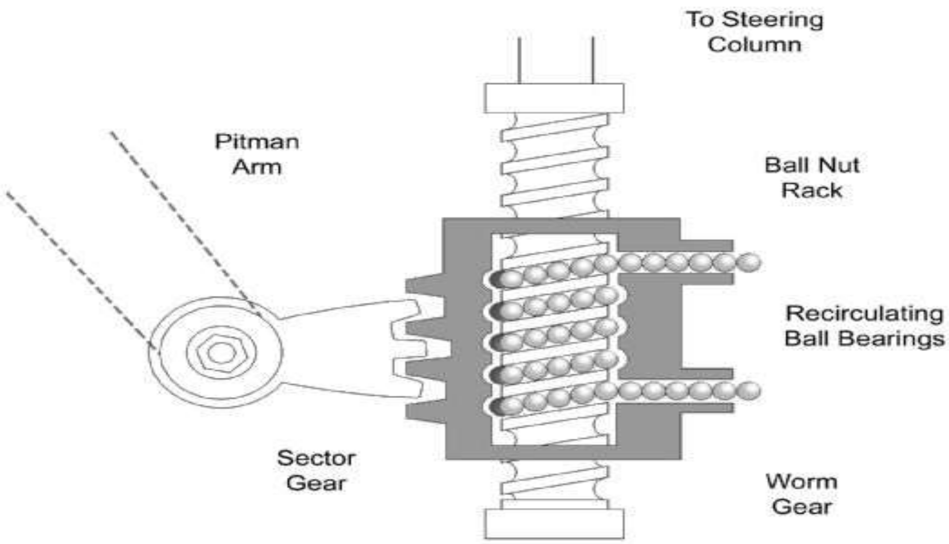
Rack-and-Pinion Steering

One of the biggest trends in the Pro Touring and g-Machine segment has been converting cars over to modern rack-and-pinion systems. This is done by either retrofitting an aftermarket rack-and-pinion to an OE subframe or by replacing the entire subframe with an aftermarket one designed to hold a rack-and-pinion unit.

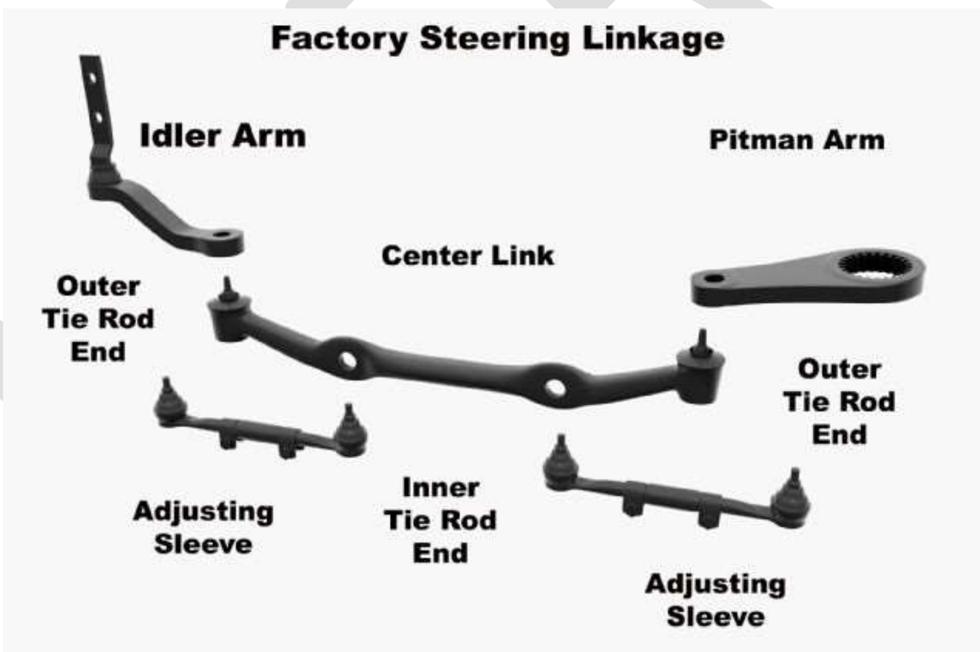
So how does a rack-and-pinion system work? A rack-and-pinion gearset is enclosed in a metal tube with each end of the rack protruding from the tube. The gearset accomplishes two things. First, it converts the rotational motion of the steering wheel into a linear motion needed to turn the front wheels, and secondly, the gearset provides gear reduction, which lessens the effort needed to turn the wheels. A rod called a tie rod connects to each end of the rack. The pinion gear is attached to the steering shaft. When you turn the steering wheel, the pinion gear spins, moving the rack. The tie rod at each end of the rack connects to the steering arm on the spindle. On a power system, part of the rack contains a cylinder with a piston in the middle and this piston is connected to the rack. There are two fluid ports on the rack; one on either side of the piston. Supplying higher-pressure fluid to one side of the piston forces the piston to move, which in turn moves the rack providing the power assist.

Advantages of the rack-and-pinion systems are many. First is its simplicity. With only two moving parts there is not only less friction, but the positive engagement of the system gives a very tight and responsive feel to the steering. Secondly, the complete system has only four wear points in the linkage: the inner ball joints and outer tie-rod ends. This simplicity and lower number of parts is one reason why most new cars use rack-and-pinion. Third, a rack-and-pinion system is quite a bit lighter than a traditional box system. Less weight off the front of the car is always a good thing to strive for. Fourth, because of its design you often gain added clearance for headers and the rack-and-pinion is sometimes easier to package into the car.

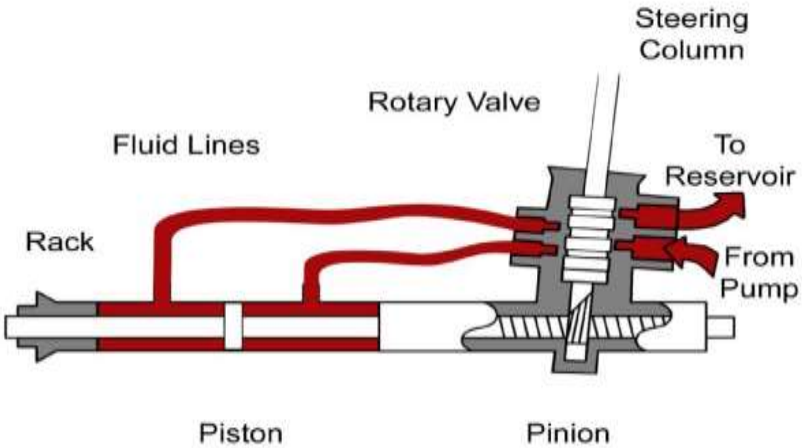
Every option in life has drawbacks and rack-and-pinion is no exception. Due to the limitations on the number of teeth that can be cut into the rack, there is typically less travel available compared to a recirculating-ball system. Another thing to consider is that a rack-and-pinion system will require quite a bit of work to retrofit into an older car. In some cases you will have to notch the frame and relocate the sway bar. You will also have to calculate the geometry so that you don't end up with poor handling due to bumpsteer and a host of other issues. If you are buying an aftermarket front subframe you may have no choice but to go with a rack-and-pinion setup, especially if it was designed to accommodate it. Some companies, like Unisteer, offer rack-and-pinion systems that have been re-engineered for specific retrofit applications onto stock subframes. While more expensive than the do-it-yourself option, the Unisteer racks are much easier to install and are more geometrically correct since they were designed to help limit issues like bumpsteer. Lastly, a rack-and-pinion system, especially in kit form, will make your wallet quite a bit lighter than tossing in a rebuilt close-ratio box.



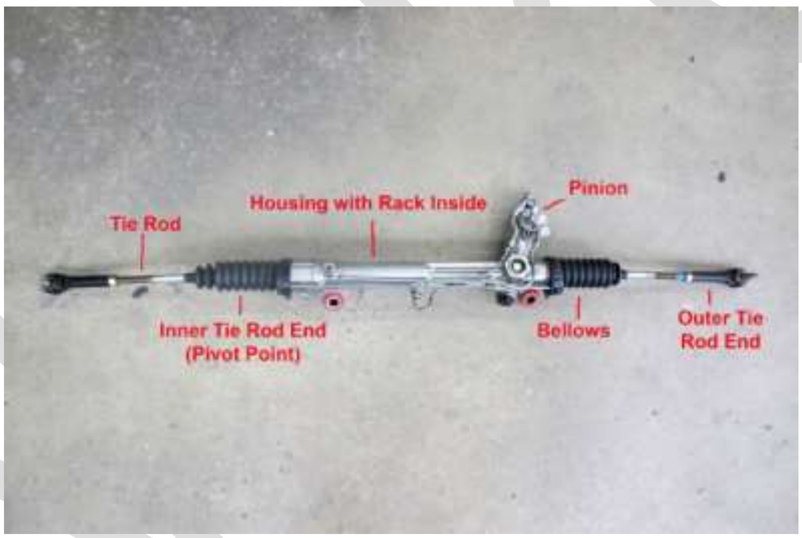
In this simplified drawing of a recirculating-ball steering system you can see how the rotational energy of the steering column is turned into the linear movement of the pitman arm. – Drawing by Kris Horton.



Here are the common steering parts used with a recirculating-ball steering gearbox-based system. The number of parts is one reason this system is heavier than a rack-and-pinion steering system. However, it is also stronger. You can also see that there are more wear points compared to a rack-and-pinion steering system. Note that this diagram does not even include the gearbox.



Here you can see how a power rack-and-pinion system works internally. Turning the steering wheel activates a rotary valve and sends high-pressure fluid to the appropriate side of the piston to assist in turning. – Drawing by Kris Horton.



Behold the simplicity of the rack-and-pinion system. While not as sturdy as a traditional steering system, it is light and responsive. In this configuration there are four wear points. This picture is of a manual rack, whereas a power-assisted rack would have fittings for the fluid lines. When retrofitting this into an older car you must be careful to end up with proper steering geometry.

The Bottom Line

According to Tristan Statler at Unisteer, "In general, when considering the option of a steering box versus a rack-and-pinion, one must always remember that either system will only perform as well as it is designed and built for its particular application. A poorly designed steering box setup may not function as well as a rack-and-pinion setup, and vice versa." You need to think about how you plan on using your car. If your car will never see the track, then you might not need to run a power steering cooler or have to worry about using the older soldered pumps. If you plan on serious track time, then a company like AGR should be able to set you up with some higher-end “race grade” steering parts, which is their specialty.

Whichever way you go, it is important that you ask the right questions of the various vendors and explain to them how you will be using your car. Through proper parts selection you will end up with a steering system that will make your ride much nicer to drive.

ADAPTIVE CRUISE CONTROL

Two companies are developing a more advanced cruise control that can automatically adjust a car's speed to maintain a safe following distance. This new technology, called **adaptive cruise control**, uses forward-looking radar, installed behind the grill of a vehicle, to detect the speed and distance of the vehicle ahead of it.

Adaptive cruise control is similar to conventional cruise control in that it maintains the vehicle's pre-set speed. However, unlike conventional cruise control, this new system can automatically adjust speed in order to maintain a proper distance between vehicles in the same lane. This is achieved through a **radar headway sensor**, **digital signal processor** and **longitudinal controller**. If the lead vehicle slows down, or if another object is detected, the system sends a signal to the engine or braking system to decelerate. Then, when the road is clear, the system will re-accelerate the vehicle back to the set speed.

What is adaptive cruise control, and how does it work?

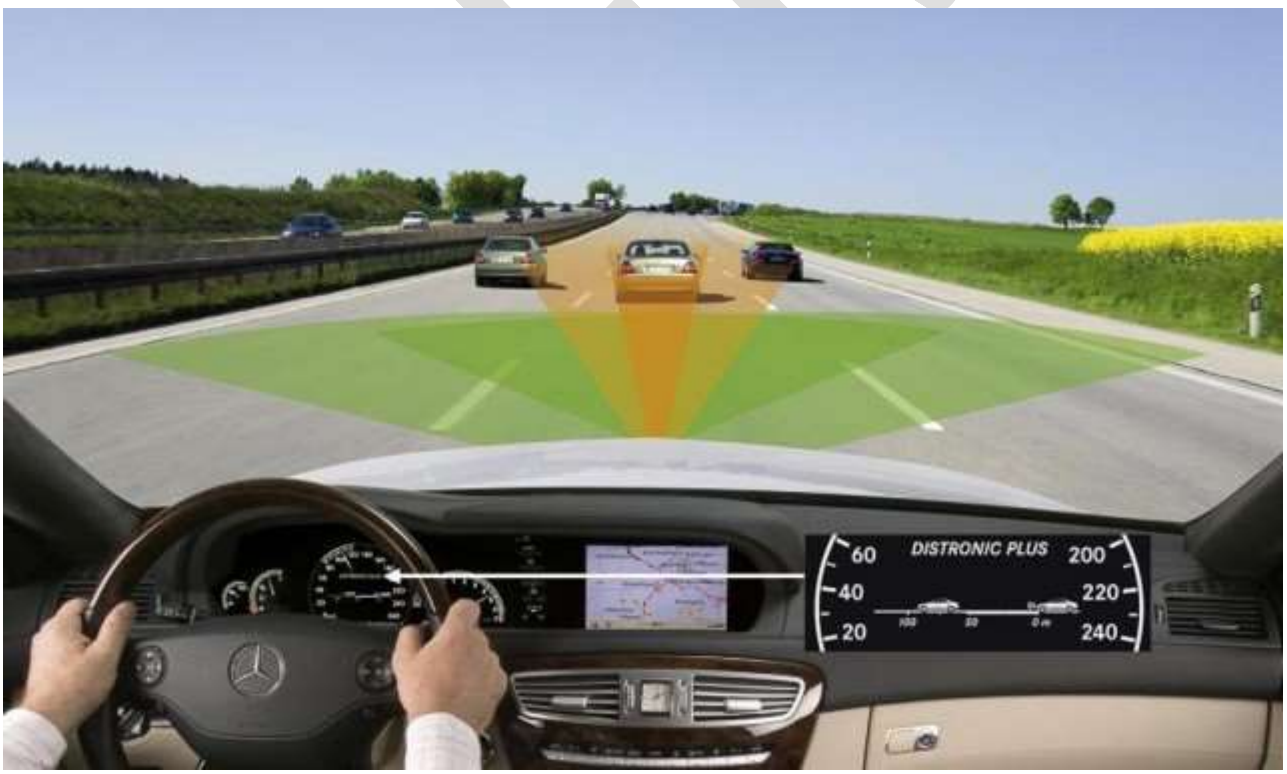
Here at Extreme Tech we see automobiles as much more than just four wheels, an engine, and a few seats. We view automobiles as being the ultimate mobile technology platform and something as worthy of our attention as the latest CPU or smartphone. With that in mind, we’ll be releasing a series of introductory auto tech articles, providing readers with in-depth explanations of today's important technologies. First up for the series: adaptive cruise control.

Adaptive cruise control basics

Adaptive cruise control (ACC) is an intelligent form of cruise control that slows down and speeds up automatically to keep pace with the car in front of you. The driver sets the maximum speed — just as with cruise control — then a radar sensor watches for traffic ahead, locks on to the car in a lane, and instructs the car to stay 2, 3, or 4 seconds behind the person car ahead of it (the driver sets the follow distance, within reason). ACC is now almost always paired with a pre-crash system that alerts you and often begins braking.

ACC is ideal for stop-and-go traffic and rush hour commuting that swings from 60 mph to a standstill. Adaptive cruise control as of 2013 ranges from $2,500 at the high end to as little as $500. Less costly "partial ACC" only works at speeds of 20 or 25 mph and up, but it's markedly cheaper.

Expect to pay $2,000-$2,500 for full-range adaptive cruse control, but the price is coming down. The first ACC systems were about $2,800 five years ago.



Adaptive cruise control is also called active cruise control, autonomous cruise control, intelligent cruise control, or radar cruise control. This is the case because distance is measured by a small radar unit behind the front grille or under the bumper. Some units employ a laser, while Subaru uses an optical system based on stereoscopic cameras. Regardless of the technology, ACC works day and night, but its abilities are hampered by heavy rain, fog, or snow.

ACC is a crucial part of the self-driving cars of the near future. On an autonomous driving car, ACC needs to track the car in front but also cars in adjacent lens in case a lane change becomes necessary.

Adaptive cruise control is typically paired with forward collision warning that functions even if you don't have ACC engaged. When ACC is engaged, the car will typically slow under ACC braking at up to half its maximum braking potential. (Beyond that, driver and passenger discomfort with automated braking sets in.) Red lights flash at the driver (as with the Ford Taurus pictured above), the words "Brake!" or "Brake Now!" show on the instrument panel or head-up display, and a loud chime sounds. When ACC isn't engaged, it's still tracking traffic in front and intervenes with the warnings if it senses a potential accident.

Using ACC

To use adaptive cruise control, you start the same as you would with standard cruise control. The driver turns ACC on, accelerates to the desired speed, then presses the "Set" button. It's then possible to tweak the "+" and "-" buttons to raise or lower the speed, typically by in 1 or 5 mph increments. Lastly, the driver can set the desired gap behind the next car, most commonly by pressing a button to cycle among short, medium, and long following distances. Some automakers show icons with 1, 2 or 3 distance bars between two vehicle icons. Others, such as Merecedes-Benz, show the following distance in feet, though it's really in seconds of following gap translated to feet — for example, 200 feet of following distance at 60 mph (88 feet per second) is about 3 seconds.

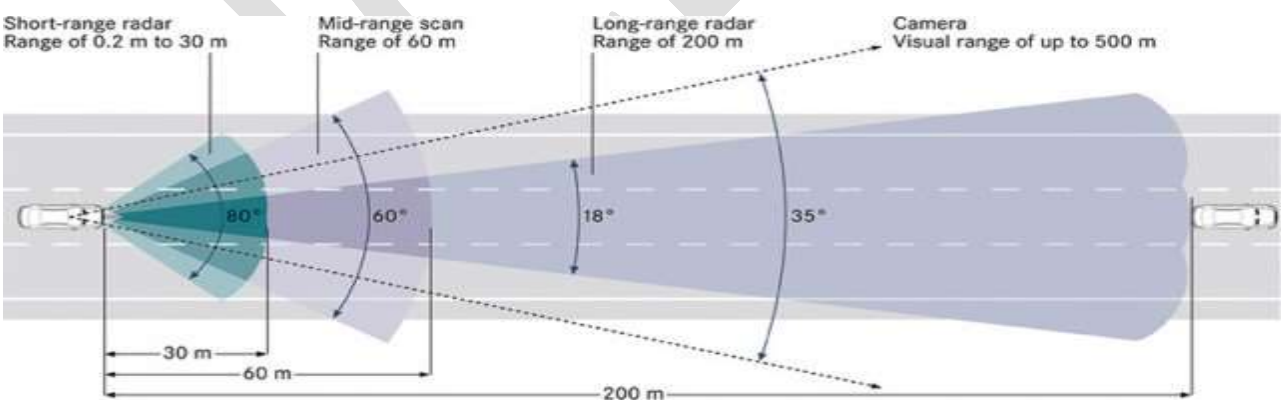
An indicator in the instrument panel or head-up display shows a car icon and often what looks like converging-at-infinity lines, indicating the roadway. When radar detects a car ahead, a second car icon appears or the lone car icon changes color.

When you're just starting out in a newly acquired car with ACC, start with the longest following distance. If you set the closest following distance, you'll get nervous if the following distance seems to get dangerously close and you're not sure if ACC is actually working. Most likely it is working and the driver may have lightly brushed the brake pedal, didn't realize it, and now ACC is available but not engaged.

THE TECHNOLOGY BEHIND ACC

Adaptive cruise control typically uses radar in a frequency band that doesn't compete with police radar and doesn't trigger radar detectors. For full-range ACC, some automakers use two radars — one for close range out to about 100 feet and a second that sees out to about 600 feet, or about 6-7 seconds at highway speeds. Partial ACC is usually a single unit, while some full-range ACC implementations are now able to use a single radar as well.

Early ACC units were a competing mix of laser on some cars and radar on the others. Radar won out because it works better in bad weather and costs came down to be competitive with laser. Even so, some ACC is optical. Subaru uses two cameras flanking the rear view mirror for its EyeSight system. It also provides unassisted automatic braking at low speeds if a pedestrian or stopped car gets in your path.



The effectiveness of even radar-based ACC is compromised in bad weather. In heavy rain or snow, it will shut off (you get a warning) or if the sensor in the grille or under the bumper is caked with snow or dirt.

So far, adaptive cruise control doesn't adjust to changing speed limits. Technology exists to do that: speed limit info is in navigation system map data, and lane departure warning cameras have the ability to read speed limit signs. In theory, you could tell ACC that at highway speeds you want your top speed to be the posted limit plus 5 mph. Then when you hit a construction zone posted for 45 mph, you'll stay reasonably close to the limit.

Is adaptive cruise control worth it?

Adaptive cruise control makes sense as the price comes down and as you drive more highway miles, especially long trips where your reflexes are dulled from driving five to 10 hours. For that, even partial ACC is helpful, and at $500-$1,000 on a $30,000 car (the typical selling price now), it could be worthwhile. If your commute involves freeways that are clogged every day, then you want full-range ACC for convenience.

The same holds if your long vacation or weekend trips involve leaving and returning big urban areas. Anyone who's driven Boston to Cape Cod on Friday night knows the pain. Returning to metro New York, Los Angeles, or Chicago, traffic starts slowing down 100 miles away on a Sunday night. Here, adaptive cruise control is a quality of life feature — just hit the "Set Speed" button and don't worry about cars stopping suddenly or creeping along.

While ACC is a great feature, I advise buyers to get lane departure warning and blind spot detection before you spend money on adaptive cruise control. These two features cost less and do more for you on most trips.

And keep in mind, vecause it's so complex, you have to order a car with ACC. You can't go to the parts department and order it added later on.

MODULE II

AUTOMOTIVE SENSORS

Today's modern automobiles have a variety of sensors. You may hear of several of them such as: Throttle position sensor, TPMS sensor, These sensors built into their engine to ensure that the owner can identify and prevent possible issues before they result in breakdowns can result in expensive repairs. These automobile engine sensors also ensure that the vehicle is operating at its most efficient. Many owners are not even aware of the amount of sensors built into their automobiles engine and what value they add.

SENSORS USED IN AUTOMOBILES

Measured variable	Direct/indirect measurement	Sensor technology/ reference	Sensor mounting location
Intake manifold absolute pressure	Indirect measurement of engine load or mass air-flow intake	Wheatstone bridge arrangement of thick film resistors bonded onto a thin alumina diaphragm	Within intake manifold
Mass airflow	Direct and indirect measurement of fuel injector basic pulse width	Various forms including 'flap' type, 'hot-wire', Karman vortex and thick-film diaphragm	Within air intake
Temperature	Direct measurement at various locations	Thermistor or thermocouple depending on temperature range	Intake air, outside air, catalytic converter, engine coolant, hydraulic oil
Engine speed and crankshft reference position	Direct measurement	Magnetic reluctance or Hall effect device	Flywheel on end of engine crankshaft

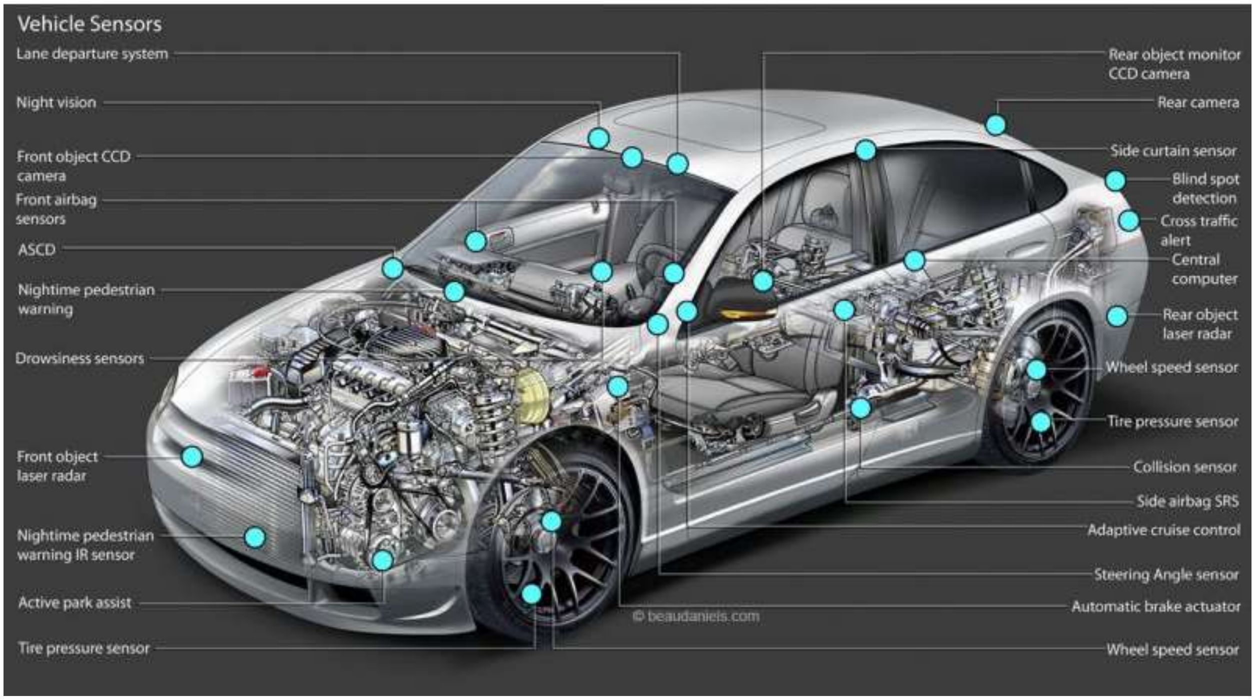
Measured variable	Direct/indirect measurement	Sensor technology/ reference	Sensor mounting location
Battery voltage	Direct measurement	Resistive attenuator	
Throttle position	Direct measurement	Potentiometer	Accelerator pedal
Knock (engine cylinder pressure oscillations during ignition)	Direct measurement	Piezoelectric accelerometer type.	Cylinder block or head
Oxygen concentration in exhaust gas (Lambda sensor)	Direct measurement	Zirconia or Titania based exhaust gas oxygen sensors	Exhaust manifold (normal operation above 300^0 C)

CHASIS CONTROL SENSORS

Measured variable and application	Direct/indirect measurement	Sensor technology/ reference	Sensor mounting location
Wheelspeed and engine speed, (ABS, TCS and electronic damping)	Direct measurement	Magnetic reluctance or Hall effect device	Brake assembly and crankshaft flywheel respectively
Steering wheel angle, (Electronic damping)	Direct measurement	Potentiometer or optical encoder	Steering shaft
Throttle position	Indirect measurement of vehicle accel.	Potentiometer	Accelerator pedal
Chassis and wheel acceleration, (electronic damping)	Direct	Piezo-electric accelerometer	Engine compart-ment and wheel assembly
Brake system pressure (electronic damping)	Indirect measurement of vehicle decelerat-ion	Flexing plate sensor with strain gauges mounted on plate	Brake master cylinder
Steering shaft torque (Electric power assisted steering)	Direct measurement	Optical device relying on steering shaft distortion under driver's twisting action	Steering shaft

SAFETY AND NAVIGATION

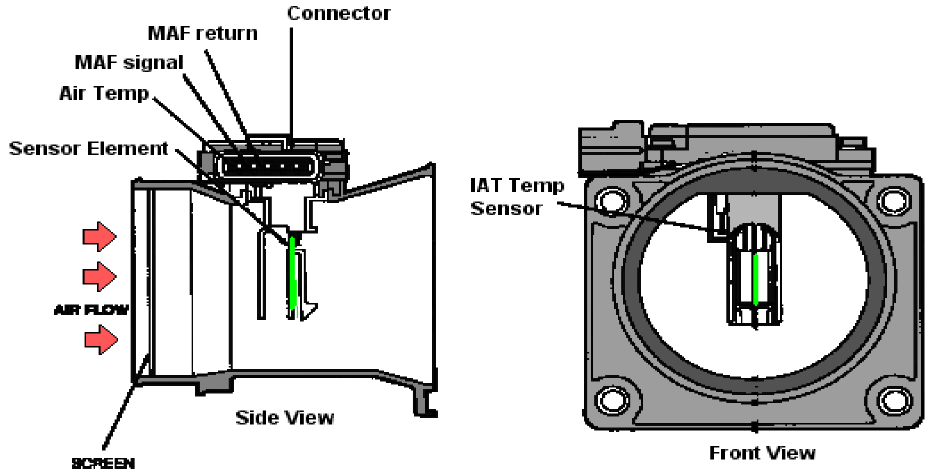
Measured variable	Direct/indirect measurement	Sensor technology/ reference	Sensor mounting location
Vehicle deceleration (air-bag systems)	Direct measurement	'G' sensor (Piezo-electric accelerometer)	Single-point electronic sensing, location in dashboard or steering wheel
Wheelspeed and engine speed (Vehicle nav. Systems)	Direct measurement	Magnetic reluctance or Hall effect device	Brake assembly.



Today's modern automobiles have a variety of sensors. They built into their engine to ensure that the owner can identify and prevent possible issues before they result in breakdowns can result in expensive repairs. These automobile engine sensors also ensure that the vehicle is operating at its most efficient. Many owners are not even aware of the amount of sensors built into their automobiles engine and what value they add. This is the list of car sensors and their functions.

- The Mass Air Flow Sensor (MAF)
- The Engine Speed Sensor
- Oxygen Sensor
- Manifold Absolute Pressure Sensor
- Spark Knock Sensor
- Fuel Temperature Sensor
- Voltage Sensor
- Car Sensors List

THE MASS AIR FLOW SENSOR (MAF)



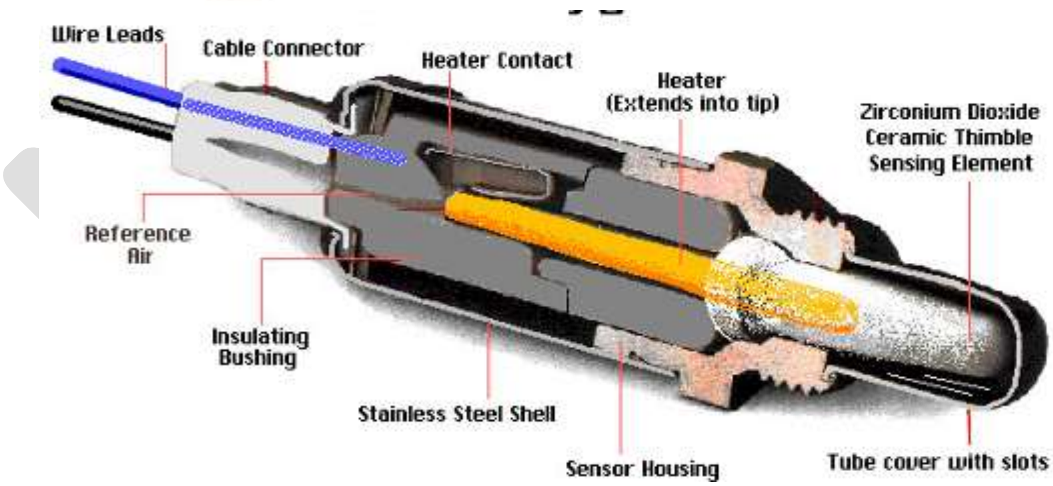
From different types of sensors used in cars, The Mass Air Flow Sensor (MAF) is a computer-controlled sensor that calculates the volume and density of the air taken in by the engine. This in turn ensures the right amount of fuel is used for optimized operating conditions. If this sensor is faulty, the car may stall and the fuel usage will be higher than necessary.

THE ENGINE SPEED SENSOR

The Engine Speed Sensor is attached to the crankshaft and monitors the spinning speed of the crankshaft, which controls the fuel injection and timing of the engine. There are many ways for car engine to stop suddenly, and this sensor will prevent that for drivers.

OXYGEN SENSOR

The Oxygen sensor measures the amount of unburden oxygen that is present in the exhaust pipe and will indicate if the fuel is burning rich or lean. A faulty oxygen sensor will cause the car to idle poorly and jerk as well as cause high fuel consumption.



MANIFOLD ABSOLUTE PRESSURE SENSOR

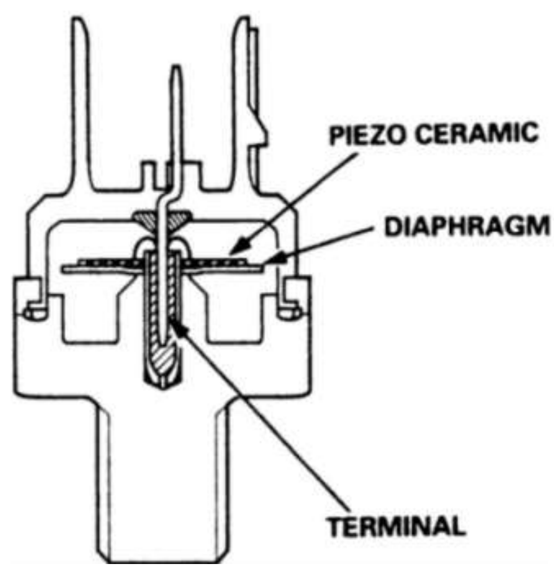
Manifold Absolute Pressure Sensor is another powerful tool

A Manifold Absolute Pressure Sensor, or MAP, senses the engine load. As it is mounted on the intake manifold it can measure the difference between the intake manifold pressure and outside.

This is important for the engine to be able to adjust the fuel injection based on the change in pressure.

SPARK KNOCK SENSOR

A spark knock sensor ensures that the fuel is burning smoothly and not detonating (exploding erratically). Detonation can cause the head gasket to fail, piston lands to crack and rings to break, as well as possible rod bearing damage.



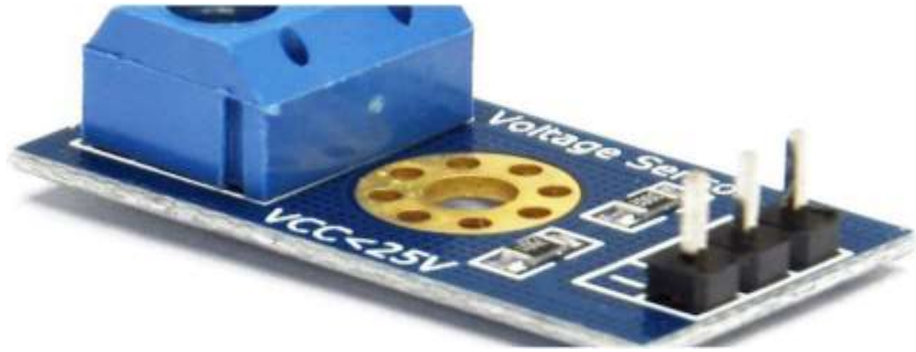
FUEL TEMPERATURE SENSOR

The Fuel Temperature Sensor is another sensor that ensures your cars fuel consumption is at its most efficient. The colder the fuel is the more dense and the slower it burns while when the fuel is warm is burns faster. There are many car parts will get damaged when the car runs out of fuel, so this sensor ensures that the right amount of fuel is injected to keep the vehicle running smoothly while being as efficient as possible.

VOLTAGE SENSOR

Another important part in car sensors list is the Voltage Sensor. This sensor manages the idling speed of the car and ensures the speed is increased or decreased as necessary.

With these many sensors, drivers might take a lot of money in order to purchase all of them, and some might not even that necessary for their needs. Experience car owners will only choose the sensors that are suitable for their vehicles, and with this article, you will now understand what your beloved car needs.



CAR SENSORS LIST

As car owners, knowing the function of these equipment is very important. In order for you to understand the definition and the function easier, here is a list of popular car engine sensors used in modern vehicles:

STT	Sensor	Main Function
1	The Mass Air Flow Sensor	Calculates the density and the volume of the air taken in by the engine
2	The Engine Speed Sensor	Monitors the spinning speed of the crankshaft
3	Oxygen Sensor	Measures the amount of unburden oxygen presented in the exhaust pipe
4	Manifold Absolute Pressure Sensor	Measures the manifold pressure inside and outside
5	Spark Knock Sensor	Ensures that the fuel is burned correctly
6	Fuel Temperature Sensor	Ensures the right amount of fuel is injected to keep the motion smoothly
7	Voltage Sensor	Manages the car speed and ensures the speed is controllable

VEHICLE SPEED SENSOR

A wheel speed sensor or vehicle speed sensor (VSS) is a type of tachometer. It is a sender device used for reading the speed of a vehicle's wheel rotation. It usually consists of a toothed ring and pickup.

General Description

VSS gives the onboard computer information about the vehicle speed. The sensor operates on the principle of the Hall Effect and is usually mounted on the tachometer or in the gearbox.

Appearance

Fig. 1 shows typical speed sensors.

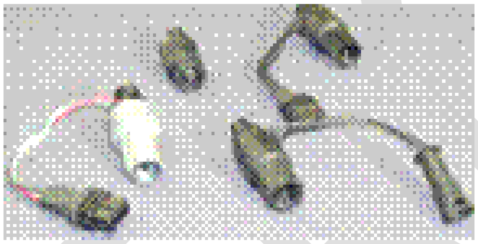


Fig. 1

Used types of sensors

- Speed sensors based on the Hall effect
- Speed sensors with mechanical tenon
- Inductive speed sensors

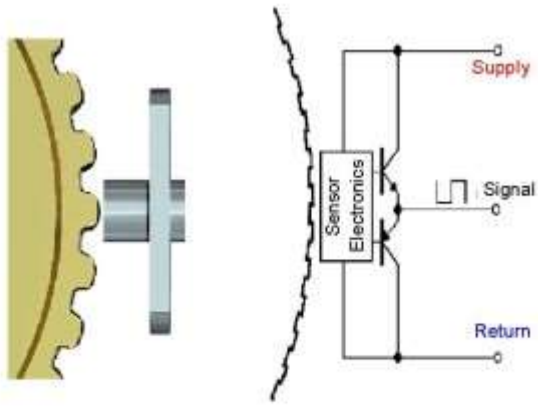
Working principle of different types of VSS

-With Hall Effect

VSS is supplied with +12V from the ignition key. When the tachometer speed cable rotates, the Hall switch is turned on and off consecutively, sending a rectangular signal to the onboard computer. The frequency of this signal indicates the speed of the car.

- Hall Effect: uses a reference voltage from the PCM to produce a DC voltage signal.

A typical Hall Effect sensor



Most sensors today are of the permanent magnet design or Hall Effect design. They are typically mounted in the transmission or differential assembly. If the PCM detects a problem with the VSS or its circuit, it sets a code and illuminates the check engine light. One such code is P0500, which stands for vehicle speed sensor malfunction.

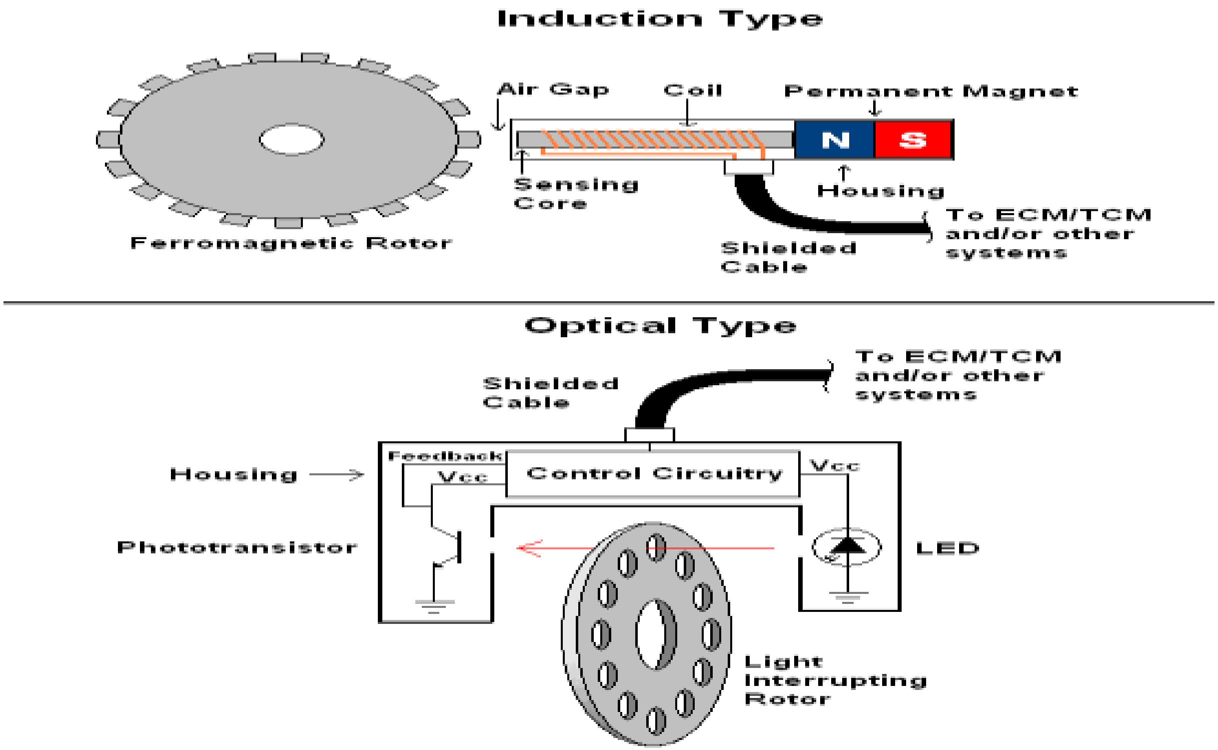
Speed sensor with mechanical tenon

The signal from the rotating drive wheel has a rectangular form. The signal voltage varies from 0V to +5 V or 0V to a value close to the nominal of the car battery. Pulses duty cycle is between 40% and 60%.

Inductive and optical speed sensor

The signal from the rotating drive wheel has a sinusoidal form (alternative current). The signal changes depending on the speed of the wheels as every inductive sensor, for example, the ABS sensor.

Vehicle speed sensors are usually either inductive or optical sensors. The most common inductive sensors consist of a rod magnet on top of a magnetic pin that is surrounded by a fixed coil. This sensor is mounted a fixed distance from a ferromagnetic rotor with teeth. As the rotor turns and a tooth comes into the proximity of the rod, the magnetic flux in the coil changes. This change in flux results in a voltage pulse across the coil. The vehicle's engine control module counts these voltage pulses and computes the vehicle's speed. Optical sensors also generate pulses at a frequency corresponding to the rotor rotation, but instead of measuring magnetic flux, the optical sensor measures either reflected light or light allowed to pass through slits. When using an optical sensor the rotor either has light and dark marks for the optical sensor to detect the reflected light using photosensors, or a series of slits that allows light from an infrared source to pass through and be detected by a phototransistor on the other side.



New technologies are being introduced to provide a more accurate and robust determination of the exact vehicle speed without the need to calculate and average the readings of the wheel speed sensors. Hitachi has developed a low cost compact speed sensor technology that measures the velocity of a vehicle relative to the ground using a millimeter-wavelength radar [1]. This sensor provides the ability to measure velocity even when all 4 tires are slipping.

Procedure for verification of functionality of the VSS sensor

NOTE: This algorithm describes how to check the most common VSS sensor, the Hall Effect type.

- VSS is usually mounted in the gearbox.
- Check the VSS connector for corrosion or mechanical damages.
- Make sure connector pins are firmly fit in their places and whether they make good contact to the VSS sensor.
- Pull off the protective rubber muff from the VSS sensor connector.
- Find the power supply, the ground and the signal terminals.
- Connect the oscilloscope GND probe to the chassis ground.

- Connect the active end of the oscilloscope probe to the signal terminal of the VSS.
- Signal is generated when the drive wheels of the car are spinning. This can be achieved in the following ways:
    - Push the car forward.
    - Lift the car at stand or jack so that the drive wheels can rotate freely.
    - Rotate the wheels by hand to get impulses.
    - On the oscilloscope screen you must observe the following signal (fig. 2).

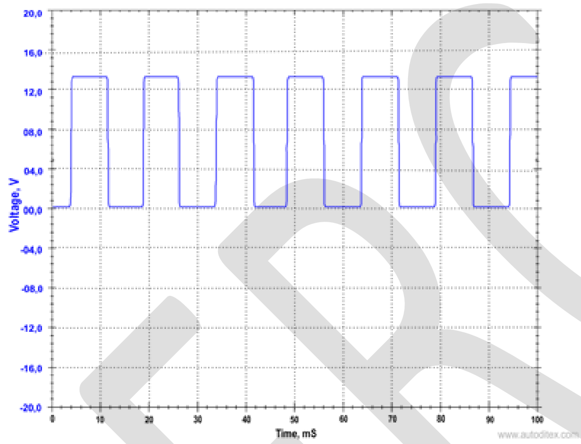


Fig. 2

Possible damages:

Interruptions or lack of signal - voltage/duty cycle

- Disconnect the VSS sensor connector and turn on the ignition key.
- Attach the oscilloscope probe to the signal terminal and measure the voltage. Its value should be from 8.8 to 10V.
- Also check the voltage of the power supply terminal. Its value should be lower than the nominal of the car battery.
- Check the GND connection of VSS sensor.
- If everything is normal, probably the fault is in the VSS sensor or the speed cable does not rotate because it is broken or the gearbox is damaged.
- Lack of signal voltage
- Check the voltage at the onboard computer connector terminals:
- If voltage of the onboard computer is normal, check the signal circuit conductivity and the diode in the circuit between the onboard computer and the VSS sensor.
- If voltage of the onboard computer is missing, check all power supply voltages and all

connections to GND of the onboard computer. If there is no problem, doubt about a damage of the onboard computer remains.

CRANK POSITION SENSOR

General description

CKP is the sensor, without operation of the fuel injection system is impossible. Defects in CKP inevitably lead to engine failure and the car will not run. Crankshaft position sensor (CKP) is an electromagnetic sensor by the help of which the fuel injection system makes synchronization of the fuel injectors operation and the ignition system. CKP sensor sends signal for the speed and the position of the crankshaft to the onboard controller. This signal is a series of repetitive electrical voltage impulses, generated by the sensor when the crankshaft is rotating. Based on these impulses, the onboard controller controls the fuel injectors and the ignition system.

Appearance

A typical CKP sensor is shown in fig.1.

Fig. 1

Working principle of the crankshaft cogwheel – CKP sensor pair

CKP is placed on the console to the cogwheel of the crankshaft.

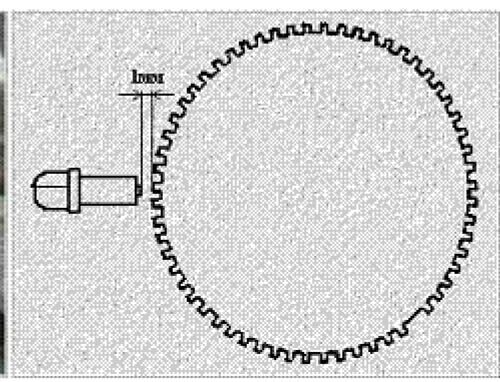


Fig. 2 Fig. 3

An air gap is placed between the sensor and the cogwheel. This gap should be about 1mm ± 0.4mm and is achieved by selecting the appropriate washers (fig. 2 and fig. 3).

The crankshaft cogwheel is manufactured as a special disk which has usually 58 teeth in each 6 degrees. There are two missing teeth which are used to generate synchronization pulse (fig. 2 and fig. 3). Crankshaft rotation causes change of the sensor magnetic field and thus creating voltage pulses. Through the pulse synchronization from the CKP sensor, the onboard controller determines the position and speed of the crankshaft and calculates the exact moment of operating the fuel injectors and the exact moment for generating the spark. The beginning of the 20th tooth (after the missing ones) of the cogwheel matches with the top dead center (TDC) of the first and the fourth cylinder.

Cogwheel can be cast, non-metallic or damper (with rubber insulation). During the exploitation of the car, wear of non-metallic cogwheel was not observed. The only thing that should be monitored is to prevent penetration of small particles and dirt between the teeth. If the cogwheel is with damper, its state should be monitored for a damper damage because it can lead to engine problems. When performing repairs you should be careful not to allow deformation of the cogwheel because this can lead to an engine collapse. Visual observation of the cogwheel can be done from the right front wheel side, as shown in fig. 4.

Fig. 4

Used types of sensors

CKP are divided into two types:

- Inductive
- Hall sensor effect

In the inductive ones, the sensitive element has a magnetization core and a copper conductor winding mounted on an isolated coil.

Hall sensors use the “hall effect” expressing the impact of magnetic field on semiconductor sensor.

Typical symptoms of defective CKP and crankshaft cogwheel

In case of failure of CKP or crankshaft cogwheel, the onboard controller records a fault event and illuminates the "CHECK ENGINE" indicator lamp. Following symptoms can be assigned to faults of these elements:

- erratic idling
- spontaneous increase and decrease of the engine speed;
- engine stop;
- engine will not start;
- poor engine performance;
- knock during acceleration;
- Engine misfire.

Fig.5 and fig.6 show the crankshaft cogwheel with a damaged damper. This failure makes proper synchronization of the phases of the injection and ignition impossible, since the inner part is shifted to the cogwheel and therefore the phases of the injection and ignition are shifted to one another.

Fig. 5 Fig. 6

Procedure for checking the condition of CKP

1. Perform an external visual inspection of the CKP and the crankshaft cogwheel.
2. Check the CKP harness for corrosion and damages.
3. Make sure harness pins are tight in their places and there’s good electrical contact.
4. Check that the air gap between the cogwheel and the CKP sensor is within the limits.
5. Disconnect the sensor harness.
6. Measure with ohmmeter the active resistance between the terminals of the CKP. Check the database what should be the value of measured resistance of the sensor for the

corresponding brand and model of the car. If the reading shows extremely high resistance, this means that there is an open circuit in the sensor. Zero or close to zero indication means short circuit in the coil.

NOTE: Regardless of measured resistance is within acceptable limits, it can't be taken as evidence that the CKP will be able to produce a correct signal.

Check the shielded CKP cable:

- CKP may have shielded cable (not in all cases). Strip the coupling of the harness.
- Connect one of the probes of ohmmeter to one of the terminals of the CKP (1 or 2).
- Connect the other probe to the terminal that corresponds to the shield. The reading should incline to infinite resistance.
- Move the probe from the shield terminal and connect it to the ground. The reading should incline to infinity.

  Note: *In some systems the CKP shield cable is connected to its feedback CKP cable to ground. In this case the ohmmeter will read short circuit, which will be normal for this system*. Explore electrical circuit of the system you are testing to identify how exactly the CKP is connected.
- Plug in the sensor connector.

Oscilloscope measurements

— Inductive type of sensor —

Connect the active end of the measuring probe to one of the terminals of the CKP and the other end to the ground. You will observe the picture as in fig. 7 - when the engine is cranking and in fig. 8 - when the engine is idling.

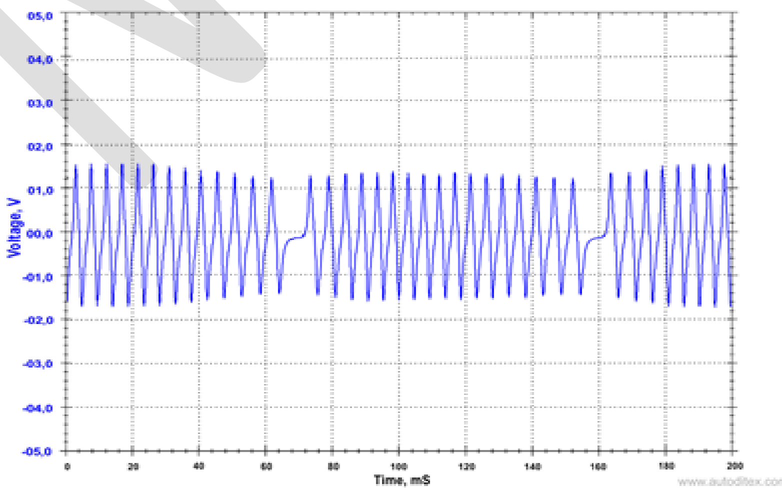


Fig. 7

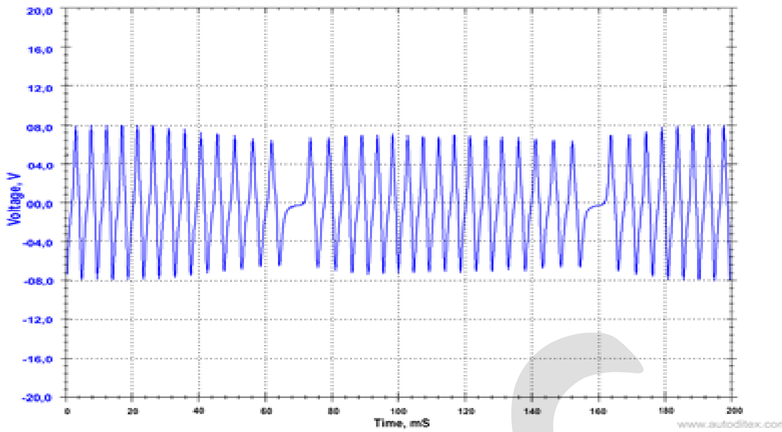


Fig. 8

Pay attention to the amplitudes of the electric pulses during engine cranking and during engine idling. In the first case the signal amplitude will be significantly lower.

Thus you can determine the performance of the CKP as well as the wear of the crankshaft cogwheel. An example representing cogwheel wear is shown in fig. 10. Fig.11 shows a high wear. You have to replace the crankshaft cogwheel in this case.

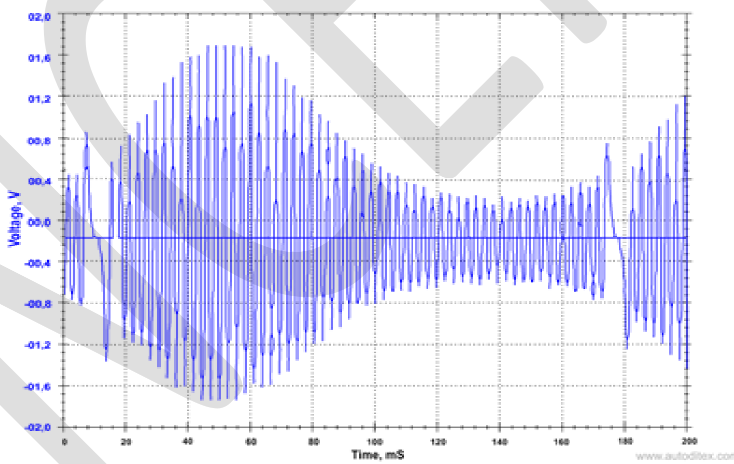


Fig. 10

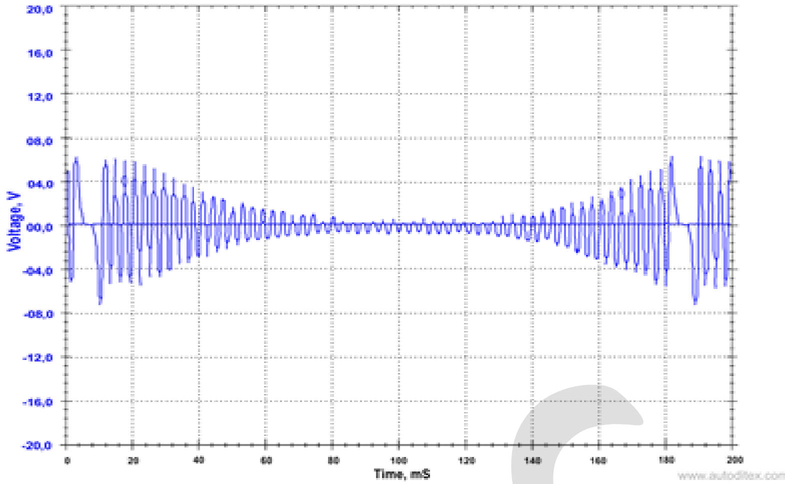


Fig. 11

NOTE: CKP is polar sensor and exchange of signal terminals "Plus" and "Minus" is equivalent to malfunction.

— Hall sensor —

The picture you have to observe in this case is as follows (fig. 12).

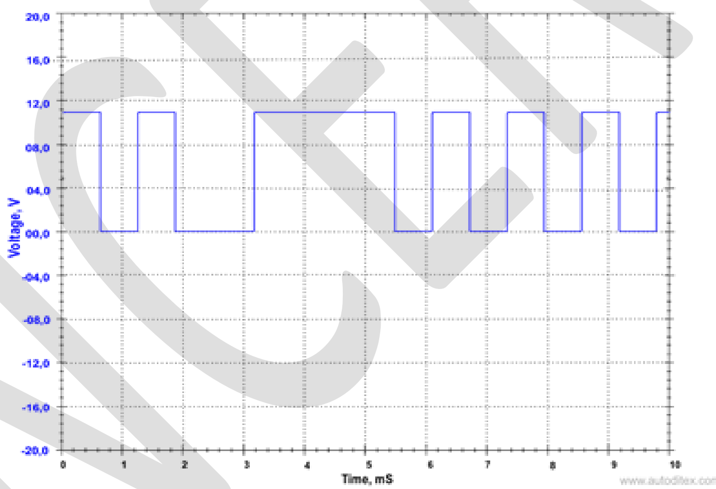


Fig. 12

Prolonged impulse marks the synchronization pulse and each of the other shows the tooth passing by the sensor.

THROTTLE POSISTION SENSOR

General description

A throttle position sensor (TPS) is used to monitor the throttle valve position in internal combustion engines. TPS is usually located on the throttle valve spindle so that it can directly monitor its position.

The TPS sensor is a potentiometer, providing a variable resistance depending on the position of the throttle valve (and hence throttle position sensor).

The sensor signal is used by the engine control unit (ECU) as an input to its control system. The ignition timing and fuel injection timing (and potentially other parameters) are altered depending on the position of the throttle valve, and also depending on the rate of change of that position.

Some throttle valve modifications have built-in end switches. They are closed throttle position sensor (CTPS) and often include a wide open throttle (WOT) sensor which is mounted on the accelerator pedal.

Throttle position signal can be produced from a simple contact (TS) or a potentiometer (TPS), and also of combined TS/TPS sensor. Some systems use both types as separate elements.

Appearance

Fig. 1 shows a typical TPS.

Fig. 1

Types of TPS sensors

According to its construction are:

- with end switches
- potentiometer type
- combination of both above

Working principle of the TPS

Throttle potentiometer sensor (TPS)

TPS gives to the onboard controller information about the idling, deceleration, rate of acceleration and the fully open throttle valve state (WOT). TPS is a three wire potentiometer. On the first wire a voltage of +5V is applied to the sensor resistive layer and the second wire closes the sensor circuit to the ground. The third wire is connected to the potentiometer wiper, thereby the changing the resistance and hence the voltage of the signal returned to the onboard computer.

Based on the received voltage, the onboard computer can calculate the idling (below 0.7V), the full load (about 4.5V), and the opening speed of the throttle valve. At full load state the onboard computer provides further enrichment of the fuel mixture. In deceleration mode (closed throttle valve and engine speed above certain RPM) the onboard computer shuts-off the fuel injection. Fuel supply is resumed after the engine speed reaches its idle value or when the throttle valve is open. Some cars allow adjustment of these values.

THROTTLE SENSOR (TS)

TS informs onboard computer about the idling state. Usually it has a second contact for the fully open throttle valve state (WOT). In most cases the onboard computer provides extra enrichment of the fuel mixture in the idle state and in the fully open throttle valve state. Each TS contact has two positions - open and closed - by which the onboard computer detects three different states of engine:

- The throttle valve is closed (the idle speed contact is closed)
- The throttle valve is opened (the idle speed contact and WOT are open)
- The throttle valve is fully open (the idle speed contact is open and the WOT contact is closed)

Some cars allow regulation of TS.

Procedure for verification of TPS functionality

— THROTTLE SENSOR (TS) —

NOTE: The following operations are applied in a typical three state throttle valve switch. In some cases the idle switch and the full load switch can be connected separately. Also there are separate idle and full load switches. In some Rover models the throttle valve switch is located on the accelerator pedal. Regardless of the location of the switch, the verification procedure is performed similarly for all types of sensors.

-- Check TS voltage

- The three wires entering the throttle switch coupling are grounding, idle mode signal and full load signal.
- Connect the negative terminal of a voltmeter to the engine ground.
- Determine the ground, idling and full load terminals of the sensor.
- Turn on the ignition, but do not start the engine.
- Connect the positive terminal of a voltmeter to the wire, connected to the idle signal

contact of the throttle switch.

- Voltmeter must read voltage of 0V. If it reads voltage 5.0V, loosen the screws and adjust the switch so that the voltmeter reads zero voltage.

NOTE: In some cars the throttle valve switch could not be adjusted.

-- Check TS resistance

- Disconnected the throttle connector.
- Connect ohmmeter between the ground and the idle mode terminals.
- When the throttle valve switch is turned on, the ohmmeter should read resistance around 0 Ω.
- Slowly open the throttle valve and when the switch opens the resistance should be equal to infinity and remain the same even if the throttle is fully opened.
- Connect ohmmeter between the ground and the full load mode terminals.
- When the throttle switch is closed, ohmmeter must read circuit break (infinite resistance).
- Slowly open the throttle valve. When the switch opens it should click and the resistance should remain equal to infinity. When the throttle valve opening angle becomes greater than 72 degrees, the resistance will be equal to 0 Ω.
- If the switch does not work in the described way, and the turning on and turning off cannot be regulated by bending the levers driving the throttle valve, most likely the throttle switch is defective.

-- Possible damages in TS:

1) Can not get voltage 0V (closed throttle valve)

- Check the throttle valve state.
- Check the switch connection to the ground.
- Take measurements of the switch resistance.
- If the voltage is normal with closed throttle valve, sharply open the throttle valve, switch must click, and the voltage should rise up to 5.0V.

2) Voltage is low or missing (the throttle valve is opened)

- Check whether the idle mode switch terminal is not connected to ground.
- Disconnect the switch connector and check for presence of 5.0V voltage in the idle mode contact. If there is no voltage, carry out the following checks:
    - check the integrity of the idle mode signal wire between the switch and the onboard controller;

    - If the switch wires are good, check all supply and ground connections of the onboard controller. If they are correct, the fault may be in the onboard controller.

3) The voltage is normal (throttle valve is opened)

- Connect the positive terminal of a voltmeter to the wire, connected to the full load mode switch contact.
- When the throttle valve is in idle state or slightly open, the voltmeter should read voltage of 5.0V.

4) Voltage is low or missing (the throttle valve is closed or slightly open)

- Check the ground connection.
- Check whether the full load mode contact of the throttle switch is not connected to ground.
- Disconnect the switch connector. Check the presence 5.0V voltage in the full load mode contact of the connector. If there is no voltage carry out the following checks:
    - check the integrity of the idle mode signal wire between the switch and the onboard controller;
    - If the switch wires are good, check all supply and ground connections of the onboard controller. If they are correct, the fault may be in the onboard controller.

5) The voltage is normal (the throttle valve is closed or slightly open)

- Fully open the throttle valve. When the opening angle becomes more than 72 degrees, the voltage should drop to zero. If the voltage does not drop most likely the throttle switch is malfunctioning.

— Throttle Position Sensor (TPS) —

-- Check TPS voltage

1. Connect the negative terminal of a voltmeter to the engine ground.
2. Determine the ground, idling and full load terminals.

NOTE: Most throttle potentiometers have three terminals, but some may have and extra contacts, which function as throttle switches. If there is such a contact, it must be checked as described above for throttle switch.

3. Connect the voltmeter positive terminal to the wire connected to the contact signal from the throttle valve potentiometer.
4. Turn on the ignition, but do not start the engine. In most systems the voltage reading should be less than 0.7V.

5. Open and close the throttle valve several times, by checking the smoothness of the rising voltage.

-- Check the resistance of the TPS

1. Connect an ohmmeter between the potentiometer wiper and the reference voltage terminal or between the potentiometer wiper and the ground.
2. Open and close the throttle valve several times and check the smoothness of resistance variation. If the potentiometer resistance is infinite or zero, this indicates a malfunction.
3. Exact values of the throttle potentiometer resistance are not shown. One of the reasons is that many manufacturers do not publish control data. The fact that the resistance of the potentiometer is kept within limits is less important than the proper operation of the potentiometer, i.e. resistance smooth change when moving the throttle valve.
4. Connect an ohmmeter between the ground and the reference voltage terminals. The resistance must be constant.
5. If the resistance is infinite or is low, the potentiometer must be replaced

-- Possible damages in TSP

Chaotic output signal

- Chaotic output signal is observed when the voltage signal changes rapidly, drops to zero and disappears.
- When the throttle valve potentiometer output signal is chaotic, a defective potentiometer is usually the reason for this. In this case, the potentiometer must be replaced.

Missing voltage signal

- Check the presence of reference voltage (5.0V) on the throttle potentiometer power terminal.
- Check the condition of the potentiometer grounding contact.
- Check the signal wire connecting the throttle potentiometer to the onboard controller.
- If the power supply and ground are bad, check the wires integrity between the potentiometer and the onboard controller.
- If the potentiometer wires are good, check all supply and ground connections of the onboard controller. If they are correct, most likely reason is the onboard controller itself.

The output signal or the reference voltage is equal to the battery voltage

- Check for short-circuit in the wire connected to the positive terminal of the car battery or the power supply wire.

Check the throttle valve potentiometer by using oscilloscope

- Best way to obtain changes of potentiometer signal is using an oscilloscope.
- Connect the oscilloscope active probe to the potentiometer signal terminal, and the GND probe - to the engine ground.
- Start the engine.
- Smoothly operate the accelerator pedal and then sharply release the pedal. You must see a signal as in fig. 2.

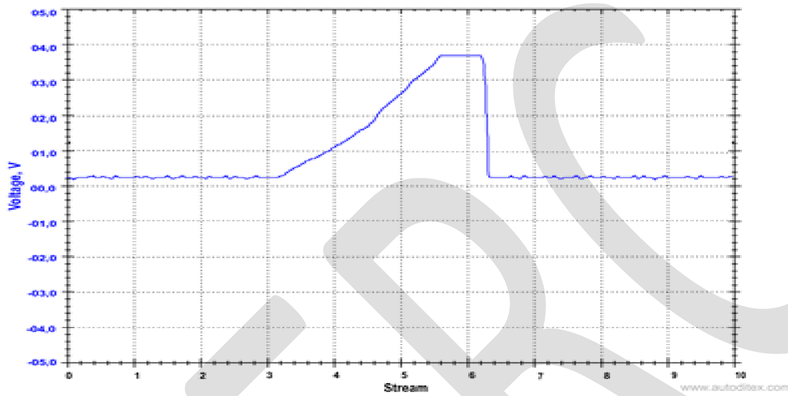


Fig. 2

This is a properly working throttle valve potentiometer waveform - a smooth voltage rising and fast collapse.

Figures 3, 4 and 5 indicate defective potentiometers waveforms.

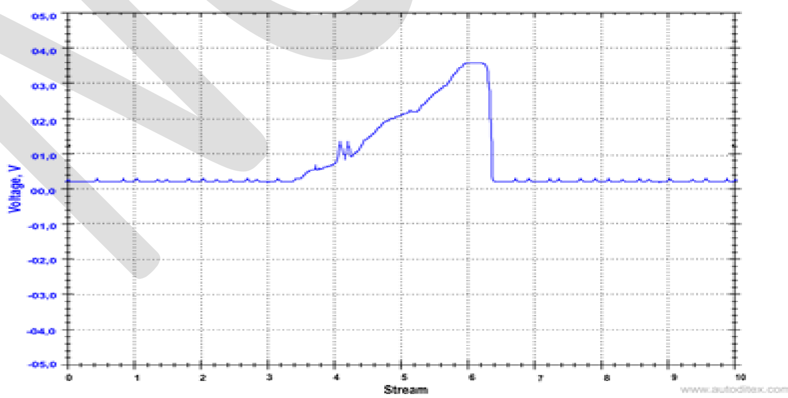


Fig. 3

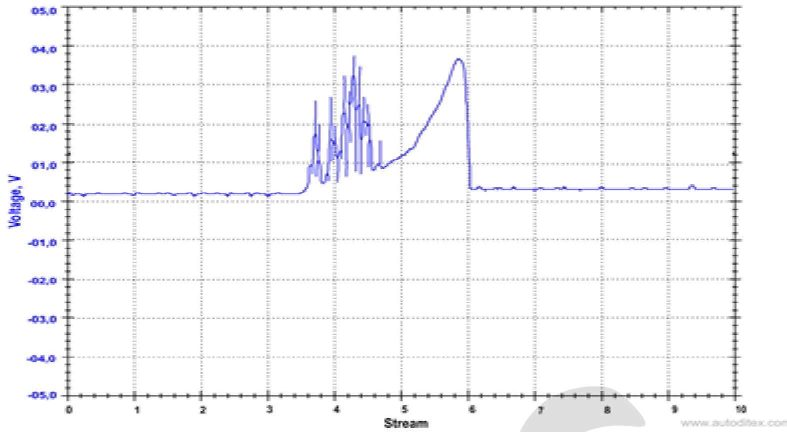


Fig. 4

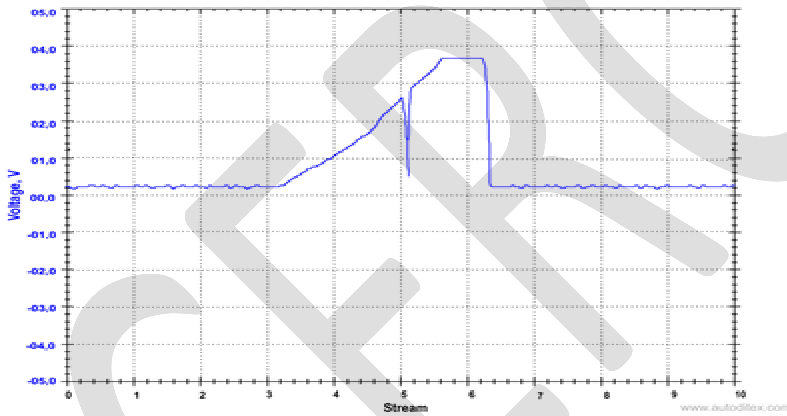


Fig. 5

You can clearly see the signal cuts, which means that there are breaks in throttle valve potentiometer resistive layer and it has to be replaced.

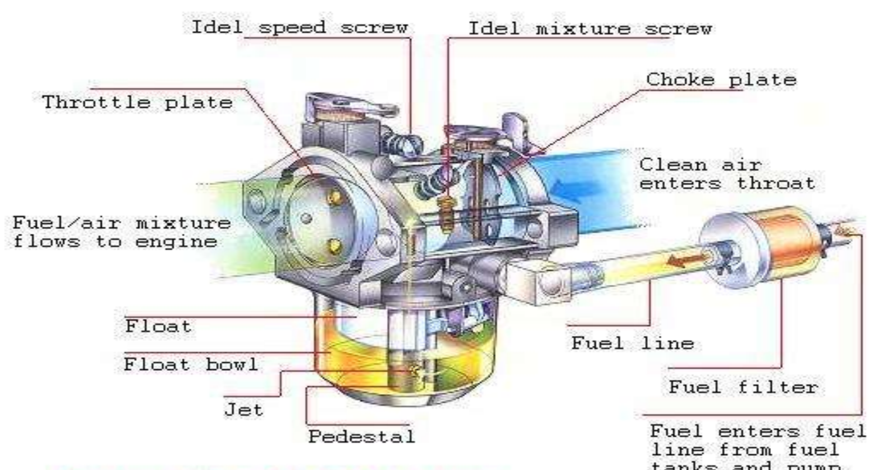
MODULE III

FUEL INJECTION AND IGNITION SYSTEMS

INTRODUCTION TO FUEL SYSTEMS

CARBURETOR SYSTEM

This is the "old school" type for getting the air/fuel mixture into the combustion chambers. Although it is very rarely used in modern vehicles it was the most common type used until the early 90s in both cars and bikes. Its design is straightforward as you can see in the figure below.



Carburetor and Fuel System

Now, looking from right to left in the above figure we have the following two paths for each of the mixture's elements…

The fuel goes like this:

– The fuel pump inside the gas tank pumps gas when the starter begins

– The fuel line drives the fuel to the fuel filter

– At last, gas enters the float bowl of the carb

On the other hand, the air has an even simpler path, which is:

– If carb has air filter/cleaner, it passes through it

– Air enters the carb's air intake

Before moving on, here is a real carb kit for V-Twin engines designed by S&S that will hopefully help you apply the above diagram information to a more realistic case.

In this picture, apart from the carb you can also see the air filter/cleaner as well as its cover, a small pipe that is used to distribute the output mixture of carb to the two cylinders of the V-Twin engine (known as intake manifold) and all the gaskets, clamps, extra fuel lines and screws required to mount this kit.

Now that you hopefully have a better picture of the whole thing, let's jump back to the carb's operation. In the figure I gave it is not very clear what happens to the fuel after it enters the float bowl. What it happens is that it moves to an adjustable tiny hole that I flow inside the main body of the carb. Now, you can see a butterfly valve named throttle plate. This is commonly connected through a line to the accelerator pedal or lever depending on the vehicle. The more you push the accelerator, the more that valve opens delivering more air/fuel mixture to the engine. Since the delivered mixture should not be the same for all engines, carb's provide some simple screws (look at the given picture for speed and mixture screws) that can be used to adjust the fuel jet and butterfly valve to provide the best possible mixture.

I'm fairly sure that by know you should be wondering what's with that "choke plate" at the very entrance of air in the carb's body. Before explaining this you should be aware that gasoline (liquid form) is not exactly flammable, its vapor is. In order to have ignition you must have gasoline that vaporizes in a good rate. You can do a simple experiment to see this working, take a small bowl filled gasoline and place a lighted match close to its vaporizing surface, it will fire up the vaporizing gas. However, if you place it fast inside the bowl, it will quench the fire of the match. That said, you can easily understand that the colder the gasoline, the lower its vaporization rate will be. For that matter, when you start your vehicle with a cold engine is called a cold start since it creates exactly this problem that requires rich mixture to overcome.

Such fuel systems (carb) have a great disadvantage when it comes to cold engine starting. Because of the high pressure that the incoming air creates, the fuel jet(s) cannot provide the appropriate amount of fuel and cylinders starve because of the lean mixture. To fix this, some manufacturers installed additional fuel jets but the most common case is the installation of a choke plate that limits the air flow and consequently lowers the pressure allowing a smooth cold start with more fuel than air (aka rich mixture). In later models, this action was performed automatically using thermal sensors that were triggering the choke plate accordingly. The main advantage of this type of fuel system is its simplicity, great torque performance and averagely easy maintenance. On the other hand, it requires small adjustments on a frequent basis, it has numerous reliability issues (it cannot perform smoothly in the whole RPM range), it has very poor fuel management efficiency and high output emission rates. However, because of its torque performance it is still used in some models either by design or as a performance tuning.

INTRODUCTION TO FUEL INJECTION SYSTEM

For the engine to run smoothly and efficiently it needs to be provided with the right quantity of fuel/air mixture according to its wide range of demands.

A fuel injection system

Petrol-engine cars use indirect fuel injection. A fuel pump sends the petrol to the engine bay, and it is then injected into the inlet manifold by an injector. There is either a separate injector for each cylinder or one or two injectors into the inlet manifold.

Traditionally, the fuel/air mixture is controlled by the carburetor, an instrument that is by no means perfect.

Its major disadvantage is that a single carburetor supplying a four-cylinder engine cannot give each cylinder precisely the same fuel/air mixture because some of the cylinders are further away from the carburetor than others.

One solution is to fit twin-carburetors, but these are difficult to tune correctly. Instead, many cars are now being fitted with fuel-injected engines where the fuel is delivered in precise bursts. Engines so equipped are usually more efficient and more powerful than carbureted ones, and they can also be more economical, as well as having less poisonous emissions.

Diesel fuel injection

The fuel injection system in petrol engine cars is always indirect, petrol being injected into the inlet manifold or inlet port rather than directly into the combustion chambers. This ensures that the fuel is well mixed with the air before it enters the chamber.

Many diesel engines, however, use direct injection in which the diesel is injected directly into the cylinder filled with compressed air. Others use indirect injection in which the diesel fuel is injected into the specially shaped pre-combustion chamber which has a narrow passage connecting it to the cylinder head.

Only air is drawn into the cylinder. It is heated so much by compression that atomized fuel injected at the end of the compression stroke self-ignites.

Basic injection

All modern petrol injection systems use indirect injection. A special pump sends the fuel under pressure from the fuel tank to the engine bay where, still under pressure, it is distributed individually to each cylinder.

Depending on the particular system, the fuel is fired into either the inlet manifold or the inlet port via an injector. This works much like the spray nozzle of a hose, ensuring that the fuel comes out as a fine mist. The fuel mixes with the air passing through the inlet manifold or port and the fuel/air mixture enters the combustion chamber.

Some cars have multi-point fuel injection where each cylinder is fed by its own injector. This is complex and can be expensive. It’s more common to have single-point injection where a single injector feeds all the cylinders, or to have one injector to every two cylinders.

Injectors

The injectors through which the fuel is sprayed are screwed, nozzle-first, into either the inlet manifold or the cylinder head and are angled so that the spray of fuel is fired towards the inlet valve.

The injectors are one of two types, depending on the injection system. The first system uses **continuous injection** where the fuel is squirted into the inlet port all the time the engine is running. The injector simply acts as a spray nozzle to break up the fuel into a fine spray – it doesn't actually control the fuel flow. The amount of fuel sprayed is increased or decreased by a mechanical or electrical control unit – in other words, it is just like turning a tap on and off.

The other popular system is **timed injection (pulsed injection)** where the fuel is delivered in bursts to coincide with the induction stroke of the cylinder. As with continuous injection, timed injection can also be controlled either mechanically or electronically.

The earliest systems were mechanically controlled. They are often called petrol injection (PI for short) and the fuel flow is controlled by a mechanical regulator assembly. These systems suffer from the drawbacks of being mechanically complex and having poor response to backing off the throttle.

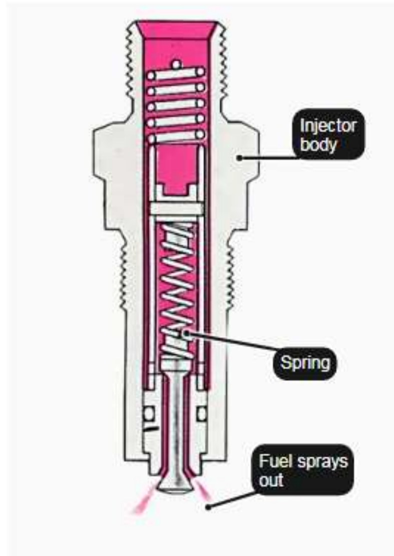
Mechanical systems have now been largely superseded by **electronic fuel injection** (known as Efi for short). This is thanks to the increasing reliability and decreasing costs of electronic control systems.

TYPES OF FUEL INJECTOR

A mechanical fuel injector

Two main types of injector can be fitted, depending on whether the injection system is mechanically or electronically controlled.

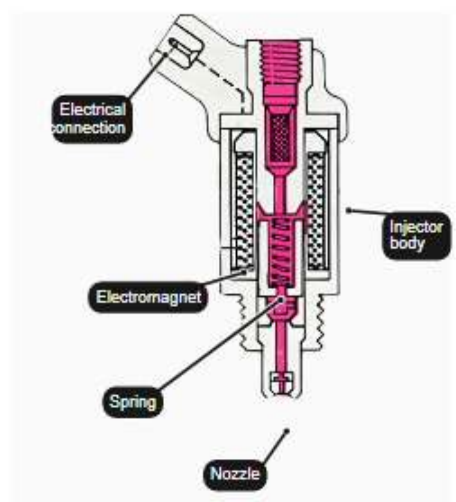
In a mechanical system, the injector is spring-loaded into the closed position and is opened by fuel pressure.



A mechanical fuel injector

An electronic injector

The injector in an electronic system is also held closed by a spring, but is opened by an electromagnet built into the injector body. The electronic control unit determines how long the injector stays open



An electronic injector

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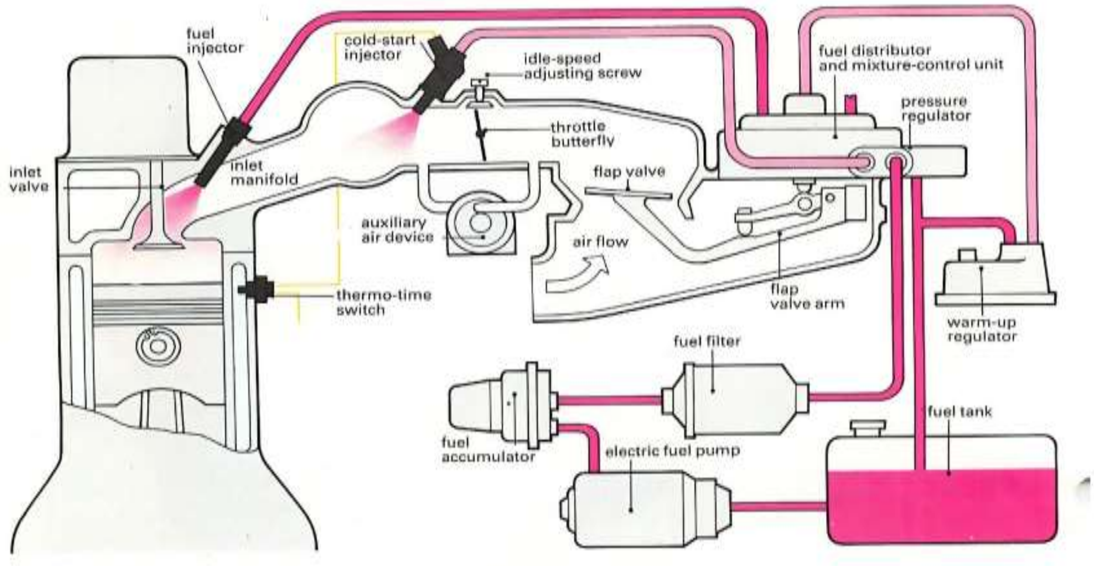
MECHANICAL FUEL INJECTION



Lucas mechanical fuel injection system

In the Lucas system, fuel from the tank is pumped at high pressure to a fuel accumulator. From there it passes into the fuel distributor, which sends a burst of fuel to each injector, from where it is fired into the inlet port.

The airflow is controlled by a flap valve which opens in response to the accelerator pedal. As the airflow increases, the fuel distributor automatically increases the flow of fuel to the injectors to keep the fuel/air mixture correctly balanced.

For cold starting, a choke on the dash or, on later models, a microprocessor control unit brings a special cold-start injector into operation, which injects extra fuel to create a richer mixture. Once the engine has warmed up to a certain temperature, a thermo switch automatically cuts off the cold-start injector.

Mechanical fuel injection was used in the 1960s and 1970s by many manufacturers on their higher-performance sports cars and sports saloons. One type fitted to many British cars, including the Triumph TR6 PI and 2500 PI, was the Lucas PI system, which is a timed system.

A high-pressure electric fuel pump mounted near the fuel tank pumps fuel at a pressure of 100psi up to a fuel accumulator. This is basically a short-term reservoir that keeps the fuel-supply pressure constant and also irons out the pulses of fuel coming up from the pump.

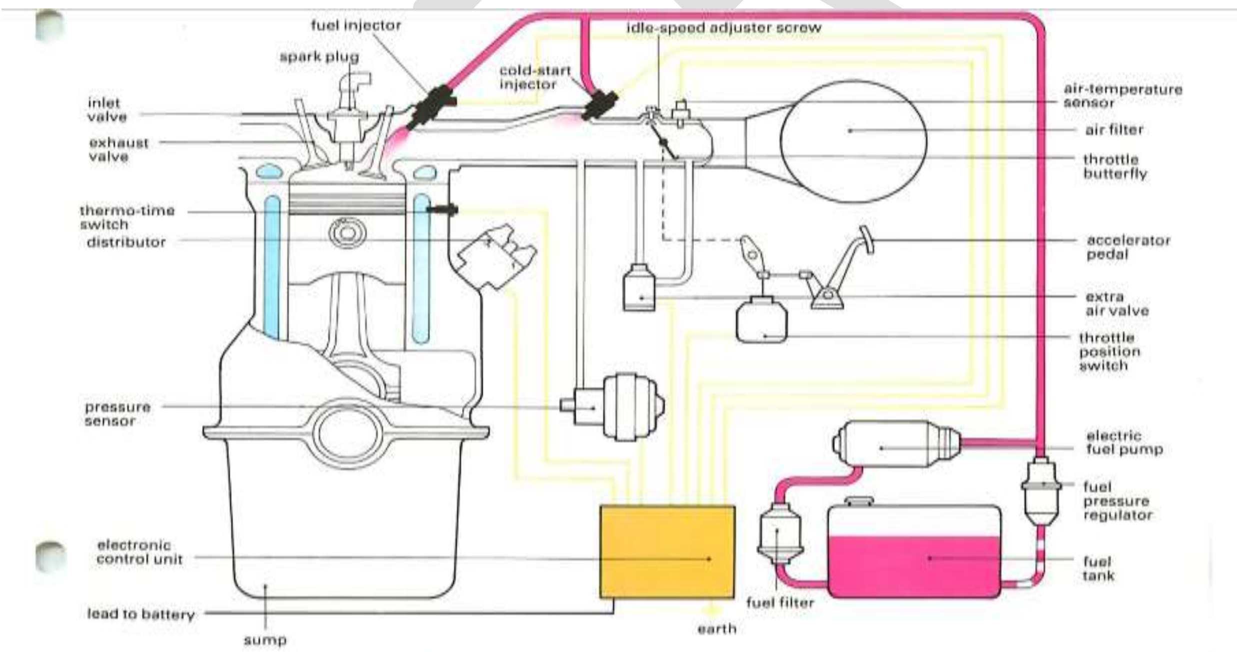
From the accumulator, the fuel passes through a paper element filter and then feeds into the fuel-metering control unit, also known as the fuel distributor. This unit is driven from the camshaft and its job, as the name suggests, is to distribute the fuel to each cylinder, at the correct time and in the correct amounts.

The amount of fuel injected is controlled by a flap valve located in the engine's air intake. The flap sits beneath the control unit and rises and falls in response to airflow – as you open the throttle, the 'suck' from the cylinders increases the airflow and the flap rises. This alters the position of a shuttle valve within the metering control unit to allow more fuel to be squirted into the cylinders.

From the metering unit, the fuel is delivered to each of the injectors in turn. The fuel then squirts out into the inlet port in the cylinder head. Each injector contains a spring-loaded valve that is kept closed by its spring pressure. The valve only opens when the fuel is squirted in.

For cold starting, you cannot just block off part of the airflow to enrich the fuel/air mixture as you can with a carburetor. Instead a manual control on the dash (resembling a choke knob) or, on later models, a microprocessor alters the position of the shuttle valve within the metering unit. This activates an extra injector mounted in the manifold, causing it to squirt in extra fuel to enrich the mixture.

ELECTRONIC INJECTION SYSTEMS



Bosch electronic fuel injection An electronic system is operated entirely by a microprocessor control unit. This measures factors such as the engine temperature, the throttle position and the engine speed to compute the fuel/air mixture required by the engine and its timing to the injectors.

An electronic system is operated entirely by a microprocessor control unit. This measures factors such as the engine temperature, the throttle position and the engine speed to compute the fuel/air mixture required by the engine and its timing to the injectors.

The main difference between electronic injection and mechanical injection is that an electronic system is controlled by a complex microprocessor control unit (sometimes called an electronic control unit or ECU), which is basically a miniature computer.

This computer is fed with information from sensors mounted on the engine. These measure factors such as the air pressure and temperature in the air intake, the engine temperature, accelerator position and engine speed. All this information allows an electronic system to meter the fuel far more accurately than the simple mechanical system, which relies on sensing the airflow alone.

The computer compares the input signals from the sensors with information already programmed into it at the factory, and works out exactly how much fuel should be delivered to the engine. It then signals the on-off valve ig the injector to open and squirt fuel into the inlet port. All this happens in a fraction of a second, the control unit responding instantly to changes in accelerator position, temperature and air pressure.

As well as improved control over fuel flow, the electronic system also operates at lower pressure than a mechanical system – usually at around 25-30psi. This makes it run more quietly than a mechanical system does.

A typical system is the Bosch LJ etronic, which is fitted to a wide range of European cars. In this system, fuel is drawn from the tank by an electric pump. It is then fed straight up pipes to the injectors. The system pumps more fuel than is needed for injection – a loop circuit returns the excess to the fuel tank via a pressure regulator which keeps the pressure in the pipes constant.

The injector valves are held closed by springs, and opened by solenoids (electromagnets) when signaled to do so by the control unit. The amount of fuel injected depends on how long the solenoid holds the injector open.

TYPES OF FUEL INJECTION SYSTEMS

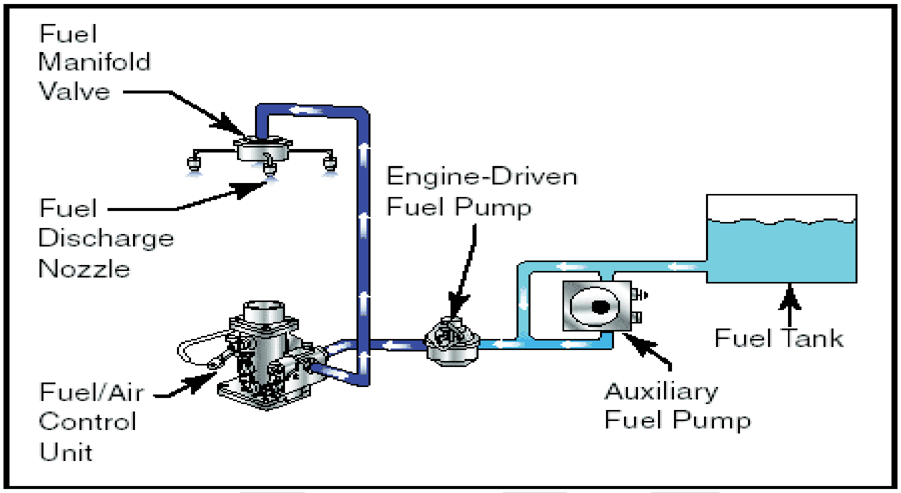
The fuel injection types used in newer cars include:

- Single-point or throttle body injection
- Port or multi-point fuel injection
- Sequential fuel injection
- Direct injection

Single-point or throttle body injection

The earliest and simplest type of fuel injection, single-point simply replaces the carburetor with one or two fuel-injector nozzles in the throttle body, which is the throat of the engine's air intake manifold. For some automakers, single-point injection was a stepping stone to the more complex multi-point system. Though not as precise as the systems that have followed, TBI meters fuel better than a carburetor and is less expensive and easier to service.

The simplest form of Electronic Fuel Injection (EFI), similar to the CPI (which is a single-point injection system) it looks like this:

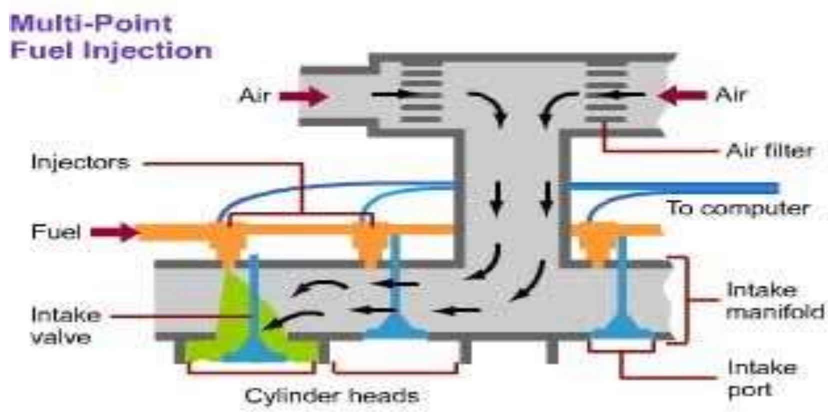


The design is the same as CPI meaning that the fuel is sprayed through a fuel injector to the intake manifold which then mixes it with air and drives it to each intake port of the engine. This is a popular setup in many modern vehicles.

Port or multi-point fuel injection

Multi-point fuel injection devotes a separate injector nozzle to each cylinder, right outside its intake port, which is why the system is sometimes called port injection. Shooting the fuel vapor this close to the intake port almost ensures that it will be drawn completely into the cylinder. The main advantage is that MPFI meters fuel more precisely than do TBI designs, better achieving the desired air/fuel ratio and improving all related aspects. Also, it virtually eliminates the possibility that fuel will condense or collect in the intake manifold. With TBI and carburetors, the intake manifold must be designed to conduct the engine's heat, a measure to vaporize liquid fuel. This is unnecessary on engines equipped with MPFI, so the intake manifold can be formed from lighter-weight material, even plastic. Incremental fuel economy improvements result. Also, where conventional metal intake manifolds must be located atop the engine to conduct heat, those used in MPFI can be placed more creatively, granting engineers design flexibility.

Similar to the previous one with the difference of having multiple fuel injectors.



In most cases, these injectors are placed in each intake port separately but some designs such as Toyota D4 simply use more than one fuel injectors in the intake manifold.

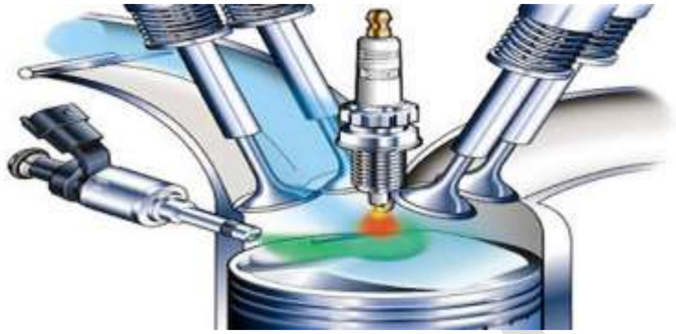
Sequential fuel injection

Sequential fuel injection, also called sequential port fuel injection (SPFI) or timed injection, is a type of multi-port injection. Though basic MPFI employs multiple injectors, they all spray their fuel at the same time or in groups. As a result, the fuel may "hang around" a port for as long as 150 milliseconds when the engine is idling. This may not seem like much, but it's enough of a shortcoming that engineers addressed it: Sequential fuel injection triggers each injector nozzle independently. Timed like spark plugs, they spray the fuel immediately before or as their intake valve opens. It seems a minor step, but efficiency and emissions improvements come in very small doses.

Direct injection

Direct injection takes the fuel injection concept about as far as it can go, injecting fuel directly into the combustion chambers, past the valves. More common in diesel engines, direct injection is starting to pop up in gasoline engine designs, sometimes called DIG for direct injection gasoline. Again, fuel metering is even more precise than in the other injection schemes, and the direct injection gives engineers yet another variable to influence precisely how combustion occurs in the cylinders. The science of engine design scrutinizes how the fuel/air mixture swirls around in the cylinders and how the explosion travels from the ignition point. Things such as the shape of cylinders and pistons; port and spark plug locations; timing, duration and intensity of the spark; and number of spark plugs per cylinder (more than one is possible) all affect how evenly and completely fuel combusts in a gasoline engine. Direct injection is another tool in that discipline, one that can be used in low-emissions lean-burn engines.

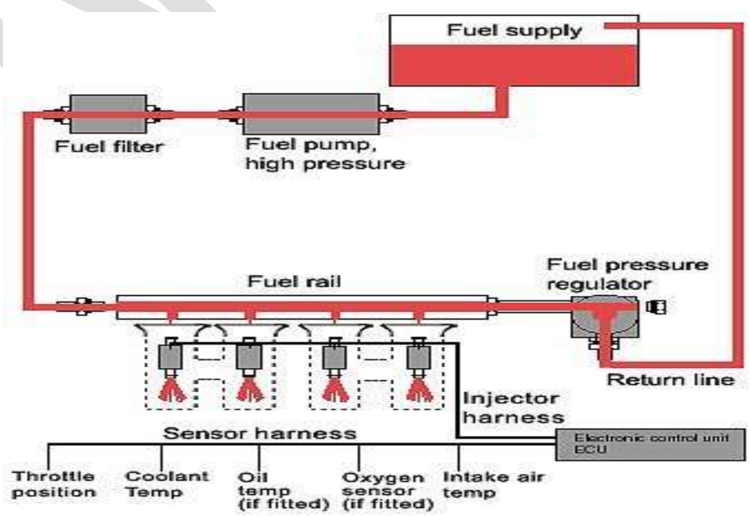
This is the most common used in modern vehicles.



As you can see in the above gasoline direct fuel injection engine, apart from the intake/exhaust valves and spark plug there is a fuel injector inside the cylinder's head. This is the direct fuel injection technology which currently is one of the most efficient designs in both performance and fuel consumption. The fuel is driven to the injectors through electronically controlled (by vehicle's ECU) rail and each fuel injector is electronically controlled to spray fuel at a defined pressure for a specified time. This way it can provide best results in the whole RPM range and solve problems such as cold start.

A similar technology is also available in diesel engines which uses a variant known as common rail.

In both cases, the setup looks like this:



Where the fuel pump drives the gas into the fuel rail and ECU controls each fuel injector's operation electronically.

Now that I have finished with this introduction to fuel systems, here are a couple of useful additional information…

BASIC COMPONENTS IN ELECTRONIC FUEL INJECTION SYSTEM

ELECTRICAL PUMP

An electric fuel pump is used on engines with fuel injection to pump fuel from the gas tank to the injectors. The pump must deliver the fuel under high pressure (typically 30 to 85 psi depending on the application) so the injectors can spray the fuel into the engine. Fuel pressure must be within specifications for the engine to run correctly. Too little pressure can starve the engine for fuel, causing it to run lean, misfire, hesitate or stall. Too much fuel pressure can cause the engine to run rough, waste fuel and pollute.

Electric fuel pumps are usually mounted inside the fuel tank, though some may be mounted outside the tank. Some vehicles may even have two fuel pumps (a transfer pump inside the tank, and a main fuel pump outside). The in-tank location helps muffle the buzzing noise produced by the electric pump motor, and immersing the pump in fuel helps lubricate and cool the pump motor. Driving with the fuel tank less than ¼ full can shorten pump life by causing it to run hot. It also increases the risk of momentarily starving the pump for fuel when cornering sharply, braking or accelerating. Running out of gas can sometimes damage an electric fuel pump by starving it for cooling and lubrication.

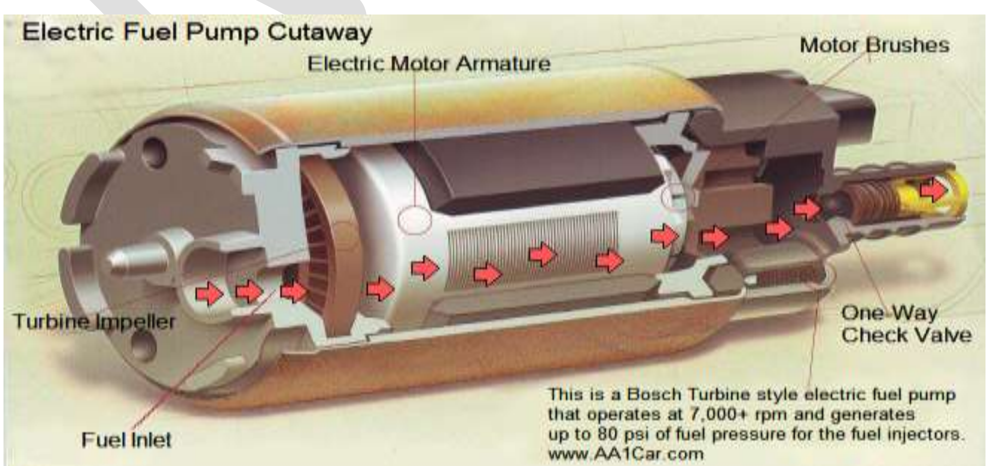
The pump is usually part of the sending unit assembly, that includes a float that sends an electrical signal to the fuel gauge on the instrument panel. If an electric fuel pump needs to be replaced, it can be replaced as a separate item or as a complete module assembly (which is more expensive but easier and less troublesome).

Electric fuel pumps come in a variety of designs. Some older applications use a positive displacement “roller cell” pump. This type uses rollers mounted on an offset disc that rotates inside a steel ring. Fuel is drawn into the spaces (cells) between the rollers and pushed along from the pump inlet to the outlet. Roller cell pumps typically spin about 3,000 rpm. This type of pump can generate very high pressure, and the flow rate tends to be constant. But the output comes in pulses, so a muffler is often mounted in the fuel line after the pump to dampen pressure pulses. A roller cell pump may also be mounted outside the fuel tank, and used with a second low pressure supply pump mounted inside the fuel tank.

Another type of positive-displacement pump is the “gerotor” pump. This design is similar to that of an oil pump, and uses an offset rotor to push fuel through the pump. A gerotor pump typically operates at around 4,000 rpm.

Another variation is the roller vane pump. Here, vanes are used instead of rollers to push fuel through the pump.

Most newer vehicles use a “turbine” style fuel pump. A turbine pump has an impeller ring attached to the motor. The blades in the impeller push the fuel through the pump as the impeller spins. This type of pump is not a positive-displacement pump, so it produces no pulsations, runs very smoothly and quietly. It operates at higher speeds, typically up to 7,000 rpm and draws less current than older style pumps. It is also less complicated to manufacture and is very durable. Some aftermarket pump supplies use this type of pump to replace the older designs.



NOTE: Replacement fuel pumps do NOT have to be the exact same type as the original. But they must be capable of generating the same operating pressure and delivering the same volume of fuel as the original. Using the wrong pump or substituting a different pump can cause drivability problems becauseo f variations in fuel pressure or flow.

How an Electric Fuel Pump Works

When the driver turns the ignition key on, the powertrain control module (PCM) energizes a relay that supplies voltage to the fuel pump. The motor inside the pump starts to spin and runs for a few seconds to build pressure in the fuel system. A timer in the PCM limits how long the pump will run until the engine starts.

Fuel is drawn into the pump through an inlet tube and mesh filter sock (which helps keep rust and dirt out of the pump). The fuel then exits the pump through a one-way check valve (which maintains residual pressure in the system when the pump is not running), and is pushed toward the engine through the fuel line and filter.

The fuel filter traps any rust, dirt or other solid contaminants that may have passed through the pump to prevent such particles from clogging the fuel injectors.

The fuel then flows to the fuel supply rail on the engine and is routed to the individual fuel injectors. A fuel pressure regulator on the fuel rail maintains fuel pressure, and routes excess fuel back to the tank.

On newer vehicles with returnless EFI systems, the fuel pressure regulator is located in the fuel tank and is part of the fuel pump module. There is no fuel return line from the engine back to the tank.

The fuel pump runs continuously once the engine starts, and continues to run as long as the engine is running and the ignition key is on. The pump may run at a constant speed, or it may operate at a variable speed depending on engine load and speed. If the engine stalls, the PCM will detect the loss of the RPM signal and turn the pump off.

Many vehicles (Fords, notably) also have an “inertia safety switch” that shuts off the fuel pump in the event of an accident. This is done to reduce the risk of fire should a fuel line be ruptured. A hard jolt trips the safety switch and opens the fuel pump circuit. This required manually resetting the safety switch after the incident by pressing the reset button on the switch.

On most older vehicles, the fuel pump runs at a constant speed. But on many newer applications, the pump speed is varied by the PCM to more closely match the engine’s fuel requirements.

Fuel Pump Failure

The fuel pump should last the life of the vehicle, but it may fail as a result of contamination inside the fuel tank (dirt or rust), fuel starvation (running out of gas), overheating (always driving with a low fuel level), low voltage (wiring problem), or overwork (trying to overcome a restriction caused by a plugged fuel filter). The harder a pump works, the hotter it runs and the more amps it pulls through its power circuit.

When a fuel pump fails, it often just quits without any warning. You are driving along fine one minute, then suddenly your engine stalls and you are stranded alongside the road. Or, you come out to start your car in the morning only to discover it cranks but won't start.

How can you tell if a bad fuel pump is causing your no-start problem? One way is to listen for pump noise after turning the ignition key on. No pump noise would tell you the pump is not running. Also, if you smell no unburned fuel fumes at the tailpipe when cranking the engine, that would tell you the engine is not getting any fuel. The fault may be a bad pump, or it could be a bad fuel pump relay, fuse or wiring connection.

On most vehicles, a failed fuel pump will not set any diagnostic trouble codes or turn on the Check Engine light (Malfunction Indicator Lamp). The engine will crank normally, and it will have spark, but it will not start because it is not getting any fuel.

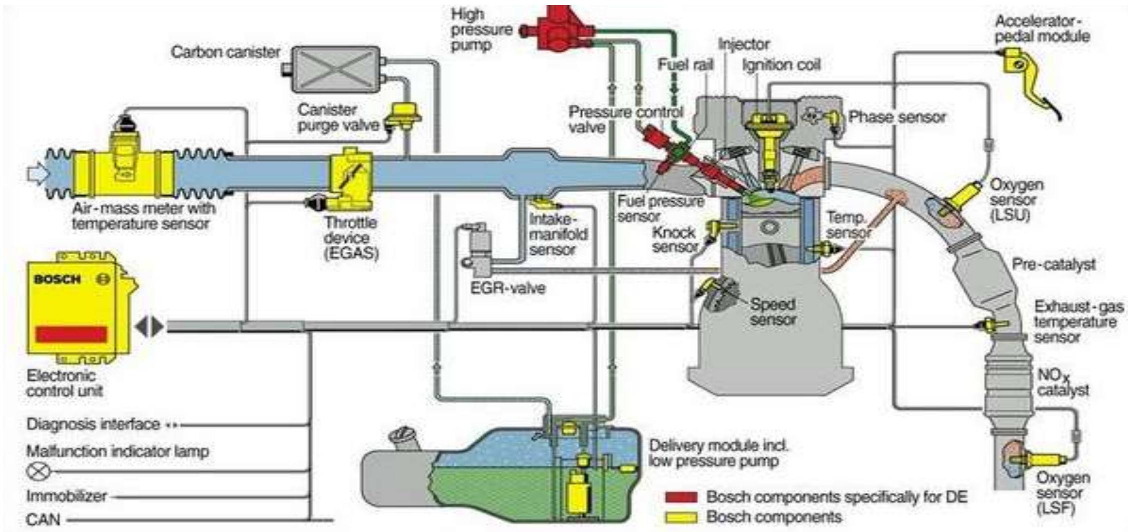
Most late model engines have a fuel pressure test fitting on the engine fuel rail. Attaching a fuel gauge to the schreader valve fitting will quickly reveal whether or not the pump is generating any fuel pressure. On engines that do not have a fuel pressure test fitting, a fuel pressure gauge can be teed into the fuel line where it connects to the fuel rail. If fuel pressure is zero, the pump is not working. If fuel pressure is less than specifications, further diagnosis will be needed to determine why. The problem may be a faulty fuel pressure regulator, a clogged fuel line or filter, or an electrical fault in the fuel pump wiring circuit.

Another way to tell if a no-start is due to no fuel is to spray some aerosol starting fluid into the throttle. If the engine starts, runs a few seconds, then dies, it has spark and compression but is not getting any fuel from the fuel pump.

Electric Fuel Pump Replacement

A fuel pump can be expensive to replace. A new electric fuel pump may cost from $100 to $300 or more depending on the application, and whether you are buying just the pump or the complete fuel pump module assembly. The labor to replace a tank-mounted pump can also add $200 or more to the repair bill. So you want to make sure a bad fuel pump is the real problem and not something else before you replace the pump.

ELECTRONICALLY CONTROLLED FUEL SUPPLY SYSTEM



The fuel supply system uses two fuel pumps – a conventional electrical fuel pressure pump (in the past dubbed a high pressure pump but now referred to in this system as a low pressure pump) and a mechanically-driven high pressure pump. The low pressure pump works at pressures of 0.3 – 0.5 Mpa while the high pressure pumps boost this very substantially to 5 – 12 Mpa. The high pressure fuel is stored in the fuel rail that feeds the injectors. The fuel rail is made sufficiently large that pressure fluctuations within it are minimized as each injector opens. The pressure of the fuel in the injector supply rail is controlled by an electronically-controlled bypass valve that can divert fuel from the high pressure pump outlet back to its inlet. The fuel bypass valve is varied in flow by being pulse-width modulated by the Electronic Control Unit (ECU). A fuel pressure sensor is used to monitor fuel rail pressure. This diagram shows a cross-sectional view of an injector. Compared with a conventional port fuel injection system, the fuel injectors must be capable of working with huge fuel pressures and also injecting large amounts of fuel in very short periods. The reason for the much reduced time in which the injection can be completed is due to the fact that all the injection must sometimes occur within just a portion of the induction stroke. Conventional port fuel injectors have two complete rotations of the crankshaft in which to inject the fuel charge – at an engine speed of 6000 rpm, this corresponds to 20 milliseconds. However, in some modes, direct fuel injectors have only 5 milliseconds in which to inject the full-load fuel. The fuel requirements at idle can drop the opening time to just 0.4 milliseconds. Direct injection fuel droplets are on average only one-fifth the droplet size of traditional injectors and one-third the diameter of a human hair. The very lean air/fuel ratios at which direct injection systems can operate results in the production of large quantities of oxides of nitrogen (Nox). As a result, direct injected cars require both a primary catalytic converter fitted close to the engine, and also a main catalytic converter – incorporating a Nox accumulator – that is fitted further downstream.

ELECTRONIC IGNITION SYSTEM

"From a little spark may burst a flame" by Dante Alighieri, Rightly said that a spark is required to start a flame and in automobile since there is a conversion of chemical energy (i.e. air-fuel mixture) into mechanical energy i.e. (crankshaft rotation) spark is essential which is responsible for the combustion, but from where does this spark comes? How does the timing of spark and prepared air-fuel mixture is managed? Let's just dig it out.

In internal combustion engine, combustion is a continuous cycle and occurs thousands time in a minute so a effective and accurate source of ignition is required. The idea of spark ignition came from a toy electric pistol that used electric spark to ignite a mixture of hydrogen and air to shoot a cork.

Electronic ignition system is the type of ignition system that uses electronic circuit,usually by transistors controlled by sensors to generate electric pulses which in turn generate better spark that can even burn the lean mixture and provide better economy and lower emission.

Why Electronic Ignition System?

Various types of ignition systems were used lately that are

1. Glow plug ignition system,
2. Magneto ignition system
3. Electric coil or Battery ignition system,

But all these systems have their own limitations that are:

Glow plug ignition system is the oldest of all and is obsolete because of its many limitations- Glow plug ignition system has a problem of causing uncontrolled combustion due to the use of electrode as a ignition source, which is solved later after the introduction of Magneto ignition system in which electrodes are replaced by spark plug. Unlike magneto ignition, Glow plug produces high exhaust emission due to the incomplete combustion.

Magneto ignition system: It is the system introduce to overcome the limitations of old ignition systems, but it has its own limitations-

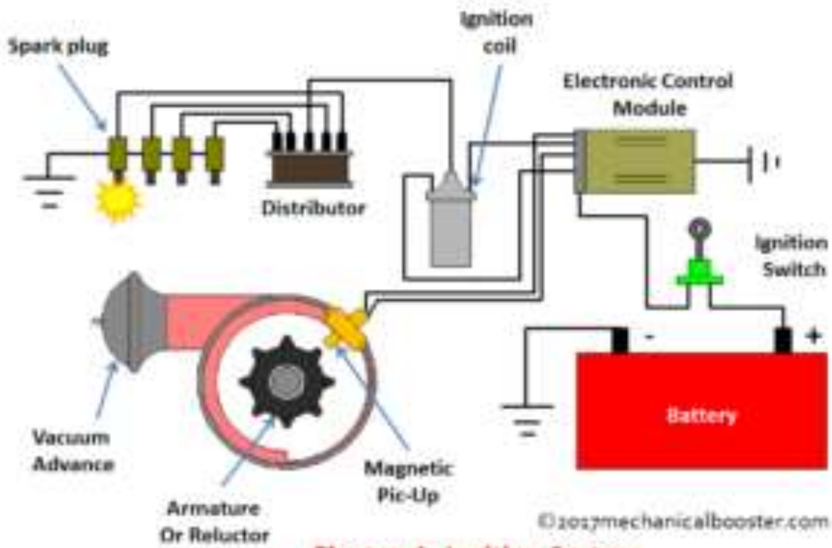
- It depends on the engine speed, so shows starting problem due to low speed at the starting of the engine, which is later solved with the introduction of Battery coil ignition system in which battery becomes the energy source for the system.
- Expensive than electric coil ignition system.
- Wear and tear is more than battery coil ignition because of greater number of mechanical moving parts than battery coil system.
- Can cause misfire due to leakage.

Electric coil ignition or Battery ignition system – System is the latest of all above and is being used from long time due to its better efficiency and accuracy but it also shows some limitations-

- Less efficient with the high speed engines
- High maintenance required due to mechanical and electrical wear of the contact breaker points

So, Since in the modern automobile new technologies are introduced and it is found that use of sensors and electronic component gives more effective and accurate outputs than that of mechanical components so the use of sensors with electronic controlled unit becomes essential to fulfill the needs of modern high power and high speed automobiles or hyper series of automobiles, so to fulfill the need for high performance, high mileage and greater reliability has led to the development of Electronic ignition system.

Main Components



Electronic Ignition System

1. Battery

It is the powerhouse of the ignition system as it supplies the necessary energy to the ignition system.same as battery coil ignition system.

2. Ignition Switch

it is the switch used in ignition system which governs the ON and OFF of the system ,same as the battery coil ignition system.

3. Ignition Control Module or Control Unit of Ignition System

It is the brain or programmed instruction given to the ignition system which monitors and control the timing and intensity of the spark automatically. It is the device that receives voltage signals from the armature and set the primary coil to ON and OFF ,it can be placed separately outside the distributor or can be place in electronic control unit box of the vehicle.

4. Armature

Contact breaker points of battery ignition system is replaced by an armature which consists of a reluctor with teeth (the rotating part), vacuum advance and a pickup coil(to catch the voltage signals),Electronic module receives the voltage signals from the armature in order to make and break the circuit, which in turn sets the timing of the distributor to accurately distribute current to the spark plugs.

5. Ignition Coil

Same as the battery ignition coil system ignition coil is used in electronic ignition system to produce high voltage to the spark plug.

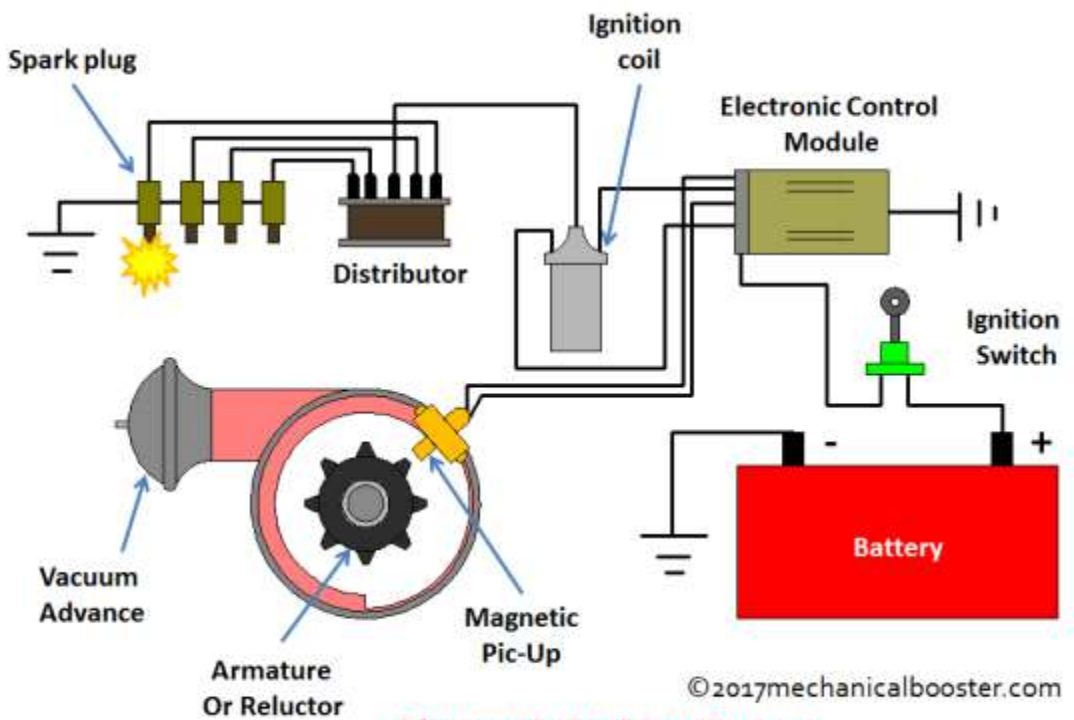
6. Ignition Distributor

As the name indicates it is the device use to distribute the current to the spark plugs of the multi cylinder engine.

7. Spark Plug

Spark plug is used to generate spark inside the cylinder.

Working of Electronic Ignition System



Electronic Ignition System

- To understand the working of the electronic ignition system let's consider above figure in which all the components mentioned above are connected in their working order.
- When the driver switch ON the ignition switch in order to start a vehicle the current starts flowing from the battery through the ignition switch to the coil primary winding, which in turn starts the armature pickup coil to receives and send the voltage signals from the armature to the ignition module.
- When the tooth of the rotating reluctor comes in front of the pickup coil as shown in the fig the voltage signal from pickup coil is sent to the electronic module which in turn senses the signal and stops the current to flow from primary coil.
- When the tooth of the rotating reluctor goes away from the pickup coil, the change in

voltage signal is sent by pickup coil to the ignition module and a timing circuit inside ignition module turns ON the current flow.

- A magnetic field is generated in the ignition coil due to this continuous make and break of the circuit which induced an EMF in secondary winding which increases the voltage upto 50000 Volts.
- This high voltage is then sent to distributor ,which has the rotating rotor and distributor points which is set according to the ignition timing.
- When the rotor comes in front of any of those distributor points the jumping of voltage through the air gap from the rotor to the distributor point takes place which is then sent to the adjacent spark plug terminal through the high tension cable and a voltage difference is generated between the central electrode and ground electrode which is responsible for generating a spark at the tip of the spark plug and finally the combustion takes place.

Application

Electronic ignition system is used in modern and hyper cars like Audi A4, Mahindra XUV-500, etc.and bikes like ktm duke 390cc,Ducati super sports etc. to meet the high reliability and performance need . It is also used in aircrafts engine due to its better reliability and less maintenance

SPARK TIMING CONTROL

The ignition system on your car has to work in perfect concert with the rest of the engine. The goal is to ignite the fuel at exactly the right time so that the expanding gases can do the maximum amount of work. If the ignition system fires at the wrong time, power will fall and gas consumption and emissions can increase.

When the fuel/air mixture in the cylinder burns, the temperature rises and the fuel is converted to exhaust gas. This transformation causes the pressure in the cylinder to increase dramatically and forces the piston down.

In order to get the most torque and power from the engine, the goal is to maximize the pressure in the cylinder during the **power stroke**. Maximizing pressure will also produce the best engine efficiency, which translates directly into better mileage. The timing of the spark is critical to success.

There is a small delay from the time of the spark to the time when the fuel/air mixture is all burning and the pressure in the cylinder reaches its maximum. If the spark occurs right when the piston reaches the top of the compression stroke, the piston will have already moved down part of the way into its power stroke before the gases in the cylinder have reached their highest pressures.

To make the best use of the fuel, **the spark should occur before the piston reaches the top of the compression stroke**, so by the time the piston starts down into its power stroke the pressures are high enough to start producing useful work.

Work = Force * Distance

In a cylinder:

- **Force** = Pressure * Area of the piston
- **Distance** = Stroke length

So when we're talking about a cylinder, **work = pressure * piston area * stroke length**. And because the length of the stroke and the area of the piston are fixed, the only way to maximize work is by increasing pressure.

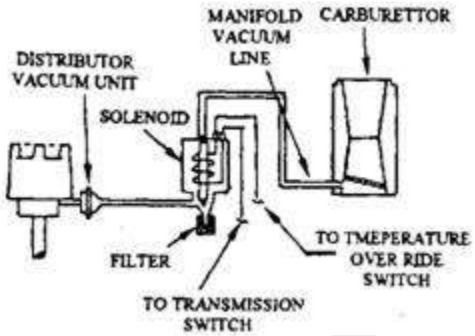
The timing of the spark is important, and the timing can either be **advanced** or **retarded** depending on conditions.

The time that the fuel takes to burn is roughly constant. But the speed of the pistons increases as the engine speed increases. This means that the faster the engine goes, the earlier the spark has to occur. This is called **spark advance**: The faster the engine speed, the more advance is required.

Other goals, like **minimizing emissions**, take priority when maximum power is not required. For instance, by retarding the spark timing (moving the spark closer to the top of the compression stroke), maximum cylinder pressures and temperatures can be reduced. Lowering temperatures helps reduce the formation of nitrogen oxides (NO_x), which are a regulated pollutant. Retarding the timing may also eliminate knocking; some cars that have knock sensors will do this automatically.

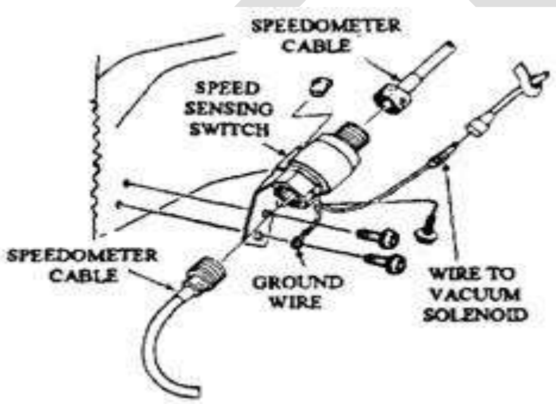
Speed-and Transmission-controlled Timing.

These systems prevent any distributor vacuum advance mechanism to act when the car is in low gear or is travelling slowly. A solenoid controls the application of 151arburetor vacuum to the advance mechanism (Fig. 17.51). A switch reacts to the cars operating conditions and accordingly controls the current flow in the solenoid winding. In a manual transmission, the control switch senses shift lever position and in an automatic transmission the switch normally works from hydraulic fluid pressure.



Transmission-controlled spark system (simplified).

A speed-sensing switch may be connected to the vehicle speedometer cable (Fig. 17.52). The switch signals an electronic control module when the vehicle is moving below a certain speed. The module activates a solenoid, which controls engine vacuum at the distributor.

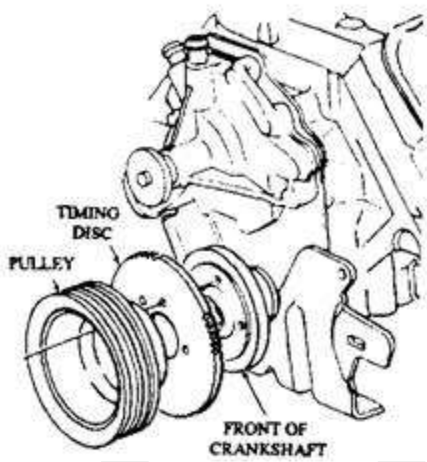


Speed-sensing switch.

Both vacuum-delay systems and speed- and transmission-controlled systems generally use an engine temperature bypass, which permits normal vacuum advance at high and low engine temperatures. Before March, 1973, some system used an ambient temperature override switch, which was mostly discontinued. Later temperature override systems sense coolant temperature or under-hood temperature. The system using these principles is known by many different trade names, and is all somewhat different.

Electronically Controlled Timing

The ignition system must perform accurately to meet emission standards and fuel mileage requirements. Centrifugal and vacuum advance devices often cannot react fast to changes in engine operating conditions. The computer-controlled ignition systems could attain the necessary accuracy.



Crankshaft position signals can be tanken directly from the crankshaft.

In computer controlled systems, various sensors send signals to an electronic control module. These signals may include information on coolant temperature, atmospheric pressure and temperature, throttle position and rate of change of position, and crankshaft position. Ics in the control module interpret this information and determine the proper ignition timing for each individual spark. The latest systems work with the manufacturer's standard solid-state ignition systems. Some modifications, however, are incorporated to the standard ignition, because it no longer has to control spark timing, but many parts remain the same. Two types of computer controlled ignition systems are in use. One type uses distributor shaft rotation for sending a crankshaft position signal to the control module. The other type receives crankshaft position information from a sensor installed near the crankshaft (Fig. 17.53). The sensor, in this type, senses the rotation of a special disc fixed to the crankshaft. When signals are taken directly from the crankshaft, they are more accurate than those taken from the distributor shaft. The gears or chain driving mechanism for the camshaft and the gears driving mechanism for the distributor shaft have tolerances. Although these tolerances are actually very small, but can combine to produce a significant difference between crankshaft position and ignition timing.

The electronic timing-regulation function of all the practical systems is similar, but the electronics are fundamentally different. The Electronic Lean-Burn (ELB) system of Chrysler uses an analogue computer, while General Motor Micro-processed Sensing and Automatic Regulation (MISAR) and Ford Electronic Engine Control (EEC) use digital microprocessors. In this kind of application, a digital computer can instantly alter timing, for example, from 1 to 65 degrees. An analogue computer has to carry out far more calculations to make such an adjustment. Since an electronic spark advance adjustment takes only few milliseconds, this fact is not practically significant in the automobile. However a digital system is more flexible to build than an analogue system.

MODULE IV
SAFETY AND COMFORT

INTRODUCTION

Automobile safety is the study and practice of design, construction, equipment and regulation to minimize the occurrence and consequences of traffic collisions. Road traffic safety more broadly includes roadway design.

One of the first formal academic studies into improving vehicle safety was by Cornell Aeronautical Laboratory of Buffalo, New York. The main conclusion of their extensive report is the crucial importance of seat belts and padded dashboards.[1] However, the primary vector of traffic-related deaths and injuries is the disproportionate mass and velocity of an automobile compared to that of the predominant victim, the pedestrian.

According to the World Health Organization (WHO), 80% of cars sold in the world are not compliant with main safety standards. Only 40 countries have adopted the full set of the seven most important regulations for car safety.

In the United States a pedestrian is injured by an automobile every 8 minutes, and are 1.5 times more likely than a vehicle's occupants to be killed in an automobile crash per outing.

Improvements in roadway and automobile designs have steadily reduced injury and death rates in all first world countries. Nevertheless, auto collisions are the leading cause of injury-related deaths, an estimated total of 1.2 million in 2004, or 25% of the total from all causes. Of those killed by autos, nearly two-thirds are pedestrians.[4] Risk compensation theory has been used in arguments against safety devices, regulations and modifications of vehicles despite the efficacy of saving lives.

Coalitions to promote road and automobile safety, such as Together for Safer Roads (TSR), brings together global private sector companies, across industries, to collaborate on improving road safety. TSR brings together members' knowledge, data, technology, and global networks to focus on five road safety areas that will make impact globally and within local communities.

The rising trend of Autonomous Things is largely driven by the move towards the Autonomous car, that both addresses the main existing safety issues and creates new issues. The autonomous car is expected to be safer than existing vehicles, by eliminating the single most dangerous element - the driver. The Center for Internet and Society at Stanford Law School claims that "Some ninety percent of motor vehicle crashes are caused at least in part by human error".But while safety standards like the ISO 26262 specify the required safety, it is still a burden on the industry to demonstrate acceptable safety.

Occupational driving

Work-related roadway crashes are the leading cause of death from traumatic injuries in the U.S. workplace. They accounted for nearly 12,000 deaths between 1992 and 2000. Deaths and injuries from these roadway crashes result in increased costs to employers and lost productivity in addition to their toll in human suffering.[8] Truck drivers tend to endure higher fatality rates than workers in other occupations, but concerns about motor vehicle safety in the workplace are not limited to those surrounding the operation of large trucks. Workers outside the motor carrier industry routinely operate company-owned vehicles for deliveries, sales and repair calls, client visits etc. In these instances, the employer providing the vehicle generally plays a major role in setting safety, maintenance, and training policy.[8] As in non-occupational driving, young drivers are especially at risk. In the workplace, 45% of all fatal injuries to workers under age 18 between 1992 and 2000 in the United States resulted from transportation incidents.[9]

Active and passive safety

The terms "active" and "passive" are simple but important terms in the world of automotive safety. "Active safety" is used to refer to technology assisting in the prevention of a crash and "passive safety" to components of the vehicle (primarily airbags, seatbelts and the physical structure of the vehicle) that help to protect occupants during a crash.[10][11]

Crash avoidance

Crash avoidance systems and devices help the driver — and, increasingly, help the vehicle itself — to avoid a collision. This category includes:

- The vehicle's headlamps, reflectors, and other lights and signals
- The vehicle's mirrors
- The vehicle's brakes, steering, and suspension systems

Driver assistance

A subset of crash avoidance is *driver assistance* systems, which help the driver to detect obstacles and to control the vehicle. Driver assistance systems include:

- *DADS : Driver Alertness Detection System* [12] System to prevent crashes caused by fatigue
- Automatic Braking systems to prevent or reduce the severity of collision.
- Infrared night vision systems to increase seeing distance beyond headlamp range
- Adaptive headlamps control the direction and range of the headlight beams to light the

driver's way through curves and maximize seeing distance without partially blinding other drivers

- Reverse backup sensors, which alert drivers to difficult-to-see objects in their path when reversing
- Backup camera
- Adaptive cruise control which maintains a safe distance from the vehicle in front
- Lane departure warning systems to alert the driver of an unintended departure from the intended lane of travel
- Tire pressure monitoring systems or Deflation Detection Systems
- Traction control systems which restore traction if driven wheels begin to spin
- Electronic Stability Control, which intervenes to avert an impending loss of control
- Anti-lock braking systems
- Electronic brake force distribution systems
- Emergency brake assist systems
- Cornering Brake Control systems
- Assured Clear Distance Ahead measurement and speed governance systems
- Pre crash system
- Automated parking system
- Obstacle detection sensor systems notify a driver how close their vehicle is to an object - usually providing a distance measurement, to the inch, as to how close they are.

Crashworthiness

Passive safety devices being put to the test in a Mazda CX-5 crossover.

Ferrari F430 steering wheel with airbag

Crashworthy systems and devices prevent or reduce the severity of injuries when a crash is imminent or actually happening. Much research is carried out using anthropomorphic crash test dummies.

- Seatbelts limit the forward motion of an occupant, stretch to absorb energy, to lengthen the time of the occupant's negative acceleration in a crash, reducing the loading on the occupants body. They prevent occupants being ejected from the vehicle and ensure that they are in the correct position for the operation of the airbags.
- Airbags inflate to cushion the impact of a vehicle occupant with various parts of the vehicle's interior. The most important being the prevention of direct impact of the driver's head with the steering wheel and door pillar.
- Laminated windshields remain in one piece when impacted, preventing penetration of unbelted occupants' heads and maintaining a minimal but adequate transparency for control of the car immediately following a collision. It is also a bonded structural part of the safety cell. Tempered glass side and rear windows break into granules with minimally sharp edges, rather than splintering into jagged fragments as ordinary glass does.
- Crumple zones absorb and dissipate the force of a collision, displacing and diverting it away from the passenger compartment and reducing the negative acceleration impact force on the vehicle occupants. Vehicles will include a front, rear and maybe side crumple zones (like Volvo SIPS) too.
- Safety Cell - the passenger compartment is reinforced with high strength materials, at places subject to high loads in a crash, in order to maintain a survival space for the vehicle occupants.

- Side impact protection beams, also called anti-intrusion bars.
- Collapsible universally jointed steering columns, along with steering wheel airbag. The steering system is mounted behind the front axle - behind and protected by, the front crumple zone. This reduces the risk and severity of driver impact or even impalement on the column in a frontal crash.
- Pedestrian protection systems.
- Padding of the instrument panel and other interior parts, on the vehicle in areas likely to be struck by the occupants during a crash, and the careful placement of mounting brackets away from those areas.
- Cargo barriers are sometimes fitted to provide a physical barrier between passenger and cargo compartments in vehicles such as SUVs, station wagons and vans. These help prevent injuries caused by occupants being struck by unsecured cargo. They can also help prevent collapse of the roof in the event of a vehicle rollover.

Post-crash survivability

Post-crash survivability is the chance that drivers and passengers survive a crash after it occurs. Technology such as Advanced Automatic Collision Notification can automatically place calls to emergency services and send information about a vehicle collision.

Pedestrian safety

1974 Mini Clubman Experimental Safety Vehicle featuring a "pedestrian-friendly" front end.

Automobiles are much more dangerous to pedestrians than they are to drivers and passengers. Two-thirds of 1.3 million yearly auto related deaths are pedestrians. Since at least the early 1970s, attention has also been given to vehicle design regarding the safety of pedestrians in car-pedestrian collisions. Proposals in Europe would require cars sold there to have a minimum/maximum hood (bonnet) height. From 2006 the use of "bull bars", a fashion on 4x4sand SUVs, became illegal in the European Union, after having been banned on all new cars in 2002.

Conspicuity

Lights and reflectors

Vehicles are equipped with a variety of lights and reflectors to mark their presence, position, width, length, and direction of travel as well as to convey the driver's intent and actions to other drivers. These include the vehicle's headlamps, front and rear position lamps, side marker lights and reflectors, turn signals, stop (brake) lamps, and reversing lamps. School buses and Semi-trailer trucks in North America are required to bear retro reflective strips outlining their side and rear perimeters for greater conspicuity at night.

Daytime running lamps have been required in Nordic countries since the mid-1970s, in Canada since 1990, and throughout the European Union since 7 February 2011.

Vehicle colour

A 2004 essay on the relation between car colour and safety stated that no previous studies had been scientifically conclusive.[18] Since then, a Swedish study found that pink cars are involved in the fewest and black cars are involved in the most crashes (Land transport NZ 2005). In Auckland New Zealand, a study found that there was a significantly lower rate of serious injury in silver cars, with higher rates in brown, black, and green cars. The Vehicle Colour Study, conducted by Monash University Accident Research Centre (MUARC) and published in 2007, analysed 855,258 crashes that occurring between 1987 and 2004 in the Australian states of Victoria and Western Australia that resulted in injury or in a vehicle being towed away. The study analysed risk by light condition. It found that in daylight black cars were 12% more likely than white to be involved in a collision, followed by grey cars at 11%, silver cars at 10%, and red and blue cars at 7%, with no other colours found to be significantly more or less risky than white. At dawn or dusk the risk ratio for black cars jumped to 47% more likely than white, and that for silver cars to 15%. In the hours of darkness only red and silver cars were found to be significantly more risky than white, by 10% and 8% respectively.

Unused safety features

Many different inventions and ideas which may or may not have been practical about auto safety have been put forward but never made it to a production car. Such items include the driver seat in the middle (to give the person a better view) (the exception being the McLaren F1 sports car), rear-facing seats (except for infant car seats), and control stick steering.

HISTORY

18th century–19th century

Automobile safety may have become an issue almost from the beginning of mechanised road vehicle development. The second steam-powered "Fardier" (artillery tractor), created by Nicolas-Joseph Cugnot in 1771, is reported by some to have crashed into a wall during its demonstration run. However, according to Georges Ageon, the earliest mention of this occurrence dates from 1801 and it does not feature in contemporary accounts. One of the earliest recorded automobile fatalities was Mary Ward, on August 31, 1869 in Parsonstown, Ireland.[22]

1920s

In 1922, the Duesenburg Model A became the first car to have four-wheel hydraulic brakes.

1930s

In 1930, safety glass became standard on all Ford cars. In the 1930s, plastic surgeon Claire L. Straith and physician C. J. Strickland advocated the use of seat belts and padded dashboards. Strickland founded the Automobile Safety League of America.

In 1934, GM performed the first barrier crash test.

In 1936, the Hudson Terraplane came with the first back-up brake system. Should the hydraulic brakes fail, the brake pedal would activate a set of mechanical brakes for the back wheels.

In 1937, Chrysler, Plymouth, DeSoto, and Dodge added such items as a flat, smooth dash with recessed controls, rounded door handles, a windshield wiper control made of rubber, and the back of the front seat heavily padded to provide protection for rear passengers.

1940s

In 1942, Hugh DeHaven published the classic *Mechanical analysis of survival in falls from heights of fifty to one hundred and fifty feet*.

In 1947 the American Tucker was built with the world's first padded dashboard. It also came with middle headlight that turned with the steering wheel, a front steel bulkhead, and a front safety chamber.

In 1949 SAAB incorporated aircraft safety thinking into automobiles making the Saab 92 the first production SAAB car with a safety cage.

Also in 1949, the Chrysler Crown Imperial was the first car to come with standard disc brakes.

1950s

In 1955 a USAF surgeon who advised the US Surgeon General wrote an article on how to make cars safer for those riding in it. Aside from the usual safety features, such as seat belts and padded dash boards, bumper shocks were introduced.

In 1956, Ford tried unsuccessfully to interest Americans in purchasing safer cars with their Lifeguard safety package. (Its attempt nevertheless earns Ford *Motor Trend*'s "Car of the Year" award for 1956.)

In 1958, the United Nations established the World Forum for Harmonization of Vehicle Regulations, an international standards body advancing auto safety. Many of the most life saving safety innovations, like seat belts and roll cage construction were brought to market under its auspices. That same year, Volvo engineer Nils Bohlin invented and patented the three-point lap and shoulder seat belt, which became standard equipment on all Volvo cars in 1959. Over the next several decades, three-point safety belts were gradually mandated in all vehicles by regulators throughout the industrialized world.

In 1959, American Motors Corporation offered the first optional head rests for the front seat. Also in 1959, the Cadillac Cyclone concept by Harley Earl had "a radar-based crash-avoidance system" located in the on the nose cones of the vehicle that would make audible and visual signals to the driver if there were obstacles in the vehicle's path.[45]

1960s

Effective on new passenger cars sold in the United States after January 1, 1964. front outboard lap belts were required.

On September 9, 1966, the National Traffic and Motor Vehicle Safety Act became law in the U.S., the first mandatory federal safety standards for motor vehicles.

Effective in 1966, US-market passenger cars were required to be equipped with padded instrument panels, front and rear outboard lap belts, and white reverse (backup) lamps.

In 1966, the U.S. established the United States Department of Transportation (DOT) with automobile safety as one of its purposes. The National Transportation Safety Board (NTSB) was created as an independent organization on April 1, 1967, but was reliant on the DOT for administration and funding. However, in 1975 the organization was made completely independent by the Independent Safety Board Act (in P.L. 93-633; 49 U.S.C. 1901).

In 1967, equipment specifications by such major fleet purchasers as the City and County of Los Angeles, California encouraged the voluntary installation in most new cars sold in the US of safety devices, systems, and design features including:

- Elimination of protruding knobs and controls in passenger compartment
- Additional padding on the instrument panel and other interior surfaces

- Mounting points for front outboard shoulder belts
- Four-way hazard flashers
- A uniform P-R-N-D-L gear sequence for automatic transmission gear selectors
- Dual-circuit brake hydraulic systems

In 1968, the precursor agency to the US National Highway Traffic Safety Administration's first Federal Motor Vehicle Safety Standard stook effect. These required shoulder belts for left and right front-seat vehicle occupants, side marker lights, collapsible steering columns, and other safety features. 1969 saw the addition of head restraints for front outboard passengers, addressing the problem of whiplash in rear-end collisions. These safety requirements did not apply to vehicles classified as "commercial," such as light-duty pickup trucks. Thus manufacturers did not always include such hardware in these vehicles, even though many did passenger-car duty.

Volvo developed the first rear-facing child seat in 1964 and introduced its own booster seat in 1978.

Consumer information label for a vehicle with at least one US NCAP star rating

1970s

In 1974, GM offered driver and passenger airbags as optional equipment on large Cadillacs, Buicks, and Olds mobiles.

In 1979 NHTSA began crash-testing popular cars and publishing the results, to inform consumers and encourage manufacturers to improve the safety of their vehicles. Initially, the US NCAP (New Car Assessment Program) crash tests examined compliance with the occupant-protection provisions of FMVSS 208. Over the subsequent years, this NHTSA program was gradually expanded in scope.

1980s

In 1984 New York State passed the first U.S. law requiring seat belt use in passenger cars. Seat belt laws have since been adopted by 49 states (New Hampshire has not). NHTSA estimates the resulting increased seat belt use saves 10,000 per year in the United States.

In 1986 the central 3rd brake light was mandated in North America with most of the world following with similar standards in automotive lighting.

In 1989, companies in Israel implemented Advanced Brake Warning systems, where the driver would be alerted as to how hard the driver in front of them was pressing on their brakes. This has yet to be implemented into mainstream Europe or America.

Airbags were first installed in production vehicles in the 1980s as standard equipment instead of an option as was done in the mid 1970s (such as the Oldsmobile Toronado in 1974· In 1981, airbags were an available option on the Mercedes-Benz W126 (S-Class). In 1987, the Porsche 944 Turbo became the first car to have driver and passenger airbags as standard equipment, and airbags were offered as an available option on the 944 and 944S. The first airbag was also installed in a Japanese car, the Honda Legend, in 1987. In 1988, Chrysler was the first United States company to install standard driver's side air bags, in six of its passenger models. In 1989, Chrysler became the first U.S. auto manufacturer to install driver-side air bags in all its domestic-built automobiles.

1990s

In 1995 the Insurance Institute for Highway Safety (IIHS) began frontal offset crash tests. Also in the same year, Volvo introduced the world's first car with side airbags: the 850.

In 1996, the European New Car Assessment Programme (Euro NCAP) was established to test new vehicles' safety performance and publish the results for vehicle shoppers' information. The NHTSA crash tests are presently operated and published as the U.S. branch of the international NCAP programme.

2000s

In 2000 the NHTSA released a regulation making trunk releases mandatory for new cars by September of the following year due, in part, to the lobbying efforts of Janette Fennell.[58]

In 2003 the IIHS began conducting side impact crash tests. In 2004 NHTSA released new tests designed to test the rollover risk of new cars and SUVs. Only the Mazda RX-8 got a 5-star rating.

In 2009 Citroën became the first manufacturer to feature "Snowmotion", an Intelligent Anti Skid system developed in conjunction with Bosch, which gives drivers a level of control in extreme ice or snow conditions similar to a 4x4

In 2009 NHTSA upgraded its roof-crush standard for vehicles weighing 6000 pounds or less. The new standard increased the crush load requirement from 1.5 to 3 times the vehicle's curb weight.

2010s

Form 2011, new cars should have brake assist system in EU, according to The Pedestrian Protection Regulation (EC) 78/2009.

Starting in 2012, all cars under 10,000 lbs. sold in the USA are required to have Electronic Stability Control.

In 2014, ESP (Electronic Stability Program) and TPMS became mandatory in European Union, with also the driver seat belt reminder and the ISOFIX system, under General Safety Regulation (EC) No 661/2009.

In 2015, recognizing that safer roads are a shared responsibility, Together for Safer Roads (TSR) was formally launched to align the private sector's road safety efforts with the United Nations Decade of Action for Road Safety.

In 2016 and 2017, ABS become mandatory on motorcycles in the EU.

In 2018, e-call became mandatory in the EU, and reverse camera in the US.

SAFETY TRENDS

Despite technological advances, about 34,000 people die every year in the U.S. Although the fatality rates per vehicle registered and per vehicle distance travelled have steadily decreased since the advent of significant vehicle and driver regulation, the raw number of fatalities generally increases as a function of rising population and more vehicles on the road. However, sharp rises in the price of fuel and related driver behavioural changes are reducing 2007-8 highway fatalities in the U.S. to below the 1961 fatality count.[68] Litigation has been central in the struggle to mandate safer cars.

Safety is also a big issue with around 25,500 fatalities yearly in the European Union (including UK).

International comparison

In 1996, the U.S. had about 2 deaths per 10,000 motor vehicles, compared to 1.9 in Germany, 2.6 in France, and 1.5 in the UK.[70] In 1998, there were 3,421 fatal crashes in the UK, the fewest since 1926;[71] in 2010 this number was further reduced to 1,857 and was attributed to the 2009–

2010 scrappage scheme.

The sizable traffic safety lead enjoyed by the USA since the 1960s had narrowed significantly by 2002, with the US improvement percentages lagging in 16th place behind those of Australia, Austria, Canada, Denmark, Finland, Germany, United Kingdom, Iceland, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Sweden, and Switzerland in terms of deaths per thousand vehicles, while in terms of deaths per 100 million vehicle miles travelled, the USA had dropped from first place to tenth place.

US specificities

Government-collected data, such as that from the U.S. Fatality Analysis Reporting System, show other countries achieving safety performance improvements over time greater than those achieved in the U.S.

	1979 Fatalities	*2002 Fatalities*	*Percent Change*
United States	51,093	42,815	-16.2%
United Kingdom	6,352	3,431	-46.0%
Canada	5,863	2,936	-49.9%
Australia	3,508	1,715	-51.1%

Research on the trends in use of heavy vehicles indicate that a significant difference between the U.S. and other countries is the relatively high prevalence of pickup trucks and SUVs in the U.S. A 2003 study by the U.S. Transportation Research Board found that SUVs and pickup trucks are significantly less safe than passenger cars, that imported-brand vehicles tend to be safer than American-brand vehicles, and that the size and weight of a vehicle has a significantly smaller effect on safety than the quality of the vehicle's engineering.[74] The level of large commercial truck traffic has substantially increased since the 1960s, while highway capacity has not kept pace with the increase in large commercial truck traffic on U.S. highways. However, other factors exert significant influence; Canada has lower roadway death and injury rates despite a vehicle mix comparable to that of the U.S. Nevertheless, the widespread use of truck-based vehicles as passenger carriers is correlated with roadway deaths and injuries not only directly by dint of vehicular safety performance *per se*, but also indirectly through the relatively low fuel costs that facilitate the use of such vehicles in North America; motor vehicle fatalities decline as fuel prices increase.

NHTSA has issued relatively few regulations since the mid-1980s; most of the vehicle-based reduction in vehicle fatality rates in the U.S. during the last third of the 20th Century were gained by the initial NHTSA safety standards issued from 1968 to 1984 and subsequent voluntary changes in vehicle design and construction by vehicle manufacturers.

Issues for particular demographic groups

Pregnant women

When pregnant, women should continue to use seatbelts and airbags properly. A University of Michigan study found that "unrestrained or improperly restrained pregnant women are 5.7 times more likely to have an adverse fetal outcome than properly restrained pregnant women".If seatbelts are not long enough, extensions are available from the car manufacturer or an aftermarket supplier.

Infants and children

Children present significant challenges in engineering and producing safe vehicles, because most children are significantly smaller and lighter than most adults. Additionally, children far from being just scaled down adults, still have an undeveloped skeletal system. This means that vehicle restraint systems such as airbags and seat belts, far from being effective, are hazardous if used to restrain young children. In recognition of this, many medical professionals and jurisdictions recommend or require that children under a particular age, height, and/or weight ride in a child seat and/or in the back seat, as applicable.

Within Europe ECE Regulation R44 dictates that children below 150 cm must travel in a child restraint that is appropriate for their weight. Each country have their own adaptions of this Regulation. For instance, in the United Kingdom, children must travel in a child restraint until they are 135 cm tall or reach 12 years of age, which ever comes soonest. As another example in Austria the driver of passenger vehicles is responsible for people shorter than 150 cm and below 14 years to be seated in an adequate child safety seat. Moreover, it is not allowed for children below the age of 3 to ride in a passenger vehicle without "security system" (which in practice means the vehicle is not equipped with any seat belts or technical systems like Isofix), whereas children between 3 and 14 years have to ride in the back seat.

Sweden specify that a child or an adult shorter than 140 cm is legally forbidden to ride in a place with an active airbag in front of it.

The majority of medical professionals and biomechanical engineers agree that children below the age of two year old are much safer if they travel in a rearward facing child restraint.

Child safety locks and driver-controlled power window lockout controls prevent children from opening doors and windows from inside the vehicle.

Infants left in cars

Very young children can perish from heat or cold if left unattended in a parked car, whether deliberately or through absentmindedness. In 2004 the U.S. NHTSA estimated 25 fatalities per year among children left in hot cars.

Teenage drivers

In the UK, a full driving licence can be had at age 17, and most areas in the United States will issue a full driver's license at the age of 16, and all within a range between 14 and 18. In addition to being relatively inexperienced, teen drivers are also cognitively immature, compared to other drivers. This combination leads to a relatively high crash rate among this demographic.

In some areas, new drivers' vehicles must bear a warning sign to alert other drivers that the vehicle is being driven by an inexperienced and learning driver, giving them opportunity to be more cautious and to encourage other drivers to give novices more leeway. In the U.S. New Jersey has Kyleigh's Law citing that teen drivers must have a decal on their vehicle.

Some countries, such as Australia, the United States, Canada and New Zealand, have graduated levels of driver's licence, with special rules. By 2010, all US states required a graduated driver's licence for drivers under age 18. In Italy, the maximum speed and power of vehicles driven by new drivers is restricted. In Romania, the maximum speed of vehicles driven by new drivers (less than one year in experience) is 20 km/h lower than the national standard (except villages, towns and cities). Many U.S. states allow 18-year-olds to skip some requirements that younger drivers would face, which statistics show may be causing higher crash rates among new drivers. New Jersey has the same requirements for new drivers up to the age of 21, which may obviate this problem.

Medical conditions

According to a study published in 2017 in the Mayo Clinic Proceedings, although most drivers with medical conditions were safe drivers, drivers with psychiatric conditions or substance abuse were particularly at higher risks of unsafe driving. The study also reported that drivers with neurological conditions were the majority of the entire study population (Belgium) who were referred for a driving evaluation, but they were not the most unsafe drivers.

Elderly

Insurance statistics in the United States indicate a 30% increase in the number of elderly killed, comparing 1975 to 2000. Several states require additional testing for elderly drivers. On a per-driver basis, the number of fatal and overall crashes decreases with age, with some exceptions for drivers over 75. The overall trend may be due to greater experience and avoiding driving in adverse conditions. However, on a per-miles-travelled basis, drivers younger than 25-30 and older than 65-70 have significantly higher crash rates. Survivability of crashes decreases monotonically with the age of the victim.

A common problem for the elderly is the question of when a medical condition or biological aging presents a serious enough problem that one should stop driving. In some cases, this means giving up some personal independence, but in urban areas often means relying more on public transportation. Many transit systems offer discounted fares to seniors, and some local governments run "senior shuttles" specifically targeted at this demographic.

Vehicle programs

While it is usually considered that the driver has the responsibility when collisions occur, vehicle can also contribute to collisions, up to 3% to 5% of crashes.[94]

Two kinds of programs exist: new car assessment program for new cars, and vehicle inspections for other ones.

NCAP

Consumer information label for a vehicle with at least one NCAP star rating

A New Car Assessment Program is a government or institutional car safety program tasked with evaluating new automobile designs for performance against various safety threats.

Two well known NCAP are United States New Car Assessment Program since 1978 and European New Car Assessment Programme since 1997.

Legal vehicle inspections

Vehicle inspection is a procedure mandated by national or subnational governments in many countries, in which a vehicle is inspected to ensure that it conforms to regulations governing safety, emissions, or both. Inspection can be required at various times, e.g., periodically or on the transfer of title to a vehicle.

If required periodically, it might be termed *periodic motor vehicle inspection*, or MOT test in UK, or *roadworthiness test* in EU directives. Typical intervals are every two years (in EU) and every year (in UK). When a vehicle passes inspection, often a sticker is placed on the vehicle's windshield or registration plate to simplify later controls, but in some countries such a Netherlands since 1994 is not necessary anymore.

Inspection stations are places to drive inside to see if a vehicle passes inspection once a vehicle is due for inspection. Most US inspection decals/stickers display the month's number and the year. They are called *testing centre* in EU directives.

Vehicle inspection exists in the United States.

In Victoria, Australia, safety features checked include the structure of the vehicle, the tires (depth of tread), the wheels, the engine, steering, suspension, brakes, and lights and seatbelts.

Other safety measures

Tires should be checked regularly. Tire check is an important measure, because tires are about the only contact which exist between the car and the road, necessary to decrease speed.

In regions with snow, such as UK or germany, snow tires might be used for safety

ANTILOCKING BRACKING SYSTEM(ABS)

ABS prevents the wheels from locking up, thus avoiding uncontrolled skidding of the vehicle and decreases the distance travelled without slipping.

Driving on express ways can be fun and thrill-inducing, as many of you surely know. One gets to unleash a car’s full potential. The city roads keep us grounded, but as soon as you hit the highway, there’s no looking back. You’ll almost never see a car going below 100 km/hr.

The situation gets particularly tricky during monsoons, as cruising in a car at such high speeds is a perfect recipe for a disaster if the roads are slick. Even so, it does happen, so what do you do in a situation on a slippery road when you have to suddenly apply the brakes of your car?

Without an anti-lock brake system, the wheels of your car stop spinning and the car will begin to skid. You'll completely lose control over the car and the results can be deadly.

Anti-lock braking systems (ABS) take a lot of the challenge out of this sometimes nerve-wrecking event. In fact, on slippery surfaces, even professional drivers can't stop as quickly without ABS as an average driver can with ABS.

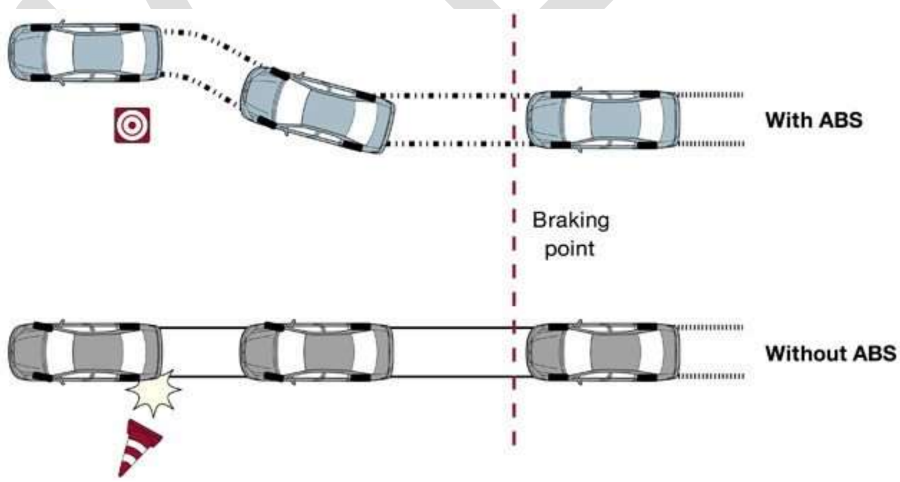
What is Anti-lock braking system (ABS) in cars?

As the name signifies, the anti-lock braking system is a safety system in cars and other automobiles that keeps their wheels from locking up and helps their drivers to maintain steering control. Also referred to as anti-skid braking system sometimes, it enables the wheels of a vehicle to maintain tractive contact with the ground so that they don't go into an uncontrolled skid.

With ABS, you have more control on your car during situations such as sudden braking. Basically, it is designed to help the driver maintain some steering ability and avoid skidding while braking.

ABS Working principle

The basic theory behind anti-lock brakes is simple. It prevents the wheels from locking up, thus avoiding uncontrolled skidding. ABS generally offers improved vehicle control and decreases stopping distances on dry and slippery surfaces.



With ABS, you get better stability and control over a car while braking

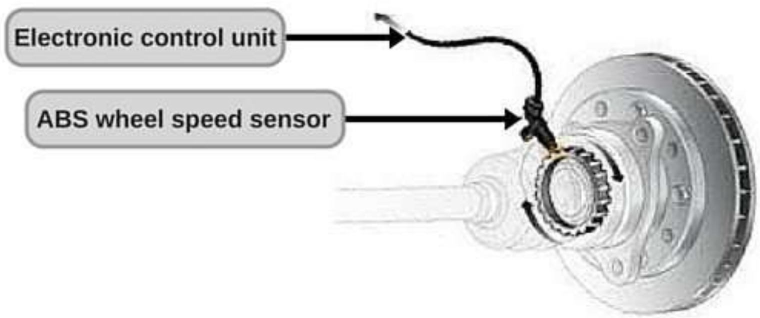
A skidding wheel (where the tire contact patch is sliding relative to the road) has less traction (grip of the tire on the road) than a non-skidding wheel. For example, if your car drives over a road covered in ice, it is unable to move forward and the wheels will keep spinning, since no traction is present. This is because the contact point of the wheel is sliding relative to the ice.

ABS modifies the brake fluid pressure, independent of the amount of pressure being applied on the brakes, to bring the speed of the wheel back to the minimum slip level that is mandatory for optimal braking performance.

ABS has four major components:

1) Speed Sensor

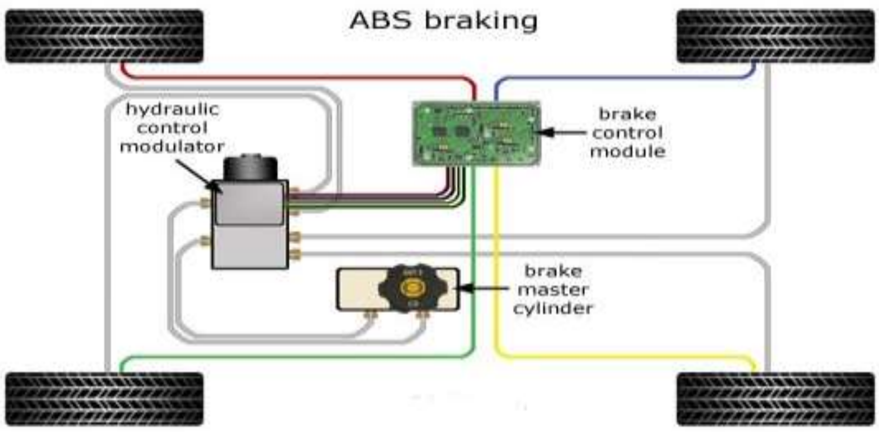
This sensor monitors the speed of each wheel and determines the necessary acceleration and deceleration of the wheels. It consists of an exciter (a ring with V-shaped teeth) and a wire coil/magnet assembly, which generates the pulses of electricity as the teeth of the exciter pass in front of it.



The speed sensor

2) Valves

The valves regulate the air pressure to the brakes during the ABS action. There is a valve in the brake line of each brake that is controlled by the ABS. In the first position, the brake valve is open and it allows the pressure from the master cylinder to be transferred to the brakes. In the second position, the brake valve remains closed and pressure from the master cylinder to the brakes is constrained. In the third position, the valve releases some of the pressure on the brakes. The third step is repeated until the car comes to a halt. The resistance that you feel when braking suddenly at high speeds is actually the brake valves controlling the pressure that is being transferred to the brakes from the master cylinder.



Components of ABS braking

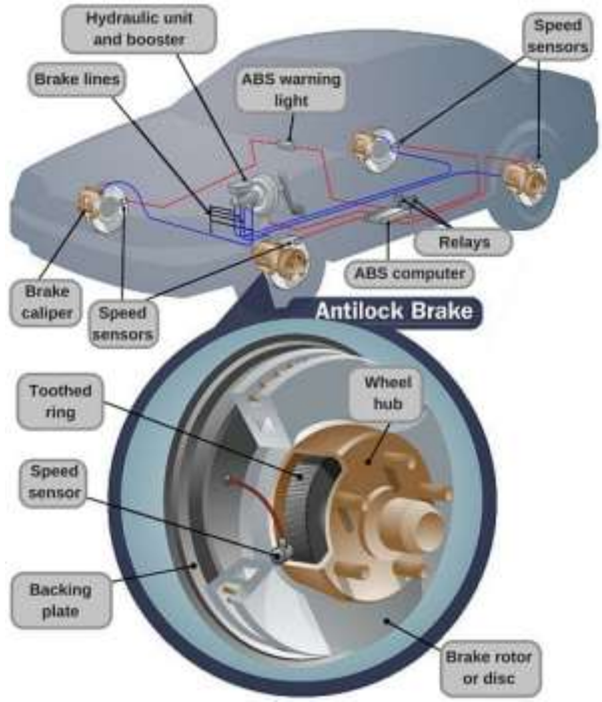
3) Electronic Control Unit (ECU)

The ECU is an electronic control unit that receives, amplifies and filters the sensor signals for calculating the wheel rotational speed and acceleration. The ECU receives a signal from the sensors in the circuit and controls the brake pressure, according to the data that is analyzed by the unit.

4) Hydraulic Control Unit

The Hydraulic Control Unit receives signals from the ECU to apply or release the brakes under the anti-lock conditions. The Hydraulic Control Unit controls the brakes by increasing the hydraulic pressure or bypassing the pedal force to reduce the braking power.

ABS in operation



Working components of an ABS.

While braking, if a wheel-locking situation is detected or anticipated, the ECU alerts the HCU by sending a current and commands it to release the brake pressure, allowing the wheel velocity to increase and the wheel slip to decrease. When the wheel velocity increases, the ECU reapplies the brake pressure and restricts the wheel slip to a certain degree (*Note:* When the braking action is initiated, a slippage between the tire and the road surface in contact will occur, which makes the speed of the vehicle different from that of the tire). The Hydraulic Control Unit controls the brake pressure in each wheel cylinder based on the inputs from the system sensor. As a result, this controls the wheel speed. This process is repeated for the next braking operation.

ABS is classified based on the number of sensors and the types of brakes used. Brakes can also be differentiated by the number of channels, i.e how many valves are individually controlled and the number of speed sensors.

Four-channel, four-sensor ABS

This is the best combination for an effective ABS system. There is a speed sensor on all four wheels and a separate valve for all four wheels. With this setup, the controller monitors each wheel individually to ensure that it is achieving maximum braking force.

Three-channel, three-sensor ABS

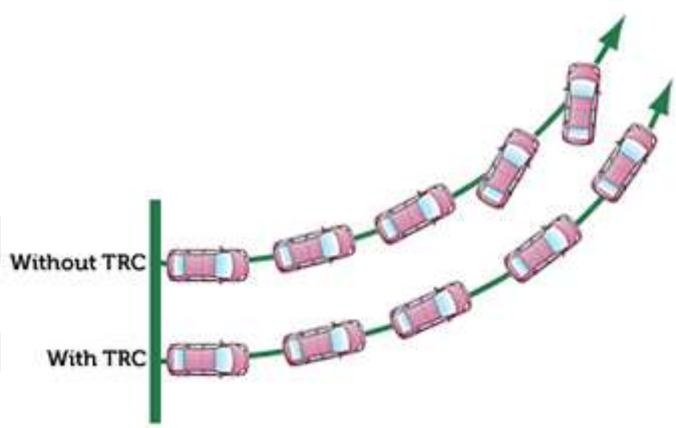
This combination, which is commonly found on pickup trucks with four-wheel ABS, has a speed

sensor and a valve for each of the front wheels, along with one valve and one sensor for both rear wheels. The speed sensor for the rear wheels is located in the rear axle.
Similarly, there are also two-channel and one-channel ABS. The one-channel variant is the least effective, as you might expect.
Most new cars come equipped with ABS, as it is considered one of the most important safety features in cars. Current research shows that cars equipped with ABS are far less likely to be involved in multi-car accidents, because they still have access to steering capabilities. ABS has completely revolutionized the automobile industry to the point where a car without ABS is like a coffee mug without a handle!

TRACTION CONTROL(TRC)

Helps prevent wheel slippage when the vehicle is starting or accelerating on wet or slippery roads

Concept of TRC/ Rear-wheel drive layout



When you are starting the vehicle or accelerating on a wet surface, you could lose control of the wheel because of wheel spin. TRC will help prevent such events from happening.
TRC continually monitors the condition between the tires and the surface of the road.
When it detects wheel spin, the system applies brakes or slows down the engine to regulate spinning and help ensure proper contact of tires. This help prevent the car from becoming unstable.
There might be the cases in which the half-side of the wheel runs off or the wheels spin off on

the snowy road. And also there might be the case that the current tractino control might not be working well.

In those cases, Auto LSD is one of the technologies which both improve startability and runability.

What does traction control do?

Basically, traction control is an onboard system designed to prevent a car's tyres from slipping during acceleration. It is typically a secondary function of the car's electronic stability control (ESC).

Traction control is most likely to come into play when the driver of a car is trying to accelerate on a road which surface has little grip on offer, likely because of the weather conditions, especially if there's rain, ice or snow involved.

How does traction control work?

Usually, traction control will make use of the same wheel-speed sensors as the antilock braking system. The feature works out the rotational speed of each wheel to determine if any of the wheels receiving power are behaving in a way that suggests it does not have enough grip to match the power being delivered without slipping.

If a car does not have traction control, then the way drivers would get around this would be to gently feather the throttle so that they can still build up speed without losing grip. When traction control figures out that a wheel is long grip during acceleration, it will automatically pump the brake attached to that wheel, reducing the car's speed but also how much it slips.

Traction control therefore gives a driver better control of their car and makes it much less likely for a driver to oversteer while negotiating a corner or lose the back end while building up speed.

When to use traction control

Traction control is a common safety feature on new cars and it is usually active automatically every time you drive a car with it. It will step in and assist when a situation occurs which it can help in.

Any car regardless of its powertrain set-up can benefit from traction control, but it is cars which send a lot of power to just the rear wheels which can end up spinning their wheels the most without it.

How to turn off traction control

Many cars on the market will give the driver the ability to turn off traction control if they know how. Normally the way to do it is to press and hold a certain button to disable the traction control.

If you don't know where it is already, the location of the button to turn off traction control (and how to use it properly) should be mentioned somewhere within your vehicle owner's manual. This same switch should be able to turn on traction control as well when you want this safety aid to reactivate.

Traction control vs stability control

Some motorists incorrectly believe that traction control is either the same as electronic stability control or you can only have one or the other. In truth, while traction control and stability control are separate systems they are both brake-based and usually exist together in one vehicle.

Traction control focuses on the job of keeping your wheels from spinning, but electronic stability control is like an evolved version of traction control. Stability control focuses on keeping the car pointing in the same direction the driver intends to point towards. While the car is being steered, ESC can control the braking to multiple wheels, and even the power to the engine, in order to keep the car going in the direction planned.

Since ESC does more tasks (all of which are critical), that explains why traction control is often nowadays considered a secondary function next to the car's stability control.

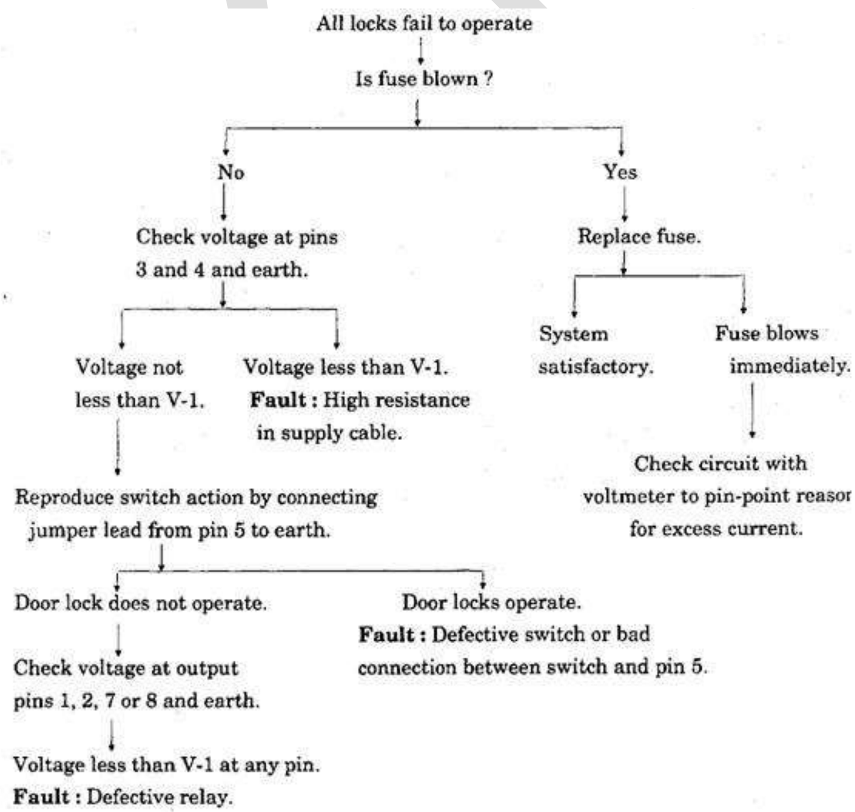
ELECTRIC SEATS, MIRRORS AND SUN ROOF OPERATION

Electric movement of seats, mirrors and the sun roof is quite similar. Basically all of these are operated through one or several permanent magnet motors, along with a supply reversing circuit. A typical motor reverse circuit is illustrated in Fig. 30.31. When the switch is operated, one of the relays operates and changes the polarity of the supply to one side of the motor. In the same way if the switch is moved in the other direction, the polarity of the other side of the motor

Fig. 30.30. Pressure wash-system with a retractable nozzle.

is altered. When the motor is stopped both sides instantly attain the same potential, which has the effect of regenerative braking. Additional refinements have been introduced to improve the operation of these systems. Limit switches, position memories and force limitation are the most common features.

Fault-diagnosis Chart for Central Door-locking System



ELECTRIC SEAT ADJUSTMENT

Seat adjustment is carried out through positioning of different parts of the seat using a number of motors. Movement is achieved in the following ways :

•Front to rear. • Rear cushion height.

• Front cushion height. • Backrest tilt.

• Headrest height. • Humber support.

Figure represents a typical electronically controlled seat, which uses four positioning motors and one smaller for a pump used to control the lumber support bag. Each motor is normally operated by a simple rocker type switch, which controls two relays to change the polarity of supply as described above. Nine relays, therefore, are used, two for each motor and one to control the main supply

.

Once the seat position is set some vehicles use set position memories for automatic repositioning, when the seat has been moved. This arrangement is often combined with electric mirror adjustments. Figure 30.33 demonstrates the circuit for position memory. As the seat is moved, a variable resistor mechanically linked to the motor also moves and the value of the resistance provides feedback to an electronic control unit. One of the techniques used in the position memory is to supply the resistor with a fixed voltage such that the output relative to the seat position is proportional to the position. This voltage is then converted from analogue to digital form producing a simple number, which is stored in a digital memory. If the memory recall switch is pressed, the ECU activates the motor relays until the number in memory and the fed back number from the seat are equal. This facility is normally isolated during operation of the engine to avoid movement of the seat to any dangerous position as the car is being driven. However the positions of the seats can still be adjusted by operating the switches as normal. Seat heaters are often used with this type of system.

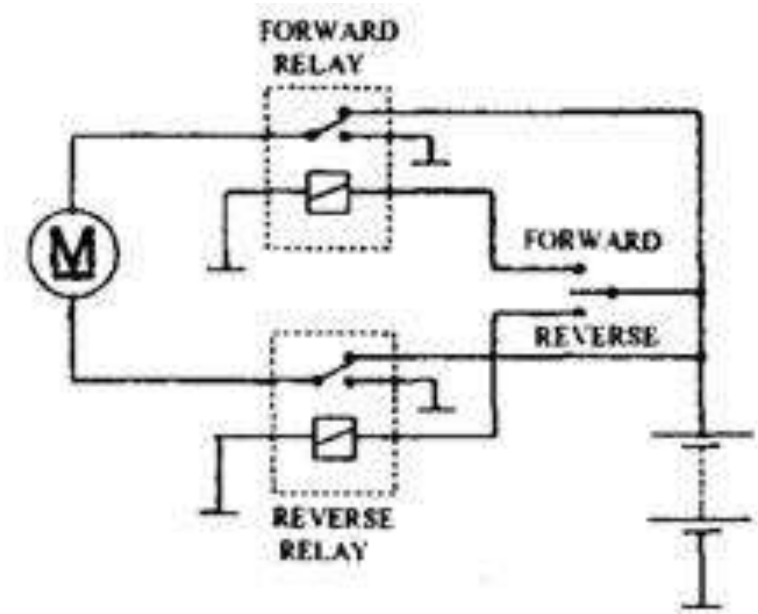


Fig.. Motor reverse circuit.

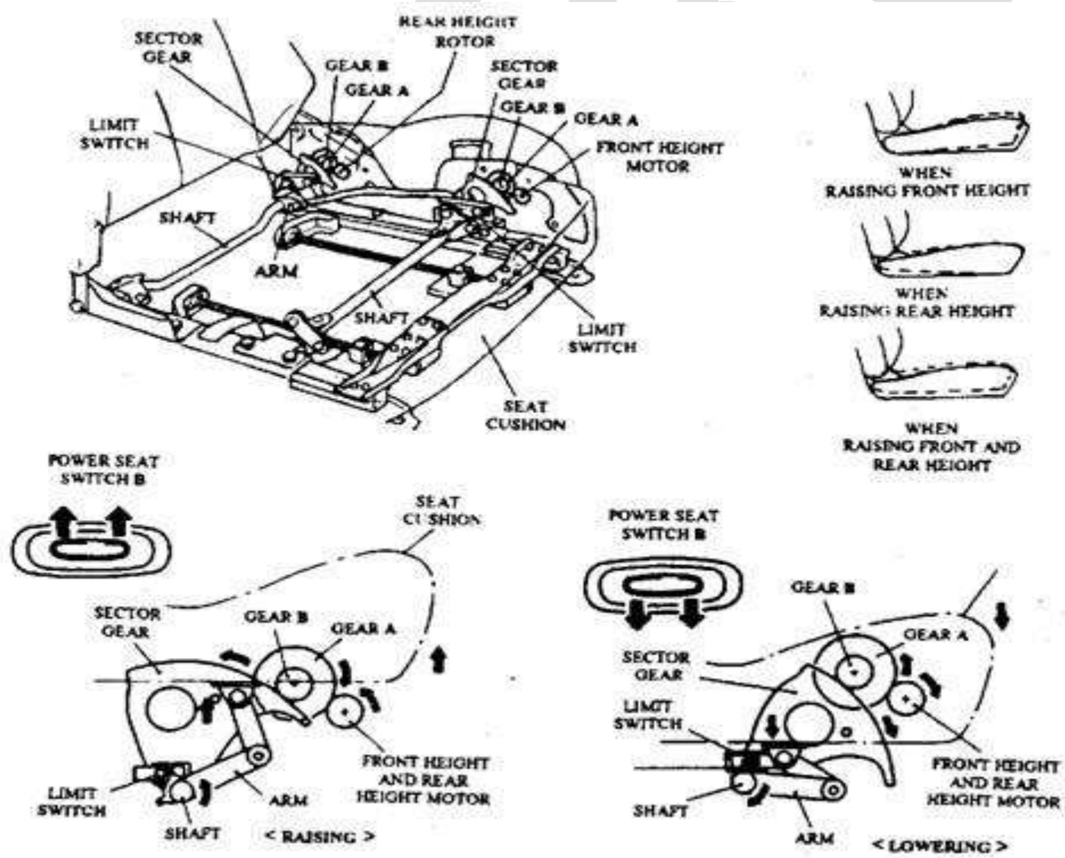


Fig. Electrically controlled seat.

ELECTRIC MIRRORS

Now-a-days many vehicles incorporate electrical adjustment of mirrors, specifically on the passenger side as it is difficult for the driver to reach for adjusting the door mirrors. Each mirror assembly contains an enclosure, fixed to the door frame, and a mirror-glass, which pivots on a nylon ball-joint. The system used is much the same as that used for seat movement. The mirror is moved vertically and horizontally by two small motors. Many mirrors also incorporate a small heating element on the rear of the glass. This is operated for a few minutes when the ignition is initially switched on. This can also be linked to the heated rear window circuit. An electrically operated mirror circuit, using feedback resistors for positional memory is shown in Fig.

ELECTRIC SUN ROOF OPERATION

Although an electric sun roof also works on the motor reverse circuit, the system incorporates additional components and circuit to allow the roof to slide, tilt and stop in the closed position. The extra components required are a micro-switch and a latching relay. A latching relay works in much the same way as a normal relay, except that it locks into position each time it is activated. To achieve this, the mechanism used is much similar to the ball point pens that use a button on top. The micro-switch is mechanically positioned and operated when the roof is in its closed position. A rocker switch permits the driver to adjust the roof.

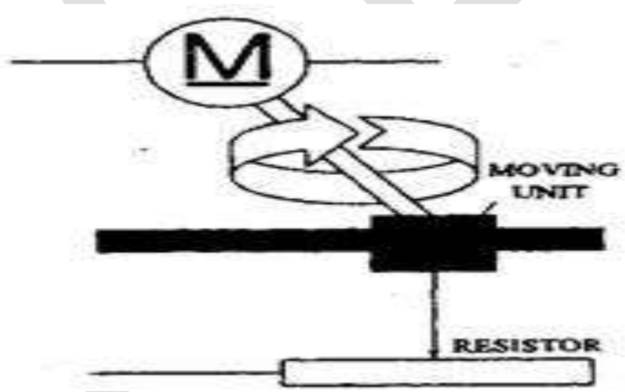


Fig. 30.33. Position memory for electric seats.

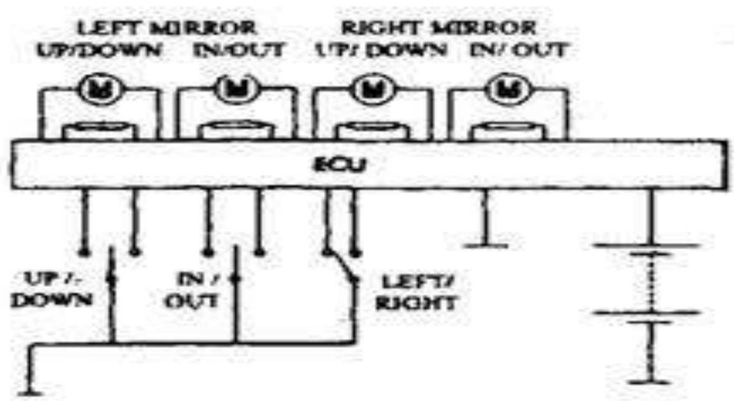


Fig. 30.34. Feedback resistor for positional memory and the circuit.

Figure 30.35 illustrates the circuit for an electrically operated sun roof. The switch allows the motor to run in the chosen direction to open or tilt the roof. To close the roof, the motor is run in the appropriate direction until the micro-switch closes while the roof is in its closed position. This causes the latching relay to change over to stop the motor. Now the control is released. Once again if the switch is pressed, the latching relay again changes over to run the motor.

Electronically Dipped Rear View Mirror

The electrically dipped rear view mirror automatically darkens when strong light falls on the mirror glass. It therefore, protects the driver from the glare of following headlights when travelling at night. This mirror uses special electro-chrome (EC) glass, the reflectivity of which can be controlled electronically. Due to the absence of any moving part, the system operates noiselessly and does not alter the angle of the mirror glass.

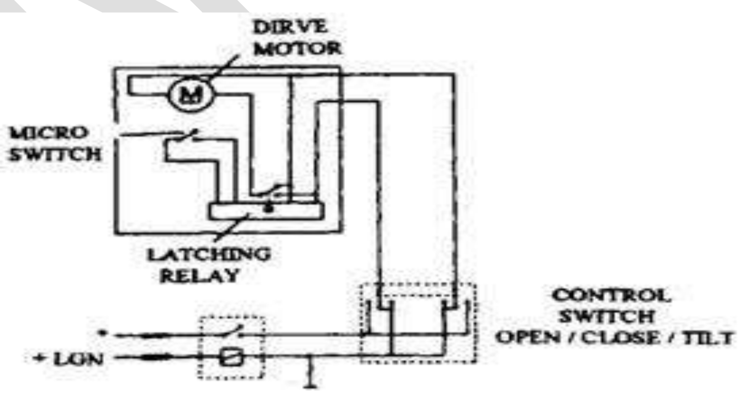


Fig. Circuit for an electrically operated sun roof.

A block diagram of the EC mirror glass and associated electronics is shown in Fig. 30.36. Two photosensitive resistors are used to determine the lighting levels. One photo resistor faces the rear window and senses the light level falling on the mirror glass. The other photo resistor faces the windscreen and senses the ambient light level seen by the driver. Based on the difference between these two light levels a differential amplifier module produces an output. The electronic module applies a bias voltage to the mirror electrodes when the light level falling on the rear-facing sensor exceeds a certain percentage of the ambient light level. This voltage causes a flow of ions from the electrolyte into the front electrodes, which darkens the EC glass thereby reduces the amount of light reflection from the mirror. The amount of darkening is proportional to the bias voltage, and hence it is dependent on the difference in light levels falling on the two sensors The alteration is mirror reflectivity takes place slowly. The dimming time (from 70% to 20% reflectance) is about four seconds, and the restoring time (from 10% to 60% reflectance) is around seven seconds. When reverse gear is engaged, an override input from the reversing light switch disables the dimming function. Figure illustrates the arrangement of the electrically dipped mirror.

The sensors and electronic module are placed inside the mirror casing and a control is incorporated to vary the sensitivity or to switch off the dipping function.

Rain Sensor

Although variable windscreen-wiper delay allows the adjustment of the wiper operating interval to suit the amount of rainfall, however it is often necessary to make frequent adjustment

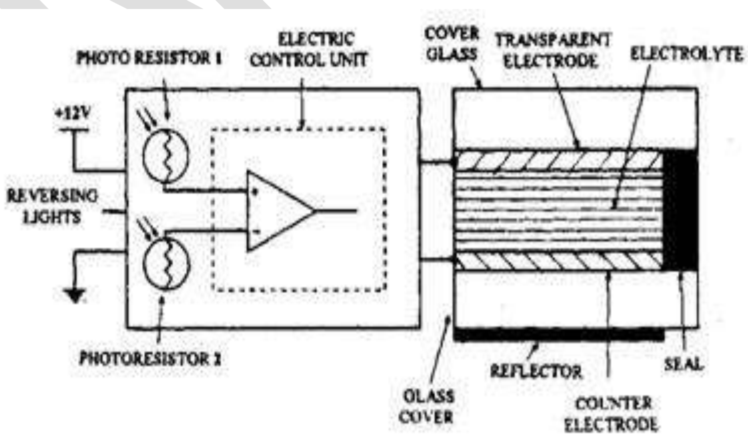


Fig.. Electro-chrome mirror glass and control electronics.

due to variation of the weather or road conditions. During light rain-fall, a rain sensor continuously monitors the amount of rain striking the windscreen. A microcomputer-based ECU processes the sensor signal and alters the wiper delay interval suiting to the rain intensity. The rain sensor is installed inside the car behind the rear view mirror and works on the principle of reflection of infrared light from the windscreen (Fig. 30.28), Light from an infrared transmitter diode is focused through a lens and then coupled to the windscreen through a light

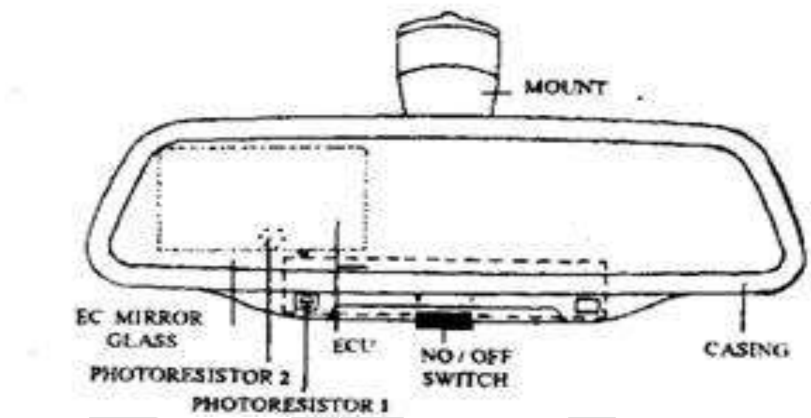


Fig. Practical arrangement of EC dipping rear view mirror.

guide, which is bonded to the glass with a transparent adhesive. When the windscreen is completely dry, the most of the light is reflected from the outer surface of the glass, which returns through the light guide to a second lens to focus the rays onto the receiver diode. On the other hand, when rain falls onto the windscreen, some of the transmitted light due to refraction is lost from the system into the raindrops, so that they do not reach the receiver. This causes a loss of signal which the ECU interprets as a particular level of rainfall, which is referred as to adjust the wiper delay interval appropriately.

CENTRAL LOCKING OF AUTOMOBILES

Power door **locks** (also known as electric door **locks** or central **locking**) allow the driver or front passenger to simultaneously **lock** or unlock all the doors of an automobile or truck, by pressing a button or flipping a switch.

Whether they are single purpose or multi-purpose, electronic car door locks have standard features:

- A latch/door lock
- An actuator
- Actuator rods
- Activated by radio

Electric car door locks operate by receiving a radio signal transmitted by the **car key fob**, signaling the **actuator** to activate, which then routes the command through the correct path (lock/unlock) and performs the desired action.

How the actuator works

On activation, the actuator unit moves a rod attached to the rear of the latch/door lock mechanism. The rod exerts pressure on the lock-open switch on the back of the door lock mechanism. The pressure opens a pair of jaws on the latch/door lock mechanism, releasing the jaws from the strike on the center pillar. The action connects the door handles to the latch/door lock mechanism. The door opens when you lift the an inside or outside door handle.

Computer-controlled automatic locks

A computer-controlled lock system also uses a radio signal to wake up door lock and unlock mode. The computer-controlled system sends out computer programming to the key controller module (computer). The module reads the programming that is directed its way and applies the proper system command. The computer-controlled key usually controls not only locking and unlocking doors but also auto security. The auto security piece includes car halt/disable programs that effectively make your car undrivable by potential thieves. The same system has the capability to:

- Open the trunk lid
- Remote start the car
- Lower the windows
- Kill the ignition

This system is potentially feature-rich. It depends on the amount the customer wants to spend, provided the manufacturer offers it.

One more way that automatic locks work is by keypad. Introduced 35 years ago, the keypad system appeared first in 1980 on Ford cars and trucks. Still available today, a car owner simply enters a computer code and the controller module tells the door actuator to go to work.

POWER WINDOWS/ ELECTRIC WINDOWS

Power windows or **electric windows** are automobile windows which can be raised and lowered by pressing a button or switch, as opposed to using a crank handle.

History

Inside drivers door showing hydraulic cylinder for power window

Window controls on center console between front seats (2005 Saab 9-5)

Packard had introduced hydraulic window lifts (power windows in fall of 1940, for its new 1941 Packard 180 series cars. This was a hydro-electric system. In 1941, the Ford Motor Company followed with the first power windows on the Lincoln Custom (only the limousine and seven-passenger sedans). Cadillac had a straight-electric divider window (but not side windows) on their series 75.

Power assists originated in the need and desire to move convertible body-style tops up and down by some means other than human effort. The earliest power assists were vacuum-operated and were offered on Chrysler Corporation vehicles, particularly the low-cost Plymouth convertibles in the late 1930s.

Shortly before World War II, General Motors developed a central hydraulic pump for working convertible tops. This system was introduced on 1942 convertibles built by GM. Previously, GM had used a vacuum system which did not have the power to handle increasingly larger and complex (four side-windows vs. only two) convertible top mechanisms.

Chief Engineer of the Buick Division, Charles A. Chayne, "...had introduced an electrically controlled hydraulic system into the 1946 Buick convertibles that provided fingertip operation of the top, door windows, and front seat adjustment".[5] These systems were based on major hydraulic advances made in military weapons in preparation for World War II.

The "Hydro-Electric" system (windows, front seat adjustment and convertible top) was standard on 1947 model year. The seat and window assist system became available on GM closed cars (standard on some Cadillac Series 75 models and all Series 60 Specials, commonly called "Fleetwood" beginning with the 1948). The full system was standard only on the high-end GM convertibles made by Oldsmobile, Buick, and Cadillac. It was only available as a package; that is, power assisted windows, front seat, and convertible top (where applicable). This feature can be identified in 1948 and later General Motors model numbers with an "X" at the end, such as the 1951 Cadillac Sixty Special sedan, model 6019X. The electrically operated hydraulic pump system was shared by Hudson and Packard for their 1948 through 1950 models. The driver's door contained four buttons in addition to the remaining individual windows.[8]

Ford also had a similar electro-hydraulic system on higher-end convertibles. Mercury and Ford Sportsman convertibles (with wood trim) were equipped with power windows on four windows from 1946 through 1948 and Mercury and Lincoln by 1951. These systems were used by other luxury car models (Imperial and Packard) until Chrysler introduced the all-electric operation on the 1951 Imperial. The availability of power windows increased with the use of small, high-torque electric motors.[9] General Motors also followed with full electric operation in 1954. This included four-way and then six-way seats, which were introduced in 1956. Chevrolet introduced the oddity of power front windows (only) in the 1954 model. Ford also introduced full four-door power windows in sedans in 1954. The full-sized 1955 Nash "Airflyte" models featured optional power windows.

Electrically-operated vent windows were available as early as 1956 on the Continental Mark II. The 1960s Cadillac Fleetwood came standard with power front and rear vent windows, in addition to standard power side windows, for a total of eight power window controls on the driver's door panel.

Modern heavy-duty highway tractors frequently have an option for power window controls; however, these are generally what is referred to as "straight air". That is, the compressed air system used for air brakes is also used for the windows. These types of trucks have long used compressed air cylinders for seat height adjustment. In a similar fashion to the electro-hydraulic system, the compressed air is merely released to lower the window and/or seat. The compressed air is then admitted to the respective cylinder to raise the window or seat.

In a typical auto/light truck installation, there is an individual switch at each window and a set of switches in the driver's door or a-frame pillar, so the driver can operate all the windows. These switches took on many different appearances, from heavy chrome plate to inexpensive plastic.

However, some models like Saab, Volvo, Mazda and Holden have used switches located in the center console, where they are accessible to all the occupants. In this case, the door-mounted switches can be omitted. This also removes the need to produce separate door components and wiring for left and right-hand drive variants.

Operation

Power windows are usually inoperable when the car is not running. This is primarily a security feature. It would be a simple thing to allow electric power windows to be operable when the ignition is turned off, however it would also make the car much easier to steal. Some systems offer the compromise of leaving power applied to the windows until a passenger door is opened at which time the window power is removed.

Hydraulic drive systems could lower the windows at rest, since pressure from the hydraulic system was merely released to lower the window. Raising the windows required an electrically operated pump to operate and introduce pressure at the appropriate cylinder. These systems also required pressure lines to each cylinder (in the doors, as well as on certain cars, to the power seat and a power operated convertible top). Because of the complexity, the system could also leak fluid.

Many modern cars have a time delay feature, first introduced by Cadillac in the 1980s, called "retained accessory power". This allows operation of the windows and some other accessories for ten minutes or so after the engine is stopped. Another feature is the "express-down" window, which allows the window to be fully lowered with one tap on the switch, as opposed to holding the switch down until the window retracts. Many luxury vehicles during the 1990s expanded on this feature, to include "express-up" on the driver's window, and recently, some manufacturers have added the feature on all window switches for all passengers' convenience. This is done by activating the switch until a "click" response is felt.

Power windows have become so common that by 2008, some automakers eliminated hand crank windows from all their models. So many vehicles now have power windows that some people no longer understand the (formerly) common sign from another driver of using their hand to simulate moving a window crank to indicate that they wish to speak with someone when stopped at a light or in a parking lot. The 2008 Audi RS4 sold in Europe, however, still has roll-up windows for the rear doors although its counterpart sold in the U.S. has power windows for all doors.

Safety

Power windows have come under some scrutiny after several fatal accidents in which children's necks have become trapped, leading to suffocation. Some designs place the switch in a location on a hand rest where it can be accidentally triggered by a child climbing to place his or her head out of the window. To prevent this, many vehicles feature a driver-controlled lockout switch, preventing rear-seat passengers (usually smaller children) from accidentally triggering the switches. This also prevents children from playing with them and pets riding with their heads out windows from activating the power window switch.

Starting with the 2008 model year, U.S. government regulations required automakers to install power window controls that are less likely to be accidentally activated by children. However, the rules do not prevent all potential injuries to a hand, finger, or even a child's head, if someone deliberately holds the switch when the window is closing. In 2009, the U.S. auto safety administration tentatively decided against requiring all cars to have automatic reversing power windows if they sense an obstruction while closing. Proposed requirements concern automatic ("one-touch up") window systems, but most vehicles with this feature already have automatic-reversing. The federal government made a written contract that all automakers should make the lever switches (as opposed to the rocker and toggle switches) standard on all new vehicles by 1 October 2010.

CRUISE CONTROL

The cruise control system actually has a lot of functions other than controlling the speed of your car. For instance, the cruise control pictured below can accelerate or decelerate the car by 1 mph with the tap of a button. Hit the button five times to go 5 mph faster. There are also several important safety features -- the cruise control will disengage as soon as you hit the brake pedal, and it won't engage at speeds less than 25 mph (40 kph).

The system pictured below has five buttons: On, Off, Set/Accel, Resume and Coast. It also has a sixth control -- the brake pedal, and if your car has a manual transmission the clutch pedal is also hooked up to the cruise control.

- The **on** and **off** buttons don't actually do much. Hitting the on button does not do anything except tell the car that you might be hitting another button soon. The off button turns the cruise control off even if it is engaged. Some cruise controls don't have these buttons; instead, they turn off when the driver hits the brakes, and turn on when the driver hits the set button.
- The **set/ accel** button tells the car to maintain the speed you are currently driving. If you hit the set button at 45 mph, the car will maintain your speed at 45 mph. Holding down the set/ accel button will make the car accelerate; and on this car, tapping it once will make the car go 1 mph faster.
- If you recently disengaged the cruise control by hitting the brake pedal, hitting the **resume** button will command the car to accelerate back to the most recent speed setting.
- Holding down the **coast** button will cause the car to decelerate, just as if you took your foot completely off the gas. On this car, tapping the coast button once will cause the car to slow down by 1 mph.
- The **brake** pedal and **clutch** pedal each have a switch that disengages the cruise control

as soon as the pedal is pressed, so you can shut off the cruise control with a light tap on the brake or clutch.

CRUISE CONTROL ACCELERATION AND DECELERATION

One of the cables is connected to the gas pedal, the other to the vacuum actuator.

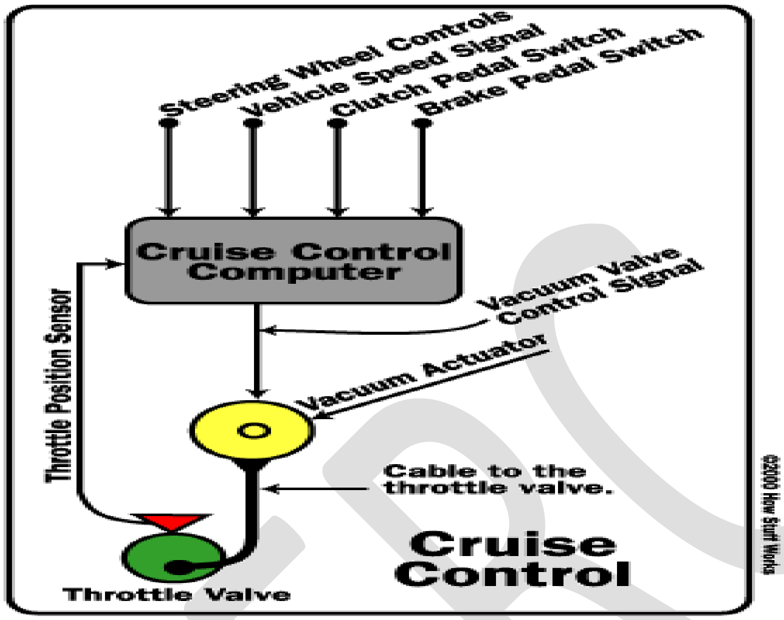
The cruise control system controls the speed of your car the same way you do -- by adjusting the **throttle position**. But cruise control actuates the throttle valve by a cable connected to an **actuator**, instead of by pressing a pedal. The throttle valve controls the power and speed of the engine by limiting how much air the engine takes in (see How Fuel Injection Systems Work for more details).

In the picture above, you can see two cables connected to a **pivot** that moves the throttle valve. One cable comes from the accelerator pedal, and one from the actuator. When the cruise control is engaged, the actuator moves the cable connected to the pivot, which adjusts the throttle; but it also pulls on the cable that is connected to the gas pedal -- this is why your pedal moves up and down when the cruise control is engaged.

The electronically-controlled vacuum actuator that controls the throttle

Many cars use actuators powered by **engine vacuum** to open and close the throttle. These systems use a small, electronically-controlled valve to regulate the vacuum in a diaphragm. This works in a similar way to the brake booster, which provides power to your brake system.

CONTROLLING THE CRUISE CONTROL



The brain of a cruise control system is a small computer that is normally found under the hood or behind the dashboard. It connects to the throttle control seen in the previous section, as well as several sensors. The diagram below shows the inputs and outputs of a typical cruise control system.

A good cruise control system accelerates aggressively to the desired speed without overshooting, and then maintains that speed with little deviation no matter how much weight is in the car, or how steep the hill you drive up. Controlling the speed of a car is a classic application of **control system theory**. The cruise control system controls the speed of the car by adjusting the throttle position, so it needs sensors to tell it the speed and throttle position. It also needs to monitor the controls so it can tell what the desired speed is and when to disengage.

The most important input is the speed signal; the cruise control system does a lot with this signal. First, let's start with one of the most basic control systems you could have -- a **proportional control**.

In a proportional control system, the cruise control adjusts the throttle proportional to the error, the error being the difference between the desired speed and the actual speed. So, if the cruise control is set at 60 mph and the car is going 50 mph, the throttle position will be open quite far. When the car is going 55 mph, the throttle position opening will be only half of what it was before. The result is that the closer the car gets to the desired speed, the slower it accelerates. Also, if you were on a steep enough hill, the car might not accelerate at all.

Most cruise control systems use a control scheme called **proportional-integral-derivative control** (a.k.a. **PID** control). Don't worry, you don't need to know any calculus to make it through this explanation -- just remember that:

- **The integral of speed is distance.**
- **The derivative of speed is acceleration.**

A PID control system uses these three factors -- proportional, integral and derivative, calculating each individually and adding them to get the throttle position.

We've already discussed the proportional factor. The **integral** factor is based on the **time integral of the vehicle speed error**. Translation: the difference between the distance your car actually traveled and the distance it would have traveled if it were going at the desired speed, calculated over a set period of time. This factor helps the car deal with hills, and also helps it settle into the correct speed and stay there. Let's say your car starts to go up a hill and slows down. The proportional control increases the throttle a little, but you may still slow down. After a little while, the integral control will start to increase the throttle, opening it more and more, because the longer the car maintains a speed slower than the desired speed, the larger the distance error gets.

Now let's add in the final factor, the **derivative**. Remember that the derivative of speed is acceleration. This factor helps the cruise control respond quickly to changes, such as hills. If the car starts to slow down, the cruise control can see this acceleration (slowing down and speeding up are both acceleration) before the speed can actually change much, and respond by increasing the throttle position.

POWER STEERING

The first commercially viable power steering system was developed by Chrysler Imperial in 1951. It was named 'Hydraguide'.

Power steering has today become a standard fitment in almost all four wheelers that we see plying on the roads. It provides easier maneuverability and a better degree of control over the vehicle, which makes driving all-the-more effort-free.

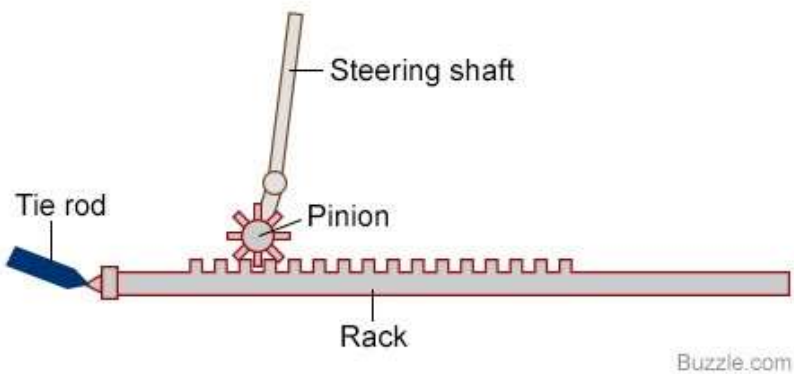
The term power steering is derived from 'power assisted steering system'. Although electric steering systems have become common in most vehicles today, initially, the basic system for power steering was hydraulic, which worked thanks to the precise functioning of a number of small and large mechanical parts. In the following sections, we shall learn about the working of the basic hydraulic power steering. But before that, we will take a look at how the steering in a vehicle functions.

Steering a vehicle involves getting its front wheels to turn synchronously, either to the left or to the right. This is achieved with the help different gear systems. The two main types of steering gear systems are the rack and pinion, and the recirculating ball type; out of which the former is found in most cars. The following is a description of the rack and pinion gear system.

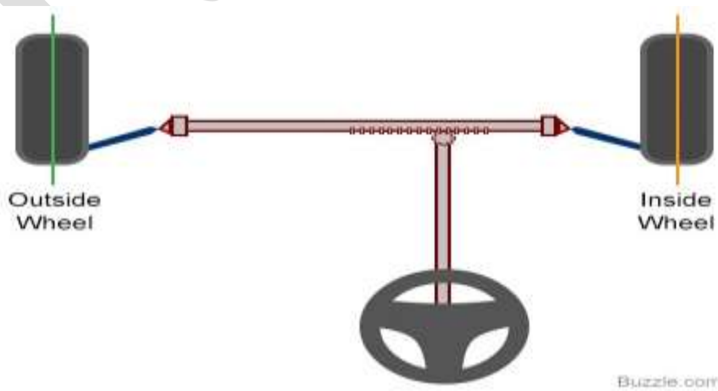
Rack and Pinion

Rack and pinion is one of the most commonly used steering systems in most cars today. Compared to other systems, it provides a better feedback (road feel) to the driver, which makes it suitable for difficult terrains.

The rack and pinion mechanism comprises the following main components, which are located within the steering gear housing: rack, pinion gear, and tie rods.

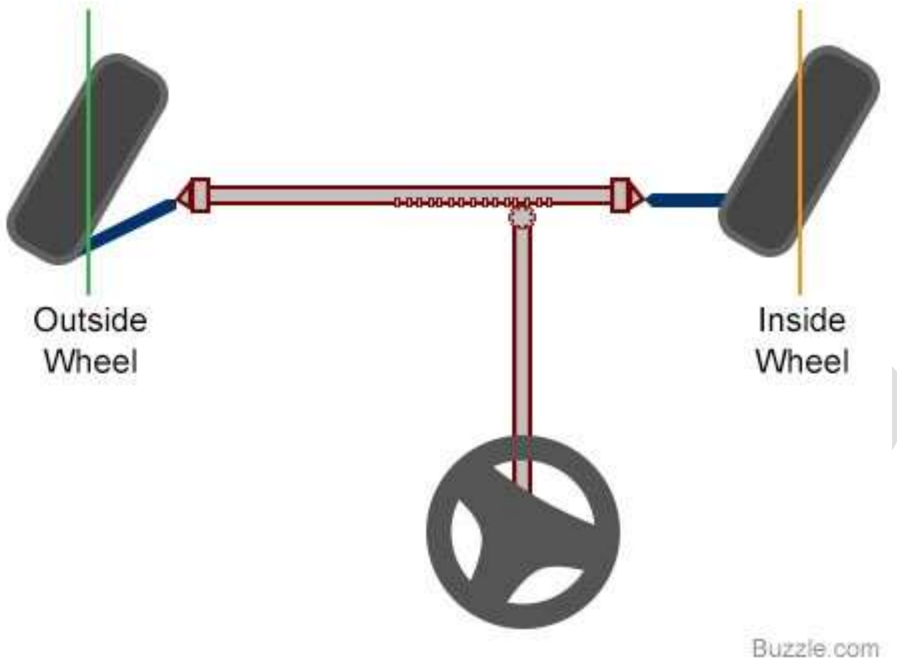


The rack is a linear gear with straight cut teeth on it, while the pinion is the normal round gear which is set at an angle over it. Typically, the pinion has a helical cut on it, designed to provide a smoother meshing between it and the rack.



The car's steering wheel is attached to the pinion gear via a steering shaft. When you turn the steering wheel, the pinion spins and drags the rack along, moving it to the left or right, depending on the direction of the turn.

The rack attaches to the steering arms of the wheels via tie rods. When the rack moves, it pushes one wheel while pulling on the other, making the car turn.



Thus, the rack and pinion arrangement is able to convert the rotational motion of the steering wheel into a linear motion, allowing the wheels to turn.

This gear mechanism is also designed to provide a gear reduction, which makes it possible to turn the wheels with much less effort, considering the weight of the vehicle.

Typically, the gear ratio is so chosen that it requires you to make up to four complete revolutions of the steering wheel to make the wheels turn from lock to lock.

Why do We Need Power Steering?

A steering system of an automobile is an integral part of vehicle dynamics of a vehicle in which a series of mechanical components having certain important angles comes together to steer the front wheels of the vehicle according to input provided by the passenger through steering wheel.

And the power steering system is the advanced steering system in which the effort required to steer the front wheels of the vehicle side to side is reduced by using intermediate electric or hydraulic devices that multiplies the force applied by the driver through steering wheel in order to achieve smooth and quick directional change of the vehicle.

Today all the 80% of the cars on road are equipped with the power steering system which has become the basic need of today's automobile.

As we have already discussed above a power steering decreases the steering efforts which is the need of a 4 wheel automobile vehicle so we need a power steering due to the following reasons

- Quick response- As the number of the vehicle on the road is increasing day by day and today almost 60% families of the world are having a 4 wheeler in their houses, with this increase in number of vehicles the danger of accidents on road is also increased, so to avoid this danger and to take quick turns required by the road conditions a quick response steering system is required in a 4 wheel vehicle.
- Steering efforts – If we drive old cars like Maruti Suzuki 800 , it is found that the steering wheel of the car feels very hard to rotate when the vehicle is going below 40 km/hr (above that the steering feels less hard) which is found to cause fatigue to the driver while going on a long ride. So a vehicle should be equipped with a power steering system so that the steering effort required to steer the front wheels can be reduced.
- Bump steer- As we know the bumps of the road is reduced by the suspension system but as the steering system is directly attached to the wheel's hub some amount of bumps force is also transferred to the steering system which in turn tries to steer the vehicle against the will of the driver due to which a vehicle can lose its stability, though the bump steer can be controlled mechanically by providing optimum scrub radius (angle between the centre line of the wheel and the king-pin inclination of the knuckle) but the power steering controls it in a more effective manner.
- Return ability- after taking a turn it is found that the steering returns automatically to its original position which in turn automatically straightens the moving vehicle. A vehicle equipped with a power steering system provides better return ability to the steering system.

TYPES OF POWER STEERING SYSTEM

On the basis of the method used to multiply the steering force there are 3 types of power steering system that are-

1. Hydraulic power steering system- It is the type of power steering system in which hydraulic system having hydraulic pump driven by the engine and hydraulic cylinders, is used to multiply the steering wheel input force which in turn reduces the efforts required to steer the front wheels of the vehicle.

- A highly compressed hydraulic fluid is used inside the hydraulic cylinder that applies pressure on the steering gear.

2. Electro – hydraulic power steering system- It is the modified version of the hydraulic system in which the rotary hydraulic pump which is driven by the engine in hydraulic power steering system is replaced with the hydraulic pump which is driven by the electric motor.

- It is also called the hybrid power steering system due to the use of both hydraulic and electric components.

3. Electronic power steering system- It is the latest type of power steering system in which the hydraulic system from the hydraulic power steering is completely replaced with electric motors and electric sensors, instead of using hydraulic force ,the motor driven by the vehicle's battery is used to apply force on the steering gear and torque provided by the motor is controlled by the sensors that detects the position of the steering column.

- The steering response of this system is quick and very effective that is why it is used in almost all the new cars today.

Important Components

The important parts of a power steering system are-

1. Steering mechanism- Usually rack and pinion steering mechanism is used in power steering in which the rotational motion of the steering wheel is converted into the transverse motion of the wheels by a set of constantly meshed worm gears called rack that provide transverse motion and a pinion that provides rotational motion.

2. Linkages – They are the mechanical constraints that provide relative motion between 2 components, the type of linkages used in power steering is the tie-roads that connects the rack to the knuckle of the wheel in order to transfer the transverse motion of the rack to the wheels.

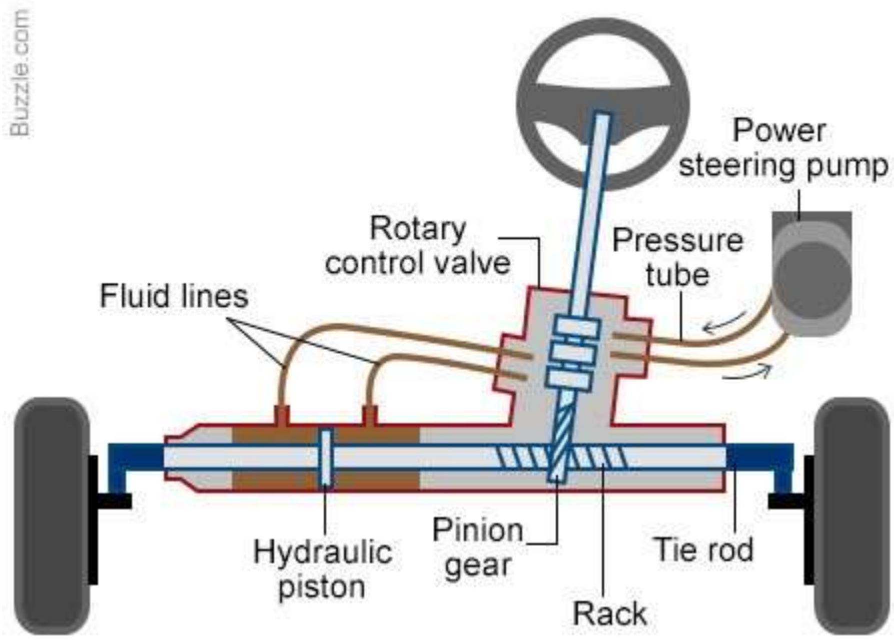
3. Power device- As we have already discussed above a force multiplying device (either hydraulic or hybrid or electric) is used to multiply the steering wheel force in order to reduce steering efforts. This device is attached with the pinion of the rack and pinion mechanism.

4. Steering wheel- A round steering wheel is used inside a cockpit (operated by the driver) that provides the rotational steering input to the further steering devices in order to steer the vehicle.

WORKING OF POWER STEERING SYSTEM

The working of the power steering system differs with the difference in force multiplying devices used. so to understand the working of the power steering all the 3 methods must be discussed separately.

1. Hydraulic Power Steering System



In this type of power steering system as we discussed above the hydraulic force is used to multiply the steering input force in order to smoothen the steering of the front wheels, this hydraulic force is generated by a series of components that includes hydraulic cylinder, rotator hydraulic pump, hydraulic lines, highly compressed hydraulic fluid and a coupling mechanism that can couple this hydraulic system with rack of the steering system.

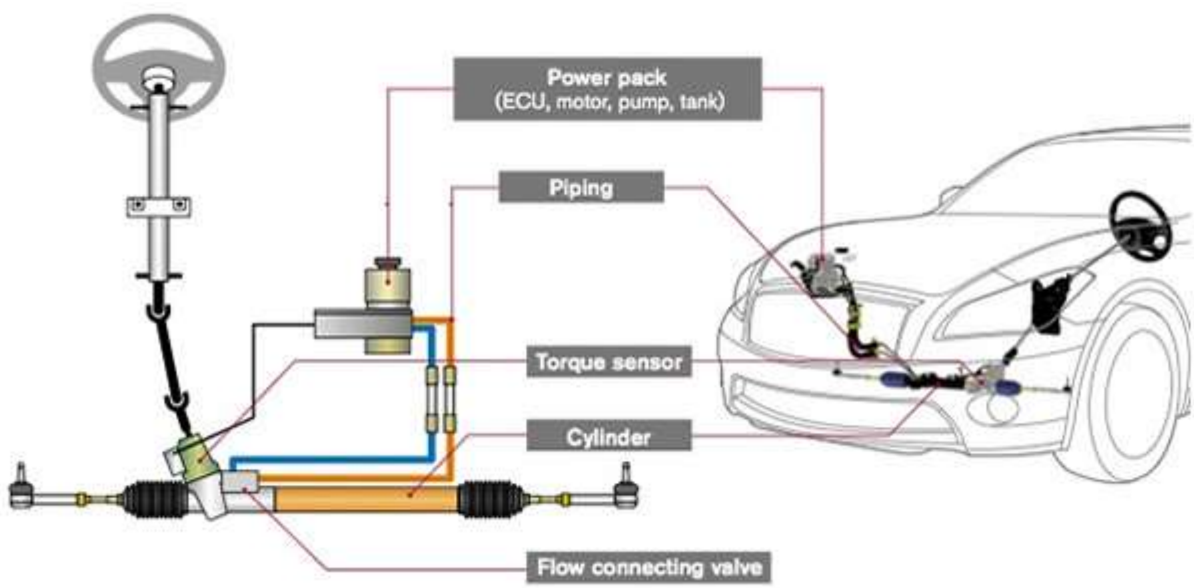
- When the driver provides input by rotating the steering wheel, the hydraulic pump driven by the engine starts pumping the highly compressed hydraulic fluid through lines.
- The hydraulic pressure produced by the pump enters the hydraulic cylinder which in turn applies pressure over the cylinder's piston.
- The piston which is under high pressure starts moving from one end to the another which in turn pushes the further fluid through lines, with this movement of piston the input force applied by the driver is multiplied several times.
- This high pressure fluid sent by the hydraulic cylinder then applies the pressure to the attached pinion through the coupling mechanism which in turn applies high force to the rack gear and the steering action in the front wheels takes place.

2. Hybrid or Semi Hydraulic Power Steering System

In this type of power steering system the hydraulic pump driven by the engine from the hydraulic power steering system is replaced with electric pump which makes it more reliable, this is the only modification made rest the working of this system is same as the hydraulic power steering system mentioned above.

3. Electric Power Steering System

This system is latest of all the steering system mentioned above in this type of steering system as we have already discussed the force multiplication is the function of the electric motor instead of hydraulic fluid and the working of this system is as follows-



- When the driver gives input through the steering wheel the electronic sensors attached to the steering column reads the input and sent them to the electric control unit of the vehicle.
- The ECU of the vehicle analyses these inputs and sent the voltage signal to the electric motor

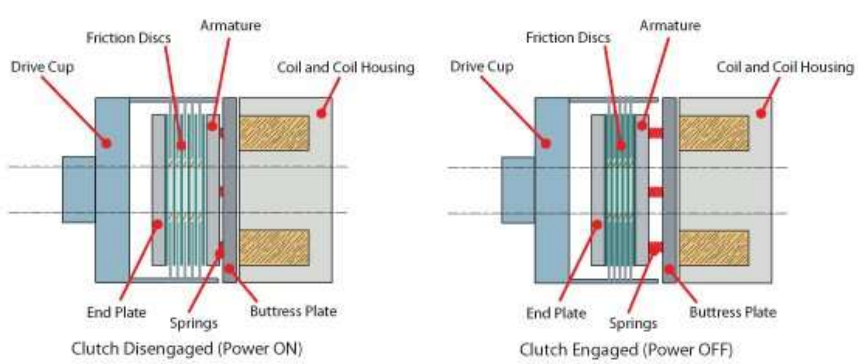
placed at the end of the steering column whose gear is in constant mesh with the pinion gear.

- Due to these voltage signals sent by the ECU the motor which is driven by the battery of the vehicle starts and provides the particular torque according to the value of the voltage signals received
- After the motor starts the gear which is in constant mesh with the pinion gear starts transmitting the multiplied torque to the pinion gear which in turn applies this torque to the rack through which it is attached.
- With this torque applied by the pinion over rack , rack moves which in turn steer the front wheels (with the help of the tie rods attached) as per the requirement.

ELECTRICAL CLUTCH AND ELECTRICAL BRAKE ENGAGEMENT

Electrically engaged clutches or brakes require that electricity be supplied to a coil for engagement. While electricity is being supplied, a coil generates a magnetic field and the unit is engaged. The magnetic field is used to pull on an end plate, which squeezes a set of friction discs together allowing the clutch or brake to transmit torque.

When the electricity is turned off, the discs are separated by wave springs, and the clutch or brake is disengaged.

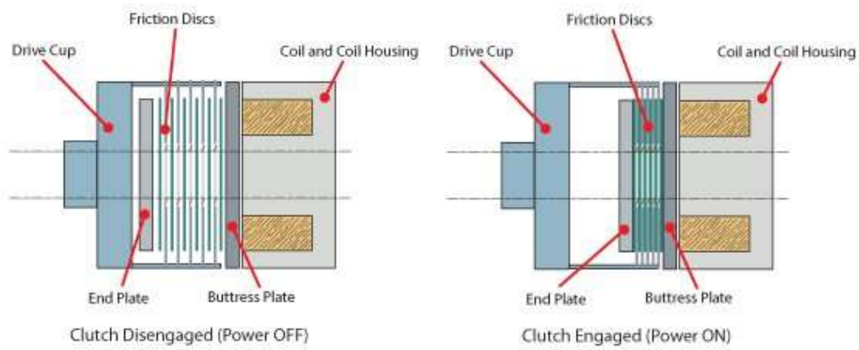


Spring Applied Electric Clutch

Electrically Released (Spring Engaged)

Electrically released clutches or brakes are engaged when electricity is absent from the coil. When electricity is not supplied (that is when the electrical power is OFF), springs are used to squeeze a set of friction discs together allowing the clutch or brake to transmit or arrest torque.

The unit is not disengaged until electricity is supplied. Under that condition, the coil generates a magnetic field which is used to pull an armature plate against the springs, overcoming the spring force and allowing the friction discs to separate. The discs are now allowed to spin freely without the ability to transmit or hold torque.



Energy Applied Electric Clutch

ELECTRONIC SUSPENSION

Electronic suspensions are the most advanced suspension systems available. In the simplest terms, electronic suspensions adjust the feel of the suspension and your vehicle's ride height to cater to changing road conditions with ease. But how exactly do they work?

Basics of Electronic Suspensions

Electronic suspension is essentially a computer-controlled system that can adjust the ride characteristics and performance of your vehicle. Unlike air suspensions, an electronic suspension modifies the shocks and/or struts electronically to ensure a smooth ride. Some electronic suspensions are also designed to automatically adapt to changing road conditions for improved handling in all sorts of terrain.

How Do Electronic Suspensions Work?

There are two types of electronic suspensions: adaptive and active. Each one works in a different way to improve performance.

Adaptive Electronic Suspensions

An adaptive electronic suspension is responsible for controlling the shock absorbers and their dampening performance. Simply put, they adjust the shocks as needed to deliver a smooth driving experience.

Adaptive suspensions can adjust the shocks using a solenoid and valve that's placed on the strut. The solenoid connects to a computer in the system and monitors the road conditions. When stiffness and overall suspension performance need to be adjusted, the solenoid communicates this information to the system. Then it will activate the valves to open and close as needed to regulate the amount of hydraulic fluid going into the shocks.

An adaptive suspension may also use a magneto damper, or a damper filled with fluid that contains metal particles. An electromagnet controls these little pieces of metal to adjust the pressure and stiffness in each damper.

Active Electronic Suspensions

An active electronic suspension changes the ride height for your vehicle to improve performance and towing capabilities. This type of electronic suspension uses hydraulics or electromagnets to operate.

Active suspensions that adjust hydraulically use sensors to monitor the vehicle's movement and ride height. When performance or ride height needs to be regulated, the system activates a hydraulic pump that pressurizes the liquid in the shocks. This will configure the stiffness of the suspension as well as the height of the vehicle to your specific preferences.

Electromagnetically controlled active suspensions work similarly to hydraulically controlled systems. The only difference is that these systems use electromagnet motors instead of pumps to adjust a car's ride height. This type of active electronic suspension is known to respond faster and use less power than hydraulics.

Which Type of Electronic Suspension is Right for You?

Both types of electronic suspensions can improve performance but in different ways. If you're looking for something to enhance your driving experience during your commutes, consider an adaptive electronic suspension. Its ability to monitor the road and automatically adjust the stiffness of the shocks will allow you to experience a smooth ride in most road conditions.

Those looking to adjust vehicle height for towing or performance purposes should consider installing an active electronic suspension kit. These allow you to raise or lower your vehicle will help you tow more and ensure a smooth ride.

But regardless of which type of electronic suspension you choose, you're sure to get a great performance.

AIRBAG SYSTEM

The airbag system is one of the most important parts of your vehicle's safety components. Proper airbag deployment can ensure that you and your passengers survive a crash where you may have otherwise experienced serious injury or death.

Air bags were introduced in passenger cars in early 1980s and their deployment has saved thousands of lives through the years. But how exactly do they work?
The airbag system is extremely complex and needs to activate within milliseconds after a crash occurs to ensure the protection of the driver and passengers from the forces of a head-on collision.

What Are Airbags?

Airbags are stretchable fabrics or other materials that are tightly packed in various locations throughout your vehicle. There are airbags at the front of the dashboard in most cars, and many vehicles have airbags along the side of the car as well. These bags are compressed and kept in a small area. When there is an accident, the airbags fill up with air very quickly to provide a cushioning system for the people in the car so that they are not thrown around in the event of a crash. While this does not necessarily prevent total injury or death, it can be very helpful in cushioning the passengers in a car in many cases.

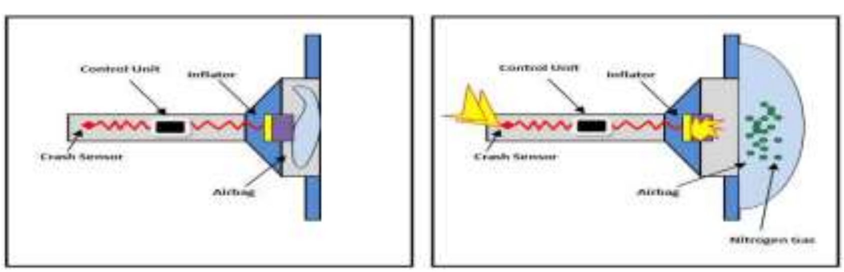
There are three main parts to an air bag.

First, There is the bag itself, which is made of thin, nylon fabric and folded into the steering wheel or the dash board.

2. Crash sensor -The most important part behind the success of the airbag system are the crash sensors. These small pieces of electronics are designed to tell when the vehicle has been damaged in an accident. They respond to several different sets of stimuli, including sudden stopping, increased pressure as pieces of the car are moved due to the force of the collision. It detects a collision force equal to running into a brick wall at 10 to 15 miles per hour (16 to 24 kph).Combination of accelaration sensors and pressure sensors are often used to detect sudden changes in pressure and acceleration experienced in the car.

3. Inflation system - Air bags are actually inflated by the equivalent of a solid rocket booster. Sodium azide (NaN_3) and potassium nitrate (KNO_3) react very quickly to produce a large pulse of hot nitrogen gas. This gas inflates the bag, which literally bursts out of the steering wheel or dashboard as it expands. About a second later, the bag is already deflating (it has holes in it) in order to get out of your way and to prevent choking hazards.

<u>The typical view of this process is shown in fig :-</u>



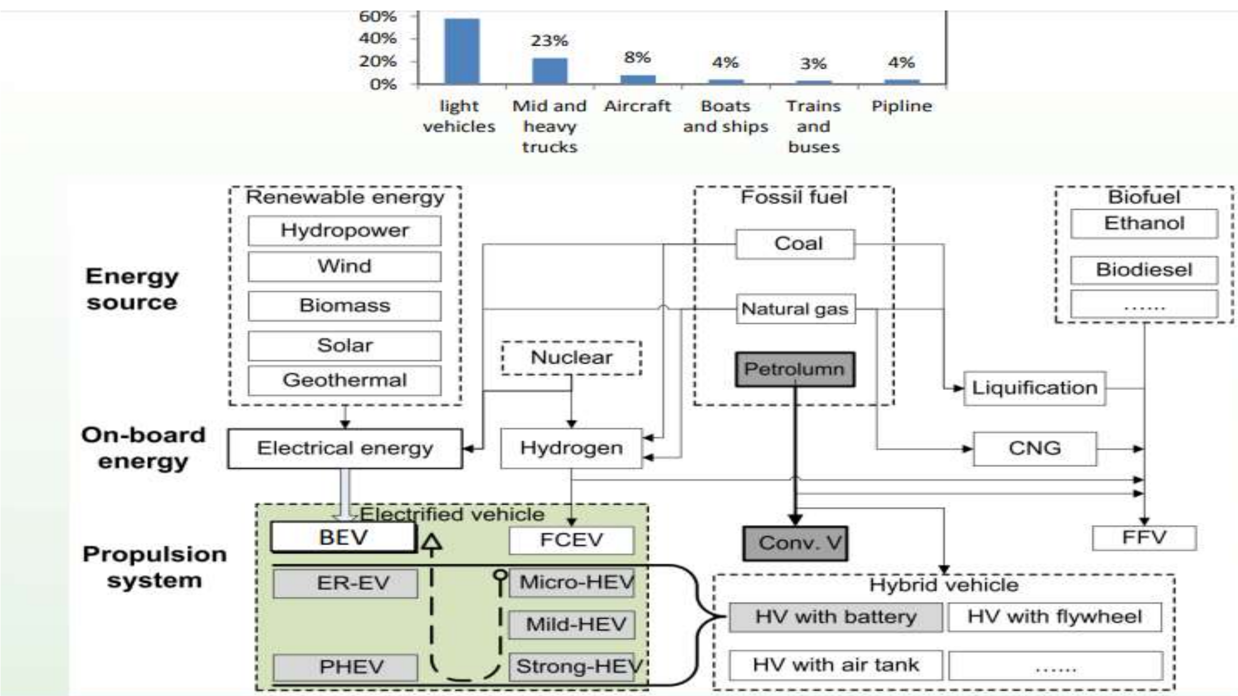
MODULE V

ELECTRIC VEHICLES AND HYBRID VEHICLES

INTRODUCTION

Electrical vehicle (EV) based on electric propulsion system. No internal combustion engine is used. All the power is based on electric power as the energy source. The main advantage is the high efficiency in power conversion through its proposition system of electric motor. Recently there has been massive research and development work reported in both academic and industry. Commercial vehicle is also available. Many countries have provided incentive to users through lower tax or tax exemption, free parking and free charging facilities.

On the other hand, the hybrid electric vehicle (HEV) is an alterative. It has been used extensive in the last few years. Nearly all the car manufacturers have at least one model in hybrid electric vehicle. The questions come to us: Which vehicle will dominate the market and which one is uitable for future? This paper is to examine the recent development of electric vehicle and suggest the future development in the area.



History

Edison and a 1914 Detroit Electricmodel 47 (courtesy of the National Museum of American History)

An EV and an antique car on display at a 1912 auto show

Electric motive power started in 1827, when Hungarian priest Ányos Jedlik built the first crude but viable electric motor, provided with stator, rotor and commutator, and the year after he used it to power a tiny car. A few years later, in 1835, professor Sibrandus Stratingh of University of Groningen, the Netherlands, built a small scale electric car and a Robert Anderson of Scotland is reported to have made a crude electric carriage sometime between the years of 1832 and 1839. Around the same period, early experimental electrical cars were moving on rails, too. American blacksmith and inventor Thomas Davenport built a toy electric locomotive, powered by a primitive electric motor, in 1835. In 1838, a Scotsman named Robert Davidson built an electric locomotive that attained a speed of four miles per hour (6 km/h). In England a patent was granted in 1840 for the use of rails as conductors of electric current, and similar American patents were issued to Lilley and Colten in 1847.

Between 1832 and 1839 (the exact year is uncertain), Robert Anderson of Scotland invented the first crude electric carriage, powered by non-rechargeable primary cells.

The first mass-produced electric vehicles appeared in America in the early 1900s. In 1902, "Studebaker Automobile Company" entered the automotive business with electric vehicles though it also entered the gasoline vehicles market in 1904. However, with the advent of cheap assembly line cars by Ford, electric cars fell to the wayside

Due to the limitations of storage batteries at that time, electric cars did not gain much popularity, however electric trains gained immense popularity due to their economies and fast speeds achievable. By the 20th century, electric rail transport became commonplace. Over time their general-purpose commercial use reduced to specialist roles, as platform trucks, forklift trucks, ambulances, tow tractors and urban delivery vehicles, such as the iconic British milk float; for most of the 20th century, the UK was the world's largest user of electric road vehicles.

Electrified trains were used for coal transport, as the motors did not use precious oxygen in the mines. Switzerland's lack of natural fossil resources forced the rapid electrification of their rail network. One of the earliest rechargeable batteries - the nickel-iron battery - was favored by Edison for use in electric cars.

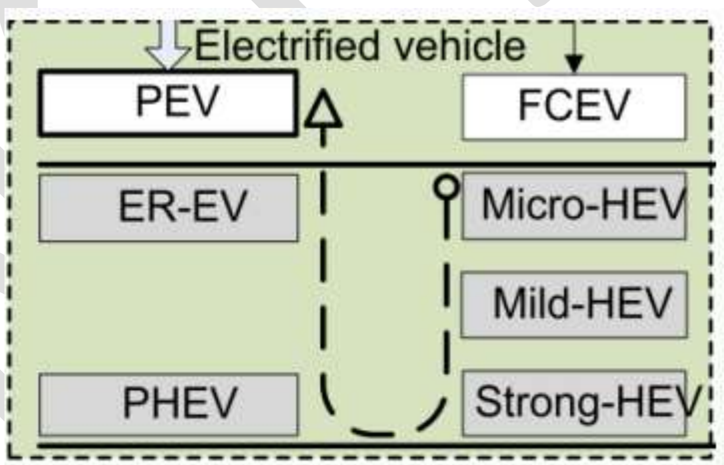
EVs were among the earliest automobiles, and before the preeminence of light, powerful internal combustion engines, electric automobiles held many vehicle land speed and distance records in the early 1900s. They were produced by Baker Electric, Columbia Electric, Detroit Electric, and others, and at one point in history out-sold gasoline-powered vehicles. In fact, in 1900, 28 percent of the cars on the road in the USA were electric. EVs were so popular that even President Woodrow Wilson and his secret service agents toured Washington, DC, in their Milburn Electrics, which covered 60–70 mi (100–110 km) per charge.

A number of developments contributed to decline of electric cars.[11] Improved road infrastructure required a greater range than that offered by electric cars, and the discovery of large reserves of petroleum in Texas, Oklahoma, and California led to the wide availability of affordable gasoline/petrol, making internal combustion powered cars cheaper to operate over long distances. Also internal combustion powered cars became ever easier to operate thanks to the invention of the electric starter by Charles Kettering in 1912, which eliminated the need of a hand crank for starting a gasoline engine, and the noise emitted by ICE cars became more bearable thanks to the use of the muffler, which Hiram Percy Maxim had invented in 1897. As roads were improved outside urban areas electric vehicle range could not compete with the ICE. Finally, the initiation of mass production of gasoline-powered vehicles by Henry Ford in 1913 reduced significantly the cost of gasoline cars as compared to electric cars.

In the 1930s, National City Lines, which was a partnership of General Motors, Firestone, and Standard Oil of California purchased many electric tram networks across the country to dismantle them and replace them with GM buses. The partnership was convicted of conspiring to monopolize the sale of equipment and supplies to their subsidiary companies, but were acquitted of conspiring to monopolize the provision of transportation services.

ELECTRIC VEHICLE CHARACTERISTICS

- Must have One or more electric machines (EMs)
- Must have an energy storage system (ESS) other than the fossil fuel tank.
- The EMs must provide propulsion power (partially or full)



EV AND HEV

HEV has been promoted extensively in the last decade. Nearly each manufacturer has at least one HEV in the market. It is supposed to rescue the battery energy storage problem at that time. Using hybrid vehicle it allows the electric power can be obtained from engine.

The HEV is broadly divided into series hybrid and series hybrid. The engine power of the series hybrid is connected totally to the battery. All the motor power is derived from the battery. For the parallel hybrid, both the engine and motor contribute the propulsion power. The torque is the sum of both motor and engine. The motor is also used as a generator to absorb the power from engine through the transmission. Bothe series or hybrid can absorb power through regeneration during braking or deceleration.

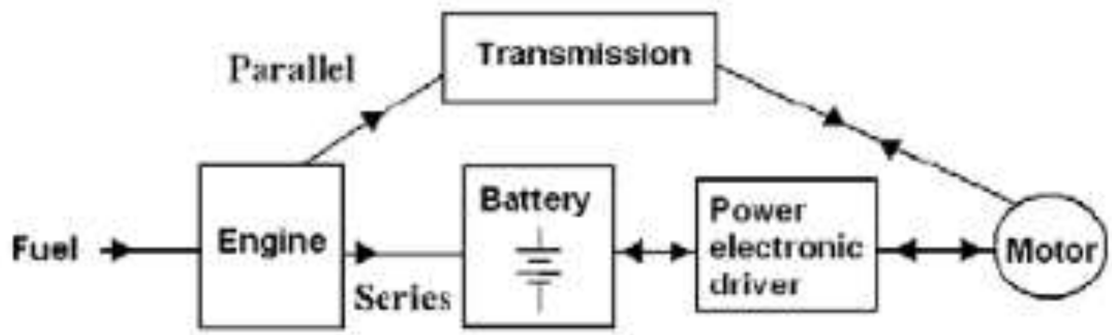


Fig 1: The series or parallel path of an HEV

Nevertheless, HEV still has emission. The introduction of plug-in HEV that solves some of the problem , It accepts the electric power to battery through plug in from the mains. Therefore when convenient, users may charge

the battery using AC from the mains.

THE KEY COMPONENTS IN EV

Electric Machines (EM) – Power electronics – Energy management system (EMS) – Energy Storage system (ESS)

The electric vehicle is rather simple in structure. The key components are the propulsion parts. Fig 2 shows the configuration.

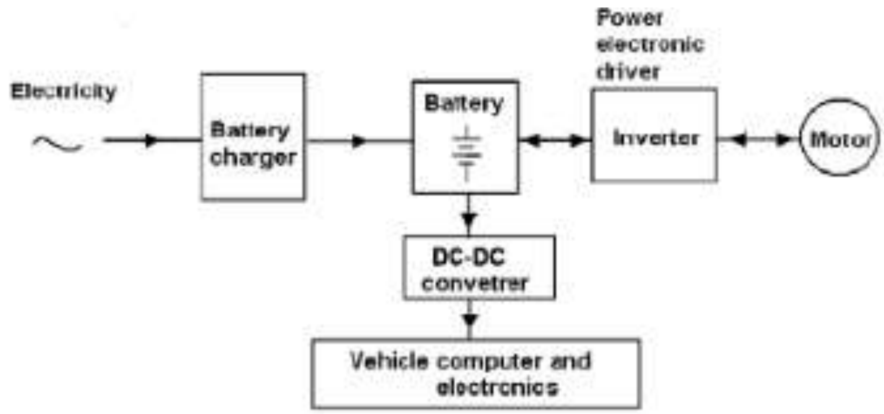


Fig 2: The key components of an Electric Vehicle.

The battery is the main energy storage. The battery charger is to convert the electricity from mains to charge the battery. The battery voltage is DC and I is inverted into switched-mode signal through power electronic inverter to drive the motor. The other electronic components in a vehicle can be supplied to the battery through DC-DC converter that step down the voltage from the battery pack to lower voltage such as 5V-20V.

THE MOTOR

There are a number of motors available for electric vehicle: DC motors, Induction motor, DC brushless motor, Permanent magnetic synchronous motor and Switched reluctance motor.

The power of a vehicle's electric motor, as in other vehicles, is measured in kilowatts (kW). 100 kW is roughly equal to 134 horsepower, but electric motors can deliver their maximum torque over a wide RPM range. This means that the performance of a vehicle with a 100 kW electric motor exceeds that of a vehicle with a 100 kW internal combustion engine, which can only deliver its maximum torque within a limited range of engine speed.

Energy is lost during the process of converting the electrical energy to mechanical energy. Approximately 90% of the energy from the battery is converted to mechanical energy, the losses being in the motor and drivetrain.[46]

Usually, direct current (DC) electricity is fed into a DC/AC inverter where it is converted to alternating current (AC) electricity and this AC electricity is connected to a 3-phase AC motor.

For electric trains, forklift trucks, and some electric cars, DC motors are often used. In some cases, universal motors are used, and then AC or DC may be employed. In recent production vehicles, various motor types have been implemented, for instance: Induction motors within Tesla Motor vehicles and permanent magnet machines in the Nissan Leaf and Chevrolet Bolt

EM Type	Current	Image	Usage in EVs	Pros and Cons
Permanent magnet (PM) motor	3 phase AC		Used in most EVs	High efficiency, high torque short constant power range
Induction motor	3 phase AC		Tesla, Toyota RAV-4 EV	Simple, robust, wide speed range Less efficient than PM motors
Switched Reluctance motor	DC		Not yet widely used in EVs	Capable of extreme high speed Costly

DC motors:

It is a classical motor and has been used in motor control for a long time. All the power involved in electromechanical conversion is transferred to the rotor through stationary brushes which are in rubbing contact with the copper segments of the commutator. It requires certain maintenance and has a shorter life time. However, it is suitable for low power application. It has found applications in electric wheel-chair, transporter and micro-car. Today, most of the golf-carts are using DC motors. The power level is les than 4kW.

Induction motor

It is a very popular AC motors. It also has a large market share in variable speed drive application such as air-conditioning, elevator or escalator. Many of the higher power electric for more than 5kW, uses for more than 5kW, uses induction motor. Usually a vector drive is used to provide torque and speed control.

DC brushless motor

The conventional DC motor is poor mechanically because the low power winding, the field, is stationary while the main high power winding rotates. The DC brushless motor is "turned inside

out. The high power winding is put on the stationary side of the motor and the field excitation is on the rotor using a permanent magnet. The motor has longer life time than the DC motor but is a

few times more expensive. Most of the DC motor can be replaced by the brushless motor with suitable driver. Presently, its applications find in low power EV.

Permanent magnetic synchronous motor

The stator is similar to that of an induction motor. The rotor us mounted with permanent magnets. It is equivalent to an induction motor but the air-gap filed is produced by a permanent

magnet. The driving voltage is sine wave generated by Pulse Width Modulation (PWM).

Switched reluctance motor

It is a variable reluctance machine and its famous recently because of the fault tolerance because each phase is decoupled from other. The power stage is different from other the motor discussed

in 2-4. Each phase winding is connected in a flyback circuit style.

DIRECT DRIVE AND IN-WHEEL MOTOR

Direct drive reduces the loss in the mechanical units of the drive train. The motor is connected directly to the shaft to reduce needs of transmission, clutch, and gear box. Recently the in-wheel motor is promoted by researcher .

The in-wheel motor is to turn the rotor inside out and attached to the wheel's rim and the tire. There is no gear box and drive shaft. Fig 3 shows the in-wheel motor.

a) Hardware b) FEM model

Fig 3: The in-wheel motor

The motor is also called wheel-hub motor. Its main advantage is the independent control of each wheel. Fig 4 shows the 4-wheele drive vehicle. Each of the wheels works any speed and direction. Therefore the parallel barking can be achieved easily. The Anti-lock braking system can be implemented easily by the technology. It has been shown that it can successfully prevent spinout. The whole vehicle is much simpler in structure. Many different types of motor can be used for in-wheel motor. The prominent one is the switched-reluctance types. Its phase-winding is independently from each and therefore the fault tolerance is much more advanced that the other. There is no permanent magnetic in the motor, it reduces any interference by permanent field and the fluctuation of the permanent magnetic materials.

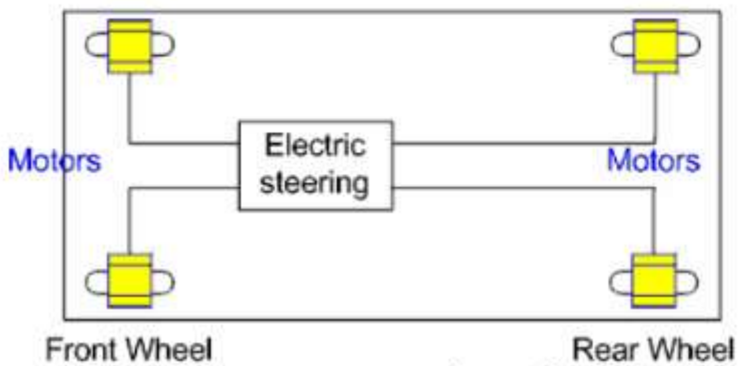


Fig. 4: True 4-wheel drive vehicle.

ELECTRICITY SOURCES

There are many ways to generate electricity, of varying costs, efficiency and ecological desirability.

A passenger train, taking power through a third rail with return through the traction rails

An electric locomotive at Brig, Switzerland

Electric bus in Santa Barbara, California

Connection to generator plants

- direct connection to generation plants as is common among electric trains, trolley buses, and trolley trucks (See also : overhead lines, third rail and conduit current collection)
- Online Electric Vehicle collects power from electric power strips buried under the road surface through electromagnetic induction

Onboard generators and hybrid EVs

- generated on-board using a diesel engine: diesel-electric locomotive
- generated on-board using a fuel cell: fuel cell vehicle
- generated on-board using nuclear energy: nuclear submarines and aircraft carriers
- renewable sources such as solar power: solar vehicle

It is also possible to have hybrid EVs that derive electricity from multiple sources. Such as:

- on-board rechargeable electricity storage system (RESS) and a direct continuous connection to land-based generation plants for purposes of on-highway recharging with unrestricted highway range
- on-board rechargeable electricity storage system and a fueled propulsion power source (internal combustion engine): plug-in hybrid

Another form of chemical to electrical conversion is fuel cells, projected for future use.

For especially large EVs, such as submarines, the chemical energy of the diesel-electric can be replaced by a nuclear reactor. The nuclear reactor usually provides heat, which drives a steam turbine, which drives a generator, which is then fed to the propulsion.

A few experimental vehicles, such as some cars and a handful of aircraft use solar panels for electricity.

Onboard storage

These systems are powered from an external generator plant (nearly always when stationary), and then disconnected before motion occurs, and the electricity is stored in the vehicle until needed.

- on-board rechargeable electricity storage system (RESS), called Full Electric Vehicles (FEV). Power storage methods include:
    - chemical energy stored on the vehicle in on-board batteries: Battery electric vehicle (BEV)
    - kinetic energy storage: flywheels
    - static energy stored on the vehicle in on-board electric double-layer capacitors

batteries, electric double-layer capacitors and flywheel energy storage are forms of rechargeable on-board electrical storage. By avoiding an intermediate mechanical step, the energy conversion efficiency can be improved over the hybrids already discussed, by avoiding unnecessary energy conversions. Furthermore, electro-chemical batteries conversions are easy to reverse, allowing electrical energy to be stored in chemical form.

Lithium-ion battery

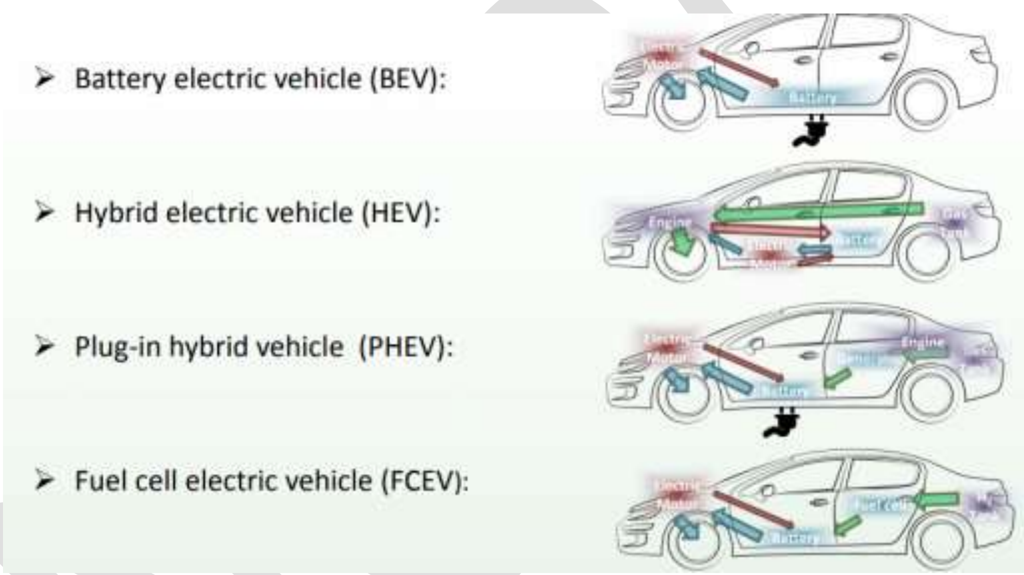
Most electric vehicles use lithium ion batteries. Lithium ion batteries have higher energy density, longer life span and higher power density than most other practical batteries. Complicating factors include safety, durability, thermal breakdown and cost. Li-ion batteries should be used within safe temperature and voltage ranges in order to operate safely and efficiently.

Increasing the battery's lifespan decreases effective costs. One technique is to operate a subset of the battery cells at a time and switching these subsets.

In the past, Nickel Metal Hydride batteries were used among EV cars such as those made by General Motors. These battery types are considered out-dated due to their tendencies to self discharge in the heat. Also the batteries' patent was held by Chevron which created a problem for their widespread development. These detractors coupled with their high cost has led to Lithium-ion batteries leading as the predominant battery for EV's.

VEHICLE TYPES

It is generally possible to equip any kind of vehicle with an electric powertrain.



Ground vehicles

Plug-in electric vehicle

The Chevrolet Volt is the world's top selling plug-in hybrid of all time. Global Volt/Ampera family sales passed the 100,000 unit milestone in October 2015.

A plug-in electric vehicle (PEV) is any motor vehicle that can be recharged from any external source of electricity, such as wall sockets, and the electricity stored in the rechargeable battery packs drives or contributes to drive the wheels. PEV is a subcategory of electric vehicles that includes all-electric or battery electric vehicles (BEVs), plug-in hybrid vehicles, (PHEVs), and electric vehicle conversions of hybrid electric vehicles and conventional internal combustion engine vehicles.

Cumulative global sales of highway-capable light-duty pure electric vehicles passed one million units in total, globally, in September 2016.[30][52] Cumulative global sales of plug-in cars and utility vans totaled over 2 million by the end of 2016, of which 38% were sold in 2016,[53] and the 3 million milestone was achieved in November 2017.[54]

As of January 2018, the world's top selling plug-in electric cars is the Nissan Leaf, with global sales of more than 300,000 units.[19] As of June 2016, it was followed by the all-electric Tesla Model S with about 129,400 units sold worldwide, the Chevrolet Volt plug-in hybrid, which together with its sibling the Opel/Vauxhall Ampera has combined global sales of about 117,300 units, the Mitsubishi Outlander P-HEV with about 107,400 units, and the Prius Plug-in Hybrid with over 75,400 units.

Hybrid EVs

A hybrid electric vehicle combines a conventional (usually fossil fuel-powered) powertrain with some form of electric propulsion. As of April 2016, over 11 million hybrid electric vehicles have been sold worldwide since their inception in 1997. Japan is the market leader with more than 5 million hybrids sold, followed by the United States with cumulative sales of over 4 million units since 1999, and Europe with about 1.5 million hybrids delivered since 2000. Japan has the world's highest hybrid market penetration. By 2013 the hybrid market share accounted for more than 30% of new standard passenger car sold, and about 20% new passenger vehicle sales including kei cars. Norway ranks second with a hybrid market share of 6.9% of new car sales in

2014, followed by the Netherlands with 3.7%

Global hybrid sales are by Toyota Motor Company with more than 9 million Lexus and Toyota hybrids sold as of April 2016,[59] followed by Honda Motor Co., Ltd. with cumulative global sales of more than 1.35 million hybrids as of June 2014, Ford Motor Corporationwith over 424,000 hybrids sold in the United States through June 2015, and the Hyundai Group with cumulative global sales of 200,000 hybrids as of March 2014, including both Hyundai Motor Company and Kia Motors hybrid models. As of April 2016, worldwide hybrid sales are led by the Toyota Prius lift back, with cumulative sales of over 3.7 million units. The Prius nameplate has sold more than 5.7 million hybrids up to April 2016.[69]

On- and off-road EVs

An electric powertrain used by Power Vehicle Innovation for trucks or buses.

EVs are on the road in many functions, including electric cars, electric trolleybuses, electric buses, battery electric buses, electric trucks, electric bicycles, electric motorcycles and scooters, personal transporters, neighborhood electric vehicles, golf carts, milk floats, and forklifts. Off-road vehicles include electrified all-terrain vehicles and tractors.

Railborne EVs

A streetcar (or Tram) drawing current from a single overhead wire through a pantograph.

The fixed nature of a rail line makes it relatively easy to power EVs through permanent overhead lines or electrified third rails, eliminating the need for heavy onboard batteries. Electric locomotives, electric trams/streetcars/trolleys, electric light rail systems, and electric rapid transitare all in common use today, especially in Europe and Asia.

Since electric trains do not need to carry a heavy internal combustion engine or large batteries, they can have very good power-to-weight ratios. This allows high speed trains such as France's double-deck TGVs to operate at speeds of 320 km/h (200 mph) or higher, and electric locomotives to have a much higher power output than diesel locomotives. In addition, they have higher short-term surge power for fast acceleration, and using regenerative brakes can put braking power back into the electrical grid rather than wasting it.

Maglev trains are also nearly always EVs.

Space rover vehicles

Manned and unmanned vehicles have been used to explore the Moon and other planets in the solar system. On the last three missions of the Apollo program in 1971 and 1972, astronauts drove silver-oxide battery-powered Lunar Roving Vehicles distances up to 35.7 kilometers (22.2 mi) on the lunar surface. Unmanned, solar-powered rovers have explored the Moon and Mars.

Airborne EVs

Since the beginning of the dawn of the time of aviation, electric power for aircraft has received a great deal of experimentation. Currently flying electric aircraft include manned and unmanned aerial vehicles.

Seaborne EVs

Oceanvolt SD8.6 electric saildrive motor

Electric boats were popular around the turn of the 20th century. Interest in quiet and potentially renewable marine transportation has steadily increased since the late 20th century, as solar cells have given motorboats the infinite range of sailboats. Electric motors can and have also been used in sailboats instead of traditional diesel engines. Electric ferries operate routinely. Submarines use batteries (charged by diesel or gasoline engines at the surface), nuclear power, fuel cells or Stirling engines to run electric motor-driven propellers.

Electrically powered spacecraft

Electric power has a long history of use in spacecraft. The power sources used for spacecraft are batteries, solar panels and nuclear power. Current methods of propelling a spacecraft with electricity include the arcjet rocket, the electrostatic ion thruster, the Hall effect thruster, and Field Emission Electric Propulsion. A number of other methods have been proposed, with varying levels of feasibility.

PROPERTIES

Components

The type of battery, the type of traction motor and the motor controller design vary according to the size, power and proposed application, which can be as small as a motorized shopping cart or wheelchair, through pedelecs, electric motorcycles and scooters, neighborhood electric vehicles, industrial fork-lift trucks and including many hybrid vehicles.

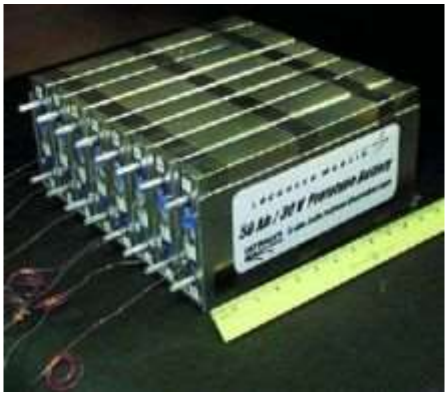
Energy sources

Although EVs have few direct emissions, all rely on energy created through electricity generation, and will usually emit pollution and generate waste, unless it is generated by renewable source power plants. Since EVs use whatever electricity is delivered by their electrical utility/grid operator, EVs can be made more or less efficient, polluting and expensive to run, by modifying the electrical generating stations. This would be done by an electrical utility under a government energy policy, in a timescale negotiated between utilities and government.

Fossil fuel vehicle efficiency and pollution standards take years to filter through a nation's fleet of vehicles. New efficiency and pollution standards rely on the purchase of new vehicles, often as the current vehicles already on the road reach their end-of-life. Only a few nations set a retirement age for old vehicles, such as Japan or Singapore, forcing periodic upgrading of all vehicles already on the road.

EVs will take advantage of whatever environmental gains happen when a renewable energy generation station comes online, a fossil-fuel power station is decommissioned or upgraded. Conversely, if government policy or economic conditions shifts generators back to use more polluting fossil fuels and internal combustion engine vehicles (ICEVs), or more inefficient sources, the reverse can happen. Even in such a situation, electrical vehicles are still more efficient than a comparable amount of fossil fuel vehicles. In areas with a deregulated electrical energy market, an electrical vehicle owner can choose whether to run his electrical vehicle off conventional electrical energy sources, or strictly from renewable electrical energy sources (presumably at an additional cost), pushing other consumers onto conventional sources, and switch at any time between the two.

Issues with batteries



lithium ion polymer batteryprototypes. Newer Li-poly cells provide up to 130 Wh/kg and last through thousands of charging cycles.

Efficiency

Because of the different methods of charging possible, the emissions produced have been quantified in different ways. Plug-in all-electric and hybrid vehicles also have different consumption characteristics.

Electromagnetic radiation

Electromagnetic radiation from high performance electrical motors has been claimed to be associated with some human ailments, but such claims are largely unsubstantiated except for extremely high exposures. Electric motors can be shielded within a metallic Faraday cage, but this reduces efficiency by adding weight to the vehicle, while it is not conclusive that all electromagnetic radiation can be contained.

CHARGING SYSTEMS AND METHODS

General charger

The charger needed for the battery system for slow charging or fast charger are both required to handle high power. The H-bridge power converter is needed . Fig 5 shows the converter. The converter is famous for its efficiency and has found application in charger and DC-DC converter.

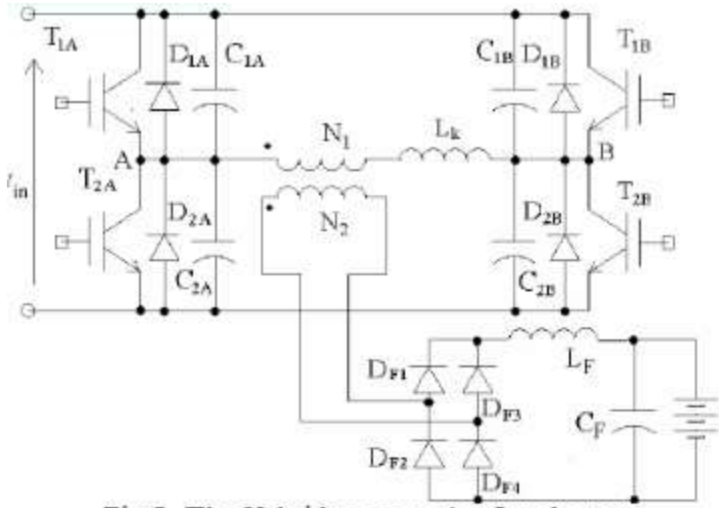


Fig 5: The H-bridge converter for charger

Ultra-capacitor charger

The voltage on the ultra-capacitor various from the full-voltage to zero when nits energy storage varies from full to zero. This is different from the battery as its voltage will only varies within

25%. The capacitor voltage is internal point and is not in contact with users. The transformer

isolated converter is not necessary. A tapped converter should be used as it will have higher efficiency for power conversion . The efficiency of the power converter is higher than the transformer-isolated version. The structure is simple.

Grid capacity

If a large proportion of private vehicles were to convert to grid electricity it would increase the demand for generation and transmission, and consequent emissions.[79] However, overall energy consumption and emissions would diminish because of the higher efficiency of EVs over the entire cycle. In the USA it has been estimated there is already nearly sufficient existing power plant and transmission infrastructure, assuming that most charging would occur overnight, using the most efficient off-peak base load sources.

In the UK however, things are different. While National Grid's high-voltage electricity transmission system can currently manage the demand of 1 million electric cars, Steve Holliday (CEO National Grid PLC) said, “penetration up and above that becomes a real issue. Local distribution networks in cities like London may struggle to balance their grids if drivers choose to all plug in their cars at the same time."

Charging stations

BYD e6 taxi in Shenzhen, China. Recharging in 15 Minutes to 80 Percent

A Sunwin electric bus in Shanghai at a charging station

EVs typically charge from conventional power outlets or dedicated charging stations, a process that typically takes hours, but can be done overnight and often gives a charge that is sufficient for normal everyday usage.

However, with the widespread implementation of electric vehicle networks within large cities in the UK and Europe, EV users can plug in their cars whilst at work and leave them to charge throughout the day, extending the possible range of commutes and eliminating range anxiety.

A recharging system that avoids the need for a cable is Curb Connect, patented in 2012 by Dr Gordon Dower. In this system, electrical contacts are fitted into curbs, such as angle parking spaces on city streets. When a suitably authorized vehicle is parked so that its front end overhangs the curb, the curb contacts become energized and charging occurs.

Another proposed solution for daily recharging is a standardized inductive charging system such as Evatran's Plugless Power. Benefits are the convenience of parking over the charge station and minimized cabling and connection infrastructure. Qualcomm is trialling such a system in London in early 2012.

Yet another proposed solution for the typically less frequent, long distance travel is "rapid charging", such as the Aerovironment PosiCharge line (up to 250 kW) and the NorvikMinitCharge line (up to 300 kW). Ecotality is a manufacturer of Charging Stations and has partnered with Nissan on several installations. Battery replacement is also proposed as an alternative, although no OEMs including Nissan/Renault have any production vehicle plans. Swapping requires standardization across platforms, models and manufacturers. Swapping also requires many times more battery packs to be in the system.

According to Department of Energy research conducted at Pacific Northwest National Laboratory, 84% of existing vehicles could be switched over to plug-in hybrids without requiring any new grid infrastructure.[87]:1 In terms of transportation, the net result would be a 27% total reduction in emissions of the greenhouse gases carbon dioxide, methane, and nitrous oxide, a 31% total reduction in nitrogen oxides, a slight reduction in nitrous oxide emissions, an increase in particulate matter emissions, the same sulfur dioxide emissions, and the near elimination of carbon monoxide and volatile organic compound emissions (a 98% decrease in carbon monoxide and a 93% decrease in volatile organic compounds). The emissions would be displaced away from street level, where they have "high human-health implications."[87]:4

Battery swapping

Instead of recharging EVs from electric socket, batteries could be mechanically replaced at special stations in a couple of minutes (battery swapping).

Batteries with greatest energy density such as metal-air fuel cells usually cannot be recharged in purely electric way. Instead, some kind of metallurgical process is needed, such as aluminum smelting and similar.

Silicon-air, aluminum-air and other metal-air fuel cells look promising candidates for swap batteries.[88][89] Any source of energy, renewable or non-renewable, could be used to remake used metal-air fuel cells with relatively high efficiency. Investment in infrastructure will be needed. The cost of such batteries could be an issue, although they could be made with replaceable anodes and electrolyte.

Chassis swapping

Instead of replacing batteries, it is possible to replace the entire chassis (including the batteries, electric motor and wheels) of an electric Modular vehicle.

Such a system was patented in 2000 by Dr Gordon Dower and three road-licensed prototypes have been built by the Ridek Corporationin Point Roberts, Washington. Dower proposed that an individual might own only the body (or perhaps a few different style bodies) for their vehicle, and would lease the chassis from a pool, thereby reducing the depreciation costs associated with vehicle ownership.

Other in-development technologies

Conventional electric double-layer capacitors are being worked to achieve the energy density of lithium ion batteries, offering almost unlimited lifespans and no environmental issues. High-K electric double-layer capacitors, such as EEStor's EESU, could improve lithium ion energy density several times over if they can be produced. Lithium-sulphur batteries offer 250 Wh/kg.[91] Sodium-ion batteries promise 400 Wh/kg with only minimal expansion/contraction during charge/discharge and a very high surface area.[92] Researchers from one of the Ukrainian state universities claim that they have manufactured samples of pseudocapacitor based on Li-ion intercalation process with 318 Wh/kg specific energy, which seem to be at least two times improvement in comparison to typical Li-ion batteries.[93]

Safety

The United Nations in Geneva (UNECE) has adopted the first international regulation (Regulation 100) on safety of both fully electric and hybrid electric cars, with the intent of ensuring that cars with a high voltage electric power train, such as hybrid and fully EVs, are as safe as combustion-powered cars. The EU and Japan have already indicated that they intend to incorporate the new UNECE Regulation in their respective rules on technical standards for vehicles.

There is a growing concern about the safety of EVs, given the demonstrated tendency of the Lithium-ion battery, most promising for EV use because of its high energy density, to overheat, possibly leading to fire or explosion, especially when damaged in a crash. The U.S. National Highway Traffic Safety Administration opened a defect investigation of the Chevy Volt on November 25, 2011 amid concerns over the risk of battery fires in a crash. At that time, automotive consulting firm CNW Marketing Research reported a decline in consumer interest in the Volt, citing the fires as having made an impact on consumer perception.[95] Consumer response impelled GM to make safety enhancements to the battery system in December, and the NHTSA closed its investigation on January 20, 2012, finding the matter satisfactorily resolved with "no discernible defect trend" remaining. The agency also announced it has developed interim guidance to increase awareness and identify appropriate safety measures regarding electric vehicles for the emergency response community, law enforcement officers, tow truck operators, storage facilities and consumers.[96][97]

ADVANTAGES AND DISADVANTAGES OF EVS

Environmental

EVs release no tail pipe air pollutants at the place where they are operated. They also typically generate less noise pollution than an internal combustion engine vehicle, whether at rest or in motion. The energy that electric and hybrid cars consume is usually generated by means that have environmental impacts. Nevertheless, adaptation of EVs would have a significant net environmental benefit, except in a few countries that continue to rely on older coal fired power plants for the bulk of their electricity generation throughout the life of the car.[99][100][101]

There are special kind of electric vehicles named SAFA TEMPO in Nepal that help lower the pollution created by vehicles. These vehicles are powered by electricity - usually charged batteries - rather than oil or gas and currently heavily promoted by the government to facilitate environmental and vehicle management issues. Electric motors don't require oxygen, unlike internal combustion engines; this is useful for submarines and for space rovers.

A study by Cambridge Econometrics shows the potential air pollution benefits of EVs. According to one of the scenarios in the study, Europe would be on track to reduce CO_2 emissions from cars by 88% by 2050. The associated technology improvements would cut toxic nitrogen oxides (NO_x) from cars from around 1.3 million tonnes per year to around 70,000 tonnes per year.

Mechanical

Electric motors are mechanically very simple and often achieve 90% energy conversion efficiency over the full range of speeds and power output and can be precisely controlled. They can also be combined with regenerative braking systems that have the ability to convert movement energy back into stored electricity. This can be used to reduce the wear on brake systems (and consequent brake pad dust) and reduce the total energy requirement of a trip. Regenerative braking is especially effective for start-and-stop city use.

They can be finely controlled and provide high torque from rest, unlike internal combustion engines, and do not need multiple gears to match power curves. This removes the need for gearboxes and torque converters.

EVs provide quiet and smooth operation and consequently have less noise and vibration than internal combustion engines.[98] While this is a desirable attribute, it has also evoked concern that the absence of the usual sounds of an approaching vehicle poses a danger to blind, elderly and very young pedestrians. To mitigate this situation, automakers and individual companies are developing systems that produce warning sounds when EVs are moving slowly, up to a speed when normal motion and rotation (road, suspension, electric motor, etc.) noises become audible.

Energy resilience

Electricity can be produced from a variety of sources, therefore it gives the greatest degree of energy resilience.

Energy efficiency

EV 'tank-to-wheels' efficiency is about a factor of 3 higher than internal combustion engine vehicles.[98] Energy is not consumed while the vehicle is stationary, unlike internal combustion engines which consume fuel while idling. However, looking at the well-to-wheel efficiency of EVs, their total emissions, while still lower, are closer to an efficient gasoline or diesel in most countries where electricity generation relies on fossil fuels.

Well-to-wheel efficiency of an EV has less to do with the vehicle itself and more to do with the method of electricity production. A particular EV would instantly become twice as efficient if electricity production were switched from fossil fuel to a wind or tidal primary source of energy. Thus, when "well-to-wheels" is cited, one should keep in mind that the discussion is no longer about the vehicle, but rather about the entire energy supply infrastructure - in the case of fossil fuels this should also include energy spent on exploration, mining, refining, and distribution.

The lifecycle analysis of EVs shows that even when powered by the most carbon intensive electricity in Europe, they emit less greenhouse gases than a conventional diesel vehicle.

Cost of recharge

The cost of operating an EV varies wildly depending on location. In some parts of the world, an EV costs less to drive than a comparable gas-powered vehicle, as long as the higher initial purchase-price is not factored in . In the US, in states which have a tiered electricity rate schedule, "fuel" for EVs today costs owners significantly more than fuel for a comparable gas-powered vehicle. A 2011 study done by Purdue University found that in California most users already reach the third pricing tier for electricity each month, and adding an EV could push them into the fourth or fifth (highest, most expensive) tier, meaning that they will be paying in excess of $.45 cents per kWh for electricity to recharge their vehicle. At this price, which is higher than the average electricity price in the US, it is dramatically more expensive to drive a pure-EV than it is to drive a traditional pure-gas powered vehicle. "The objective of a tiered pricing system is to discourage consumption. It's meant to get you to think about turning off your lights and conserving electricity. In California, the unintended consequence is that plug-in hybrid cars won't be economical under this system," said Tyner (the author), whose findings were published in the online version of the journal Energy Policy.

Stabilization of the grid

Since EVs can be plugged into the electric grid when not in use, there is a potential for battery powered vehicles to even cut the demand for electricity by feeding electricity *into* the grid from their batteries during peak use periods (such as midafternoon air conditioning use) while doing most of their charging at night, when there is unused generating capacity. This vehicle-to-grid (V2G) connection has the potential to reduce the need for new power plants, as long as vehicle owners do not mind reducing the life of their batteries, by being drained by the power company during peak demand.

Furthermore, our current electricity infrastructure may need to cope with increasing shares of variable-output power sources such as wind and solar PV. This variability could be addressed by adjusting the speed at which EV batteries are charged, or possibly even discharged.

Some concepts see battery exchanges and battery charging stations, much like gas/petrol stations today. Clearly these will require enormous storage and charging potentials, which could be manipulated to vary the rate of charging, and to output power during shortage periods, much as diesel generators are used for short periods to stabilize some national grids.[113][114]

Range

Electric vehicles may have shorter range compared to Internal Combustion Engines, however, the price per mile of electric vehicles is falling. Most owners opt to charge their vehicles primarily at their houses while not in use due to their typically slower charging times, and added convenience.

Heating of EVs

In cold climates, considerable energy is needed to heat the interior of a vehicle and to defrost the windows. With internal combustion engines, this heat already exists as waste combustion heat diverted from the engine cooling circuit. This process offsets the greenhouse gases' external costs. If this is done with battery EVs, the interior heating requires extra energy from the vehicles' batteries. Although some heat could be harvested from the motor or motors and battery, their greater efficiency means there is not as much waste heat available as from a combustion engine.

However, for vehicles which are connected to the grid, battery EVs can be preheated, or cooled, with little or no need for battery energy, especially for short trips.

Newer designs are focused on using super-insulated cabins which can heat the vehicle using the body heat of the passengers. This is not enough, however, in colder climates as a driver delivers only about 100 W of heating power. A heat pump system, capable of cooling the cabin during summer and heating it during winter, seems to be the most practical and promising way of solving the thermal management of the EV. Ricardo Arboix introduced (2008) a new concept based on the principle of combining the thermal-management of the EV-battery with the thermal-management of the cabin using a heat pump system. This is done by adding a third heat-exchanger, thermally connected with the battery-core, to the traditional heat pump/air conditioning system used in previous EV-models like the GM EV1 and Toyota RAV4 EV. The concept has proven to bring several benefits, such as prolonging the life-span of the battery as well as improving the performance and overall energy-efficiency of the EV.[119][120][121][122]

Electric public transit efficiency

Shifts from private to public transport (train, trolleybus, personal rapid transit or tram) have the potential for large gains in efficiency in terms of an individual's distance traveled per kWH.

Research shows people do prefer trams, because they are quieter and more comfortable and perceived as having higher status. Therefore, it may be possible to cut liquid fossil fuel consumption in cities through the use of electric trams. Trams may be the most energy-efficient form of public transportation, with rubber wheeled vehicles using 2/3 more energy than the equivalent tram, and run on electricity rather than fossil fuels.

In terms of net present value, they are also the cheapest—Black pool trams are still running after 100-years, but combustion buses only last about 15-years.

Incentives and promotion

In May 2017, India was the first to announce plans to sell only electric vehicles by 2030.[125][126] Prime Minister Narendra Modi's government kickstarted the ambitious plan by floating a tender to purchase 10,000 electric vehicles,[127] hailed as "the world's single-largest EV procurement initiative."[128] Along with fulfilling the urgent need to keep air pollution in check, the Indian government aims at reducing the petroleum import bill and running cost of vehicles. With nearly a third of all cars sold in 2017 of all new cars either fully electric or a hybrid, Norway is the world leader in the adoption of electric cars and pushes to sell only electric or hybrid cars by 2030. The other nations followed the lead, with France and UK announcing the plan to ban the sale of gas and diesel cars by 2040. Austria, China, Denmark, Germany, Ireland, Japan, the Netherlands, Portugal, Korea and Spain have also set official targets for electric car sales.

Many governments offer incentives to promote the use of electric vehicles, with the goals of reducing air pollution and oil consumption. Some incentives intend to increase purchases of electric vehicles by offsetting the purchase price with a grant. Other incentives include lower tax rates or exemption from certain taxes, and investment in charging infrastructure.

In some states, car companies have partnered with local private utilities in order to provide large incentives on select electric vehicles. For example, in the state of Florida, Nissan and NextEra Energy, a local energy company, are working together to offer $10,000 incentives on the all-electric 2017 Nissan Leaf. In addition, the government offers electric vehicle incentives up to $7,500 to people who meet the qualifications outlined by the Federal Electric Vehicles Tax Credit. A standard 2017 Nissan Leaf costs around $30,000. As a result, Florida residents could purchase a new Leaf for less than half of the market value price.

San Diego's local private utility, San Diego Gas and Electric (SDG&E), offers its customers an electric vehicle incentive of $10,000 for a 2017 BMW i3.[130]

Sonoma Clean Power, the public utility that serves both Sonoma and Mendocino, offers its customers EV incentives up to $2,000 on a Volkswagen e-Golf. In addition, Volkswagen offers an incentive of $7,000 towards the purchase of an e-Golf. On top of these local incentives, and the federal tax credit, California residents can receive state incentives up to $2,500 in the form of state rebates. Therefore, Sonoma Clean Power customers can potentially save up to $19,000 on an e-Wolf

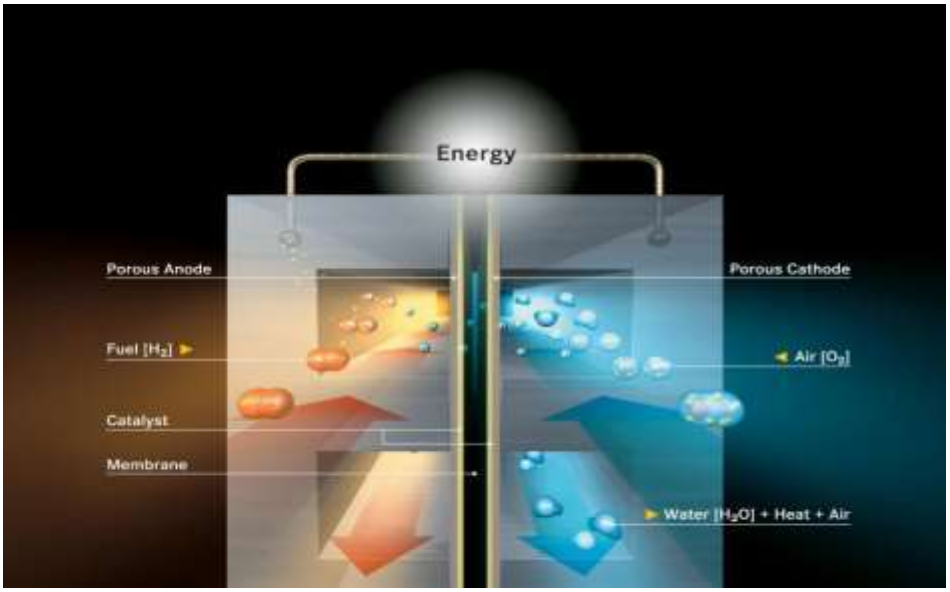
Battery management and intermediate storage

Another improvement is to decouple the electric motor from the battery through electronic control, employing supercapacitors to buffer large but short power demands and regenerative brakingenergy. The development of new cell types combined with intelligent cell management improved both weak points mentioned above. The cell management involves not only monitoring the health of the cells but also a redundant cell configuration (one more cell than needed). With sophisticated switched wiring it is possible to condition one cell while the rest are on duty.

ELECTRIC VEHICLE FUEL CELL

Fuel Cell Electric Vehicle (FCEV) also known as Fuel Cell Vehicle (FCV) or Zero Emission vehicle. It is a type of electric vehicle that employs 'fuel cell technology' to generate the electricity required to run the vehicle. In these vehicles, the chemical energy of the fuel is converted directly into electric energy. The working principle of a 'fuel cell' electric vehicle is different compared to that of a 'plug-in' electric vehicle. This is because the FCEV generates the electricity required to run this vehicle on the vehicle itself. Toyota is working on one such car called Toyota Mirai.

What is a fuel cell?

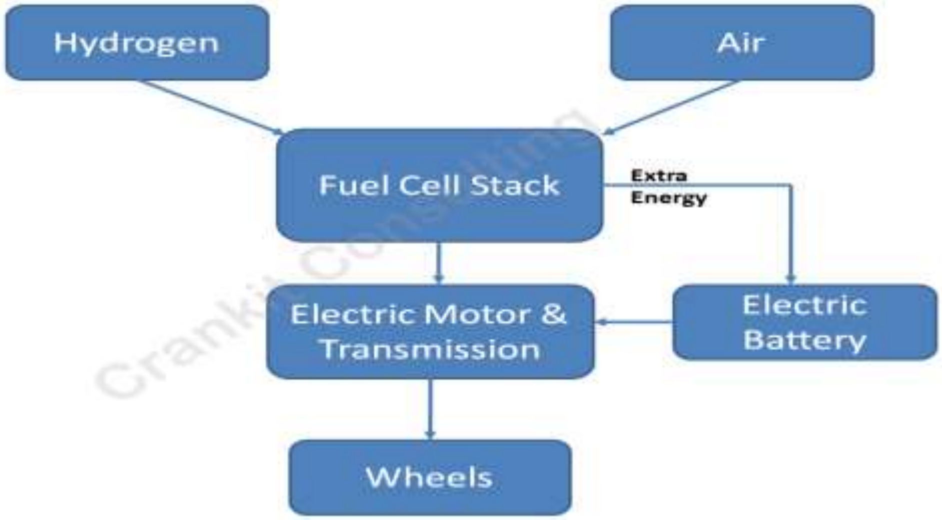


Working of Fuel cell (Courtesy: Daimler AG)

A fuel cell is a device in which electrochemical reaction takes place between Hydrogen and Oxygen. The main components of a fuel cell include an anode, a cathode, and an electrolyte. In presence of an electrolyte, the fuel ions i.e. Hydrogen ions react with the Oxygen ions to produce electricity, water vapor and heat. Also, this reaction takes place at a temperature of 80^0C only. Thus, the other name for this reaction is the 'cold combustion'. The electricity so generated drives an electric motor which in turn rotates the wheels of the vehicle.

The thickness of an individual fuel cell is about two millimeters. But, it can generate a potential difference of 1 volt only. Thus, a Fuel Cell Electric Vehicle uses an array of hundreds of fuel cells called 'Fuel Cell stack'.

Main components of a Fuel Cell Electric Vehicle (FCEV):



Schematic of Fuel cell vehicle

1. Hydrogen storage tank/ fuel tank:

The gaseous Hydrogen is used as fuel in fuel cell electric vehicles. These storage tanks store Hydrogen under the very high pressure of the order of 700 bar.

2. Fuel cell stack:

This is the powerhouse of these vehicles where Hydrogen from the storage tank and Oxygen from the ambient air react to form electricity.

3. Electric Motor:

The fuel cell stack generates the electricity and supplies to the electric motor. The motor, in turn, rotates the wheels of the vehicle.

4. Electric Battery:

The function of an electric battery is to store the extra electric energy which the fuel cell stack generates. It then supplies the same when the vehicle needs more energy to run.

5. Control Module:

The control unit monitors the overall energy demand of the vehicle and thus regulates the functions of Fuel cell stack, Motor and Battery to achieve optimum performance.

Advantages of Fuel Cell Electric Vehicle (FCEV):

1. Fuel cell vehicles are more efficient compared to any other conventional internal combustion engine.
2. The tailpipe emissions of these vehicles contain only the water vapor and hence are non-polluting vehicles.

Limitations of Fuel Cell Electric Vehicle (FCEV):

1. Storing Hydrogen under high pressure is a risky affair and may prove fatal in case of collisions.
2. The excess heat generated by the fuel cell is difficult to handle and also hampers the performance over the long run.
3. Furthermore, it requires modern infrastructure such as fuel refilling stations with sophisticated handling capabilities.

HYBRID VEHICLES

In our busy lives, cars are sought out to be one of the best modes of transportation. But, with the rising economy, people tend to buy cars that have better mileage. But still we think of trading cars with something that is cheaper when we look at the rising petrol costs. Though we do not think much about the environmental effects, we must still consider the fact that cars are the major contributors to pollution. To an extent, hybrid cars can be a remedy to many of these problems. A lot of car manufacturers have started new plants to produce their own version of hybrid cars.

As a matter of fact, we have seen many versions of hybrid vehicles before. Some of them are the simple motorized-pedal bike (moped), pulling trains, diesel-electric buses, and diesel-electric mining trucks and so on. A moped is actually a combination of gasoline and pedal power. Diesel-electric buses run on diesel for a while and later when connected to overhead electric wires, they run on electricity. The submarines used by our country are also hybrid models, where their fuel may be either nuclear-electric or diesel-electric. Some of the earliest hybrid cars include Toyota

Prius (1997), Honda Civic Hybrid (2002), and later on many more. Ford Company introduced the first hybrid SUV called The Escape in 2004. Similarly came companies like Chevrolet Silverado and so on.

In this post we are going to give you a detailed explanation on how hybrid cars work, their efficiency, advantages and disadvantages.

What are hybrid cars?

In simple words, the word hybrid refers to anything that has a combination of two different ideas. When a car uses two different ideas to move, it is called a hybrid car. Usually our cars run on petrol, diesel or gas. But their inefficiency, as explained earlier, led to the invention of electric cars. But, since electric cars also had disadvantages of frequent battery charging and inefficient long drives, there evolved a combination of both. When gas and electricity were used in the combined mode, a better solution was made to the inefficiency and mileage.

A user of a car always asks for some minimum requirements while using a car. They are

- For long distances, the car must run for at least 450 kilometres before refuelling.
- The drive should be smooth and easy.
- The car should maintain a good speed so as to cope up with other cars in traffic.
- Easy and fast refuelling of cars.
- A good mileage
- Less pollution

Though most of the conventional cars can provide the first four requirements correctly, they are very much backwards in the case of mileage and pollution. Electric cars, on the other hand can provide a very good mileage and very less pollution. But, the first four requirements will be let down. A combined use of both electric and gas energy will clearly find all these requirements satisfactory.

As Hybrid cars use two energy sources, a lot of energy consumption was reduced for travel (As both the gas and electricity share their energy.) As explained in my article about electric cars, there would not be a disadvantage of recharging the battery frequently. They will be spontaneously charged, while the car is running. Apart from the mileage, the car has also proved to give a performance almost adequate to a conventional car. Due to its improved mileage and reduced pollution, the governments in most countries have been pleased and have helped in its promotion.

Parts Of a Hybrid Car

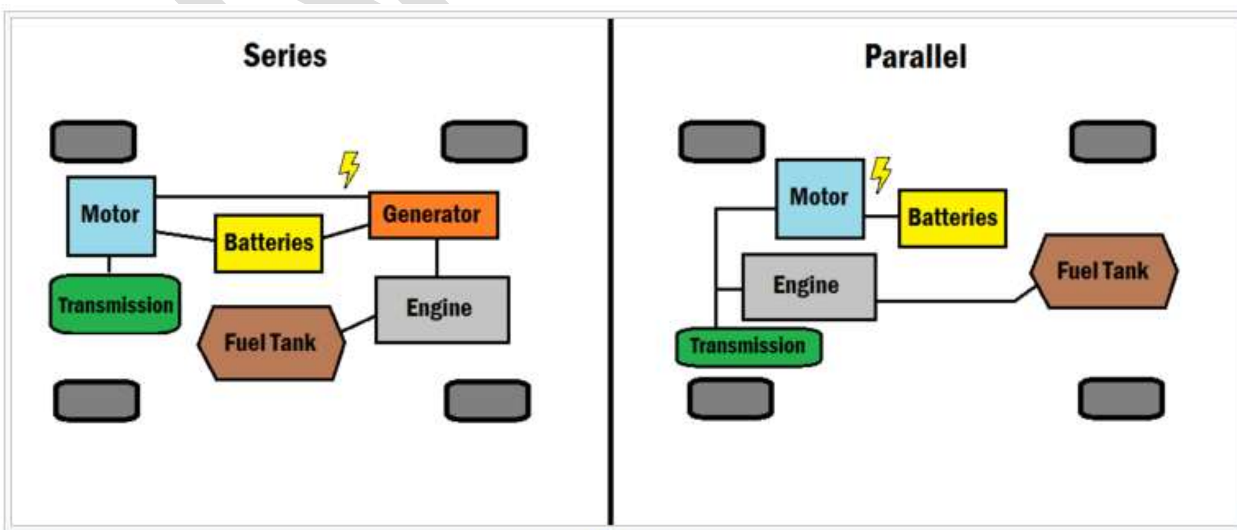
There are mainly 5 essentials for a hybrid car. They are

1. Conventional car engine – It can be a gasoline engine or also petrol or diesel respectively. But whatever engine is used, will be more advanced than the usual ones, as they have to work together with the electrical system. They will be smaller with greater efficiency and lesser emissions.
2. Fuel Tank – For storing the fuel needed to rum the car engine.
3. Batteries – Batteries are needed to store and release energy as required by the car. The energy from the battery is taken by the motor.
4. Electric Motor and generator – Though motors can act as generators, both of them are needed for this car. A motor will be needed to take energy from the batteries and accelerate the car. Generators, on the other hand, are needed to produce the electrical power.
5. Transmission System – The entire transmissions that were performed in a conventional car will be done here as well, but in the hybrid manner.

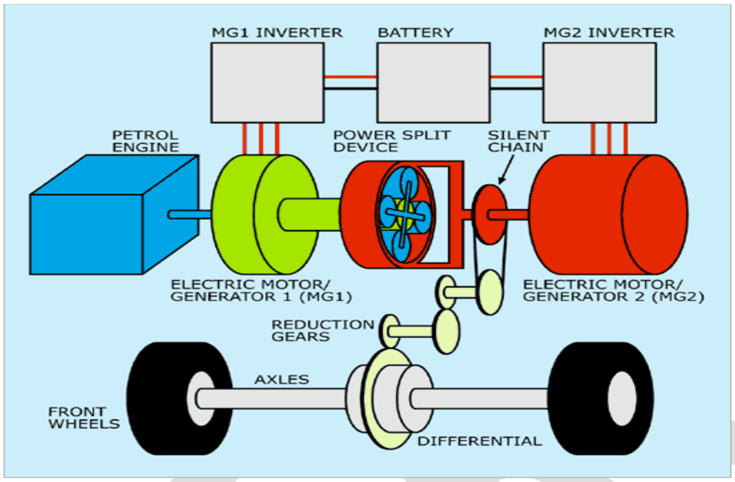
Series and Parallel Hybrids

There are mainly two types of hybrid cars – Series and Parallel. They differ in the manner in which the two energy sources are combined.

The series hybrid has the generator driven by the engine. This generator is used to charge the batteries and also drive the electric motor, which drives the transmission. Thus power to the vehicle is never directly given by the engine.



Parallel hybrid, on the other hand has both the engine and the electric motor to drive the transmission at the same time. This transmission is then used to turn the wheels. The fuel is given to the engine and the motor is supplied power by the motor. Parallel hybrids are considered straight forward, and hence are used widely. Take a look at the block diagram of a Hybrid Car.

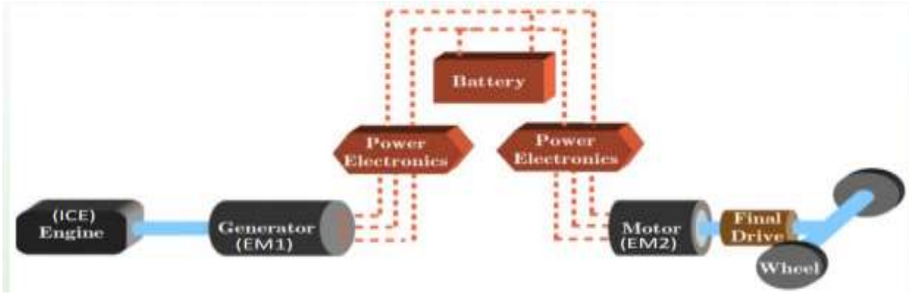


Hybrid Car Block Diagram

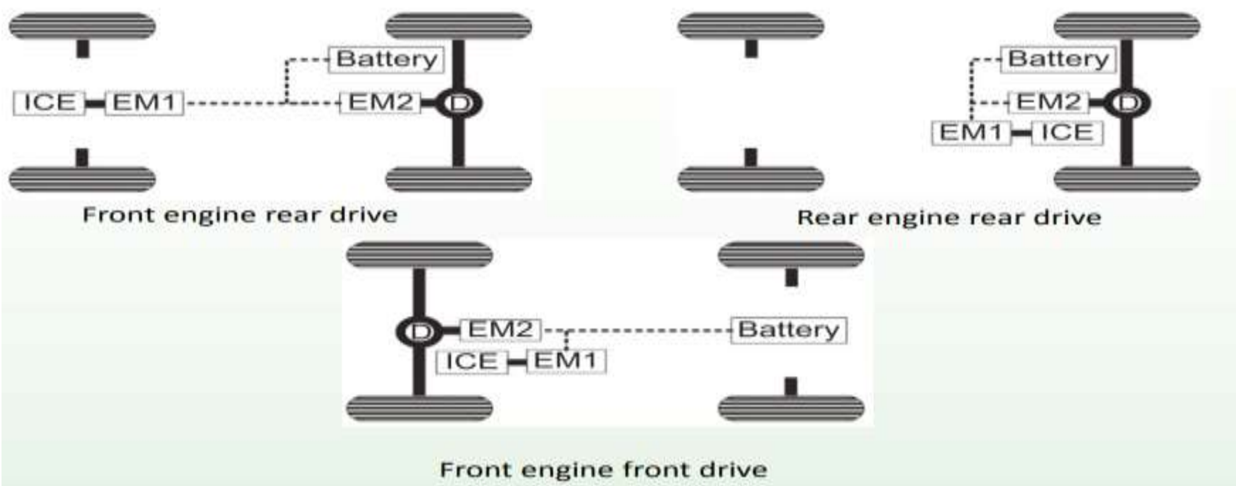
SERIES HYBRID ARCHITECTURE

The components of the series drivetrain include an electric motor, gasoline engine, computer controls, battery and generator. In a series hybrid, only the electric motor directly turns the wheels. Rather than operating in parallel, the energy to drive the car is supplied in a series from one power source, the gasoline engine, to another, the electric motor. The gasoline engine turns the generator that powers the electric motor. Batteries can be recharged from regenerative braking and from the engine and generator. Computer controls determine how much power to the motor comes from the battery or the engine or generator

- ICE and EM are connected in series
- Basic components: ICE, electric generator (EM1), electric motor (EM2), and ESS (battery)
- Only EM provides torque to the final drive
- Suitable for: mining vehicle, city bus (with frequent start-stop).



Series Hybrid layouts



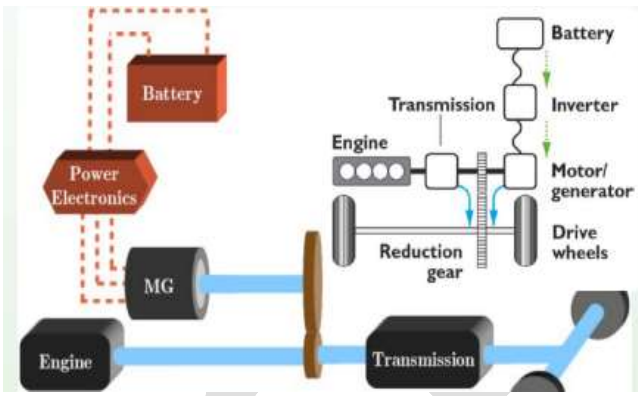
Advantages and Dis advantages of series hybrid

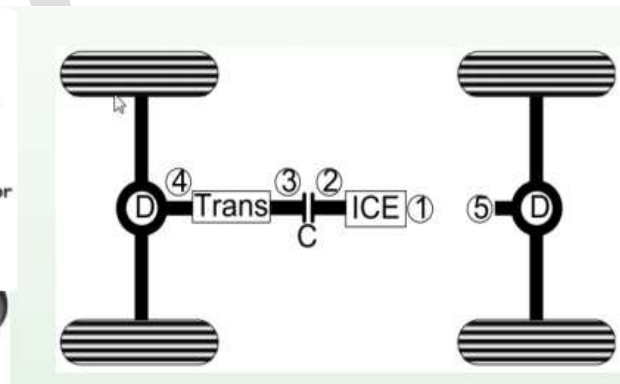
ICE always operates at peak efficiency range	Overall efficiency suffers especially at high speed
Efficiency loss can be further reduced due to fewer gear pairs and absence of transmission	EM can only output a portion of its maximum power at low speed, reversely increases EM size and costs.
Outstanding towing capacity at low speed	EM2 needs to meet all driving needs, increasing cost, weight, and installation space
Big EM2 motor is able to capture more regen braking	ICE is not engaged in final driving
Control system is relatively simple	

PARALLEL HYBRID ARCHITECTURE

Parallel drivetrain components commonly include the gasoline engine, electric motor, computer controls and battery. The engine and motor are parallel to one another in the design and they both connect to the transmission to directly turn the wheels. The computer controls are needed to coordinate the engine and motor working together either independently or simultaneously depending on the power needs. The battery is, in part, recharged from regenerative braking, a technology that allows the storage of kinetic energy from coasting and braking. The electric motor can also help recharge the battery

- Engine and electric motor are connected with fixed speed ratio.
- Both ICE and EM can provide torque to final driving, separately or together.
- Usually includes a transmission.





Advantages and Dis advantages of parallel hybrid

Total efficiency is higher doing cruising and highway driving	Complicated system with many variables
Required relatively small EM	ICE does not always operate at peak efficiency
Large design flexibility	Battery cannot be charged at standstill

How Hybrid Cars work?

To know the working of a hybrid car, we must understand the basics of Mild Hybrid cars and Full Hybrid cars.

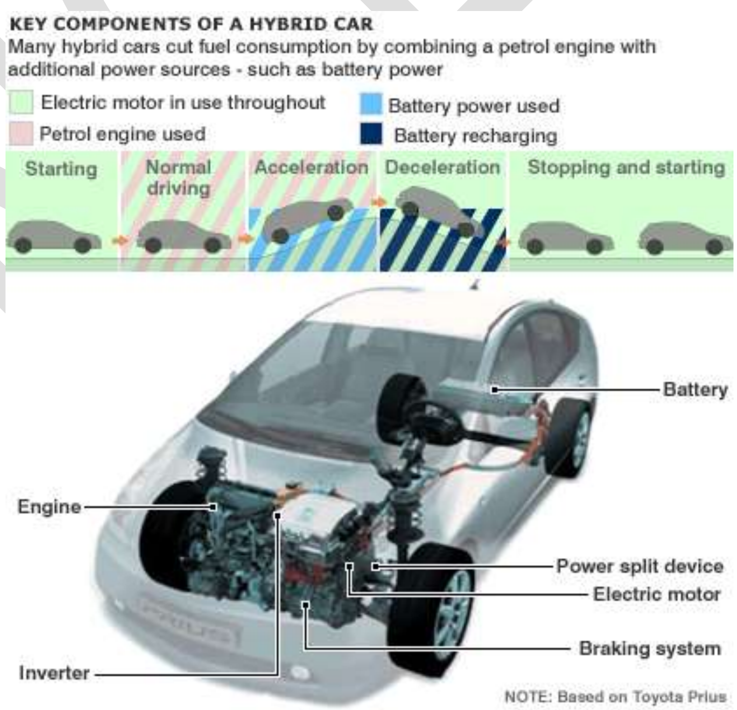
In mild hybrid cars, the electrical motor is used only when additional power is needed. The conventional engine is used to provide most of the power. The electrical motor alone cannot operate the vehicle. Whenever power is needed the electric motor acts as a side-kick to the conventional engine. Some vehicles that carry this concept is the Honda Civic and Insight.

In a full hybrid car, the electrical energy is used while the car needs less power. The gasoline energy is used when the car needs less power. Thus at lower speeds the battery drives the vehicle and at higher speed the gasoline drives the vehicle. This technology has been used in cars like Toyota Prius and Ford Escape.

Both of them though have a little different mode of operation provide the same amount of efficiency.

Since both electric motor and an engine are used simultaneously, the size of the engine will be considerably smaller than the usual ones. But they will be a lot more advanced than the usual ones. The motor, on the other hand is also used to give power for the air conditioner, power windows, water pump and also power steering.

Take a look at the diagram given below. It shows the actual working of the hybrid car Toyota Prius. During the starting position, none of the system is working. After the car starts to move, it is in the normal driving mode. Thus the car will automatically change to the use of electric motor. Later when the car is accelerated and gains speed, it switches from the use f motor to the use of engine. Thus the gasoline engine supplies the required power. This switching is carried out automatically, with the help of an on-board computer. Since the battery has lost some of its charge, it needs to be immediately recharged. This is also done automatically. When the car starts to go in a uniform speed or when it is descending a road, the generator starts charging the battery.



Working of Hybrid Cars

Comparison between a hybrid car and a gasoline car

If you compare the power drive of both the cars, you will see that both of them are equally efficient. While a gasoline car has a bigger engine, the hybrid car has a smaller engine. Conventional cars have enough power to attain the required speed, and that too at the required time. In a hybrid car, as the engine is smaller, it is more efficient. It has lighter parts and reduced number of cylinder. The fuel required for smaller engines is lesser than the other ones. Since bigger engines have all the pistons in a bigger size, they need more energy when they make an up and down movement in the cylinder. Even if the car is not moving, the engine may be on. At this time also the big engine cylinders use fuel.

If both the cars are moving equally the car with gas engine will use its whole single power to drive the car. The hybrid car will also need the same output power to drive the car. But, as it is smaller, it makes lesser power than the bigger one. This is when the electric motor comes into play. They provide the rest of the power from the battery to compensate the balance.

Types by degree of hybridization

Type	*Start-stop system*	*Regenerative braking* *Electric boost*	*Charge-depleting mode*	*Rechargeable*
Micro hybrid	Yes	No	No	No
Mild hybrid	Yes	Yes	No	No
Full hybrid	Yes	Yes	Yes	No
Plug-in hybrid	Yes	Yes	Yes	Yes

Micro hybrids

Micro hybrid is a general term given to vehicles that use some type of start-stop system to automatically shut off the engine when idling. Strictly speaking, micro hybrids are not real hybrid vehicles, because they do not rely on two different sources of power.[28]

Mild hybrids

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Mild hybrids are essentially conventional vehicles with some hybrid hardware, but with limited hybrid features. Typically, they are a parallel hybrid with start-stop only or possibly with modest levels of engine assist or regenerative braking. Mild hybrids generally cannot provide all-electric propulsion.

Mild hybrids like the General Motors 2004-07 Parallel Hybrid Truck (PHT) and the Honda Eco-Assist hybrids are equipped with a three-phase electric motor mounted within the bell-housing between the engine and transmission, allowing the engine to be turned off whenever the truck is coasting, braking, or stopped, yet restart quickly to provide power. Accessories can continue to run on electrical power while the engine is off, and as in other hybrid designs, regenerative braking recaptures energy. The large electric motor spins up the engine to operating speeds before injecting fuel.

The 2004–07 Chevrolet Silverado PHT was a full-size pickup truck. Chevrolet was able to get a 10% efficiency improvement by shutting down and restarting the engine on demand and using regenerative braking. The electrical energy was used only to drive accessories such as power steering. The GM PHT used a 42 volt system via three 12 volt vented lead acid batteries connected in series (36V total) to supply the power needed for the startup motor, as well as to power the electronic accessories.

General Motors then introduced their BAS Hybrid system, another mild hybrid implementation officially released on the 2007 Saturn Vue Green Line. Its "start-stop" functionality operates similarly to the Silverado, although via a belted connection to the motor/generator unit. However the GM BAS Hybrid System can also provide modest assist under acceleration and during steady driving, and captures energy during regenerative (blended) braking. BAS Hybrid offered as much as a 27% improvement in combined fuel efficiency in EPA testing of the 2009 Saturn VUE. The system can also be found on the 2008-09 Saturn Aura and the 2008-2010

Malibu hybrids.

Another way to offer start/stop is by employing a static start engine. Such an engine requires no starter motor, but employs sensors to determine the exact position of each piston, then precisely timing the injection and ignition of fuel to *turn over* the engine.

Mild hybrids are sometimes called *Power assist hybrids* as they use the ICE for primary power, with a torque-boosting electric motor connected to a (largely) conventional power train. The electric motor is mounted between the engine and transmission. It is essentially a large starter motor that operates when the engine needs to be turned over and when the driver "steps on the gas" and requires extra power. The electric motor may also restart the combustion engine and shutting down the main engine at idle, while the enhanced battery system is used to power accessories. GM announced Buick LaCrosse and Buick Regal mild hybrids dubbed Eassist.

Honda's hybrids, including the Insight, use this design, leveraging their expertise in small, efficient gasoline engines; their system is dubbed Integrated Motor Assist (IMA). IMA hybrids cannot provide propulsion on electric power alone. However, since the amount of electrical power needed is much smaller, system size is reduced.

Another variation is the Saturn Vue Green Line BAS Hybrid system that uses a smaller electric motor (mounted to the side of the engine) and battery pack than the Honda IMA, but functions similarly.

Another variation on this type is Mazda's e-4WD system, offered on the Mazda Demio sold in Japan. This front-wheel drive vehicle has an electric motor that can drive the rear wheels when extra traction is needed. The system is disengaged in all other driving conditions, so it does not directly enhance performance or economy but allows the use of a smaller and more economical engine relative to total performance.

Ford has dubbed Honda's hybrids "mild" in their advertising for the Escape Hybrid, arguing that the Escape's full hybrid design is more efficient.

Full hybrids

Engine compartment of a 2006 Mercury Mariner Hybrid.

A **full hybrid**, sometimes also called a **strong hybrid**, is a vehicle that can run on just the engine, the batteries, or a combination. The Toyota Prius, Toyota Camry Hybrid, Ford Escape Hybrid/Mercury Mariner Hybrid, Ford Fusion Hybrid/Lincoln MKZ Hybrid/Mercury Milan Hybrid, Ford C-Max Hybrid, Kia Optima Hybrid, as well as the General Motors 2-mode hybrid trucks and SUVs, are examples of this type of hybridization as they can operate on battery power alone. A large, high-capacity battery provides battery-only operation. These vehicles have a split power path that allows more flexibility in the drivetrain by inter-converting mechanical and electrical power. To balance the forces from each portion, the vehicles use a differential-style linkage between the engine and motor connected to the head end of the transmission.

The Toyota brand name for this technology is Hybrid Synergy Drive, which is used in the Prius, the Highlander Hybrid SUV and the Camry Hybrid. A computer oversees system operation, determining how to mix the power sources. The Prius operations can be divided into six distinct regimes.

Electric vehicle mode—The ICE is off and the battery powers the motor (or charges during regenerative braking). Used for idling when the battery state of charge (SOC) is high.

Cruise mode—The vehicle is cruising (i.e. not accelerating), and the ICE can meet the demand. The power from the engine is split between the mechanical path and the generator. The battery also powers the motor, whose power is summed mechanically with the engine. If the battery state-of-charge is low, part of the power from the generator charges the battery.

Overdrive mode—A portion of the rotational energy produces electricity, because the ICE's full power is not needed to maintain speed. This electrical energy is used to drive the sun gear in the direction opposite its usual rotation. The end result has the ring gear rotating faster than the engine, albeit at lower torque.

Battery charge mode—Also used for idling, except that in this case the battery state-of-charge is low and requires charging, which is provided by the engine and generator.

Power boost mode—Employed in situations where the engine cannot maintain the desired speed. The battery powers the motor to complement the engine power.

Negative split mode—The vehicle is cruising and the battery state-of-charge is high. The battery provides power to both the motor (to provide mechanical power) and to the generator. The generator converts this to mechanical energy that it directs towards the engine shaft, slowing it down (although not altering its torque output). The purpose of this engine "lugging" is to increase the fuel economy of the vehicle.

Plug-in hybrid

Chevrolet Volt charging

A plug-in hybrid electric vehicle (PHEV) has two defining characteristics. It:

- Can be plugged into an electrical outlet to be charged.
- Can travel powered only by the battery.

They are full hybrids, able to run on battery power. They offer greater battery capacity and the ability to recharge from the grid. They can be either parallel or series designs. They are also called *gas-optional*, or *griddable* hybrids. Their main benefit is that they can be gasoline-independent for significant distances, with the extended range of an ICE for longer trips. Electric Power Research Instituteresearch found a lower total cost of ownership for PHEVs due to reduced service costs and gradually improving battery technology. The "well-to-wheel" efficiency and emissions of PHEVs compared to gasoline hybrids depends on the grid energy sources (the US grid is 30% coal; California's grid is primarily natural gas, hydroelectric power, and wind power).

Prototypes of PHEVs, with larger battery packs that can be recharged from the power grid, were built in the U.S., notably at Andy Frank's Hybrid Center[31] at University of California, Davis. One production PHEV, the Renault Kangoo, went on sale in France in 2003. DaimlerChrysler built PHEVs based on the Mercedes-Benz Sprinter van. Light Trucks are offered by Micro-Vett SPAthe so-called Daily Bimodale.

The California Cars Initiative converted the 2004 and newer Toyota Prius to become a prototype of what it calls PRIUS+. With the addition of 140 kg (300 lb) of lead-acid batteries, the PRIUS+ achieved roughly double the gasoline mileage of a standard Prius and could make trips of up to 16 kilometres (10 mi) using only electric power.

Chinese battery manufacturer and automaker BYD Auto released the F3DM compact sedan to the Chinese fleet market on December 15, 2008, later replaced by the BYD Qin plug-in hybrid. General Motors began deliveries of the Chevrolet Volt in the United States in December 2010, and its sibling, the Opel Ampera, was released in Europe by early 2012. As of November 2012, other plug-in hybrids available in several markets were the Fisker Karma, Toyota Prius Plug-in Hybrid and Ford C-Max Energi.

As of October 2012, the best selling PHEV is the Volt, with more than 33,000 units of the Volt/Ampera family sold worldwide since December 2010, led by US sales of 27,306, followed by the Netherlands with 2,175 Amperas sold through October 2012. The Prius Plug-in Hybrid had sold 21,600 units sold worldwide through October 2012, with US sales of 9,623 units, followed by Japan with 9,500 units.[41][44]

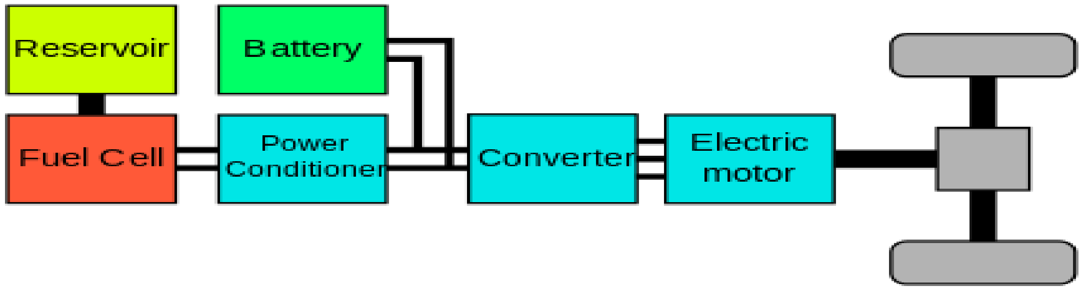
Types by power source

Electric-internal combustion engine hybrid

There are many ways to create an electric-Internal Combustion Engine (ICE) hybrid. The variety of electric-ICE designs can be differentiated by how the electric and combustion portions of the powertrain connect, at what times each portion is in operation, and what percent of the power is provided by each hybrid component. Two major categories are **series hybrids** and **parallel hybrids**, though **parallel designs** are most common today.

Most hybrids, no matter the specific type, use regenerative braking to recover energy when slowing down the vehicle. This simply involves driving a motor so it acts as a generator.

Many designs also shut off the internal combustion engine when it is not needed in order to save energy. That concept is not unique to hybrids; Subaru pioneered this feature in the early 1980s, and the Volkswagen Lupo 3L is one example of a conventional vehicle that shuts off its engine when at a stop. Some provision must be made, however, for accessories such as air conditioning which are normally driven by the engine. Furthermore, the lubrication systems of internal combustion engines are inherently least effective immediately after the engine starts; since it is upon startup that the majority of engine wear occurs, the frequent starting and stopping of such systems reduce the lifespan of the engine considerably. Also, start and stop cycles may reduce the engine's ability to operate at its optimum temperature, thus reducing the engine's efficiency.



Structure of a fuel cell hybrid electric vehicle

Electric-fuel cell hybrid

Fuel cell vehicles are often fitted with a battery or supercapacitor to deliver peak acceleration power and to reduce the size and power constraints on the fuel cell (and thus its cost); this is effectively also a series hybrid configuration.

Internal combustion engine-hydraulic hybrid

Chrysler are adapting a minvan to a gasoline-hydraulic hybrid setup.

A hydraulic hybrid vehicle uses hydraulic and mechanical components instead of electrical. A variable displacement pumpreplaces the electric motor/generator. A hydraulic accumulatorstores energy. The vessel typically carries a flexible bladder of pre-charged pressurized nitrogen gas. Pumped hydraulic fluid is compressed against the bladder storing the energy in the compressed nitrogen gas. Some versions have a piston in a cylinder rather than a pressurized bladder. The hydraulic accumulator is potentially cheaper and more durable than batteries. Hydraulic hybrid technology was originally implemented in Germany in the 1930s. Volvo Flygmotor used petro-hydraulic hybrids experimentally in buses from the early 1980s.

The initial concept involved a giant flywheel (see Gyrobus) for storage connected to a hydrostatic transmission. The system is under development by Eaton and several other companies, primarily in heavy vehicles like buses, trucks and military vehicles. An example is the Ford F-350 Mighty Tonka concept truck shown in 2002. It features an Eaton system that can accelerate the truck to highway speeds.

The system components were expensive, which precluded installation in smaller trucks and cars. A drawback was that the power motors were not efficient enough at part load. Focus switched to smaller vehicles. A British company made a breakthrough by introducing an electronically controlled hydraulic motor/pump that is efficient at all ranges and loads, making small applications of petro-hydraulic hybrids feasible.[45] The company converted a BMW car to prove viability. The BMW 530i gave double the MPG in city driving compared to the standard car. The test used the standard 3,000 cc engine. Petro-hydraulic hybrids allows downsizing an engine to average power usage, not peak power usage. Peak power is provided by the energy stored in the accumulator.

The kinetic braking energy recovery rate is higher and therefore the system is more efficient than 2013-era battery charged hybrids, demonstrating a 60% to 70% increase in economy in EPA testing. In EPA tests a hydraulic hybrid Ford Expedition returned 32 mpg_{-US} (7.4 L/100 km) in urban driving and 22 mpg_{-US}(11 L/100 km) on the highway.

One research company's goal was to create a fresh design to improve the packaging of gasoline-hydraulic hybrid components. All bulky hydraulic components were integrated into the chassis. One design claimed to reach 130mpg in tests by using a large hydraulic accumulator that is also the structural chassis. The hydraulic driving motors are incorporated within the wheel hubs and reversing to recover braking energy. The aim is 170 mpg in average driving conditions. Energy created by shock absorbers and kinetic braking energy that normally would be wasted assists in charging the accumulator. An ICE sized for average power use charges the accumulator. The accumulator is sized to run the car for 15 minutes when fully charged.[49][50][51]

In January 2011, Chrysler announced a partnership with the EPA to design and develop an experimental gasoline-hydraulic hybrid powertrain suitable for use in passenger cars. Chrysler adapted an existing production minvan to the powertrain.[52][53][54][55][56]

NRG Dynamix of the U.S.A. claimed its approach reduced cost by one-third compared with electric hybrids and added only 300 lbs (136 kg) to vehicle weight vs. 1,000 lbs (454 kg) for electric hybrids. The company claimed a standard pickup vehicle powered by a 2.3 litre 4 cylinder engine achieved 14 MPG (16.8 l/100 km) in city driving. Using the petro-hydraulic setup fuel economy reached "the mid 20s".[57]

Internal combustion engine-pneumatic

Compressed air can power a hybrid car with a gasoline compressor to provide the power. Motor Development International in France was developing such air-powered cars. A team led by Tsu-

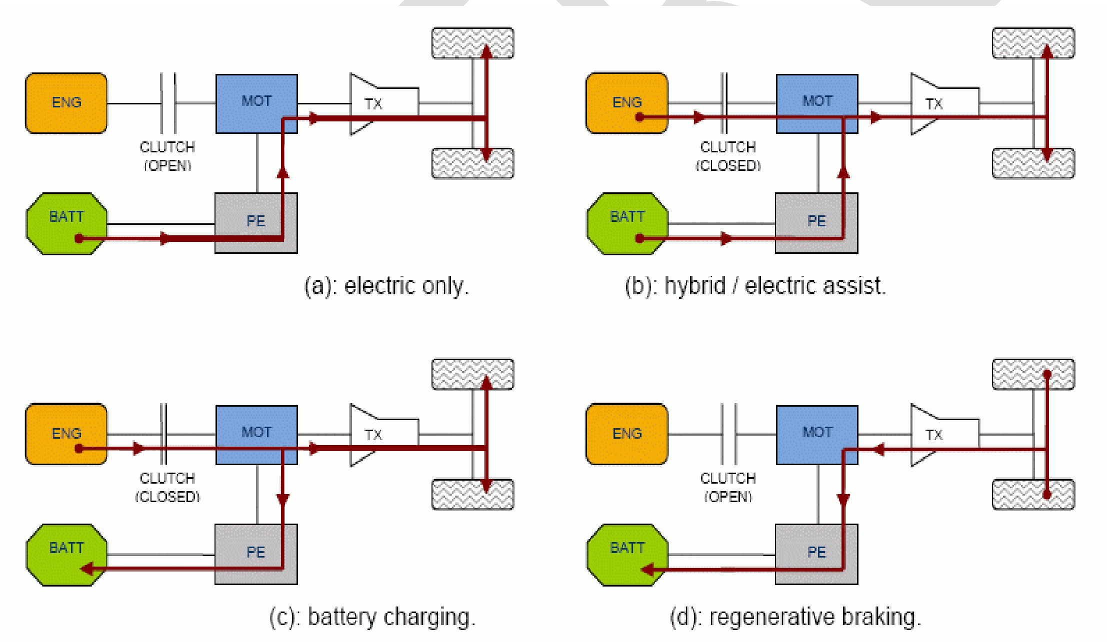
Chin Tsao, a UCLA mechanical and aerospace engineering professor, collaborated with engineers from Ford to get pneumatic hybrid technology up and running. The system is similar to that of a hybrid-electric vehicle in that braking energy is harnessed and stored to assist the engine as needed during acceleration.

Human power-environmental power

Many land and water vehicles use human power combined with a further power source. Common are parallel hybrids, e.g. a sailboat with oars, motorized bicycles or a human-electric hybrid vehicle such as the Twike. Some series hybrids exist. Such vehicles can be tribrid vehicles, combining three power sources e.g. on-board solar cells, grid-charged batteries and pedals.

Hybrid vehicle operation modes

Hybrid vehicles can be used in different modes. The figure shows some typical modes for a parallel hybrid configuration.



Advantages Of Hybrid Cars

- Very less pollution.
- Better mileage.
- More reliable and comfortable.
- Very clean cars due to less emissions.
- Batteries need not be charged by an external source.

- Warranties available for batteries as well as motors.
- Less dependence on fuels.

Disadvantages Of Hybrid Cars

- The initial cost will be very high – higher than other cars.
- Since a lot of batteries will be needed, the car will be very heavy.
- As there are electrical components, there is risk of shock during an accident.
- The vehicle can be repaired only by professionals.
- Spare parts will be very costly and rare.

COMPRESSED NATURAL GAS HYBRID SYSTEMS(CNG HYBRIDS)

The system components can be augmented with range extension kits that make efficient use of fossil fuels such as compressed natural gas (CNG) to supply energy to augment the battery packs.

The result is a battery-dominant natural gas plug-in hybrid drive system architecture that can use the additional energy of an onboard natural gas-driven generator to extend vehicle operating range by a factor of two or more. While this augmentation results in some fuel use and emissions, the effective fuel economy of natural gas hybrid systems can be far greater than that of conventional vehicles or competing hybrid systems with smaller battery packs.

Battery-dominant hybrid systems can also be configured to operate in a battery-only mode, producing zero emissions, for extended periods.

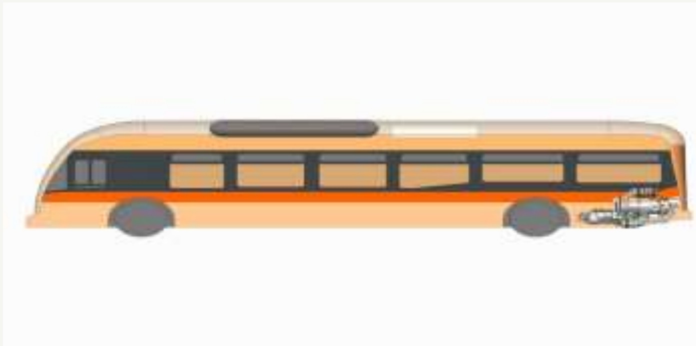
Product Description

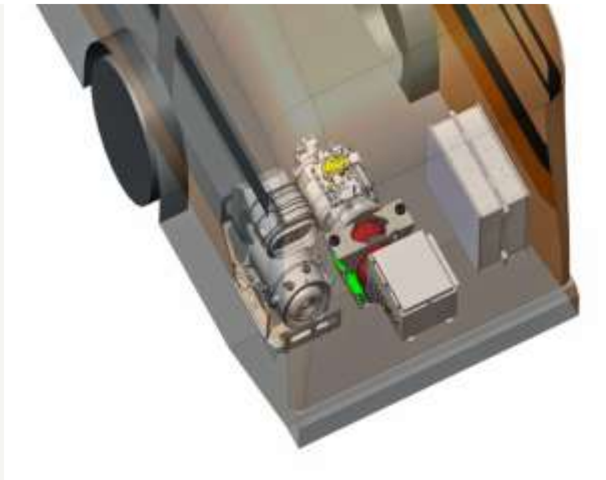
Natural gas hybrid drive system merges the battery-electric drive system with an innovative new range extender that can use an internal combustion engine or a microturbine.

When a combustion engine is utilized, it is mated to a compact, advanced generator. The engine-generator or microturbine produces electric energy that can be used to augment and recharge the vehicle's batteries or to operate the vehicle at modest power levels when the batteries are depleted.

By taking advantage of the energy stored in the battery packs and the system's high-power electric motors, range extension can be achieved using extremely small CNG power plants such as the CNG version of the 3.7 liter engine used in the Ford Mustang and F-150, which was recently certified by the California Air Resources Board. While this engine was developed for passenger vehicles, when used as a range extender it can enhance the performance of much larger vehicles up to and including the Class 8 trucks.

Microturbines, developed initially for stationary power applications, provide another option for augmenting battery energy in a compact geometry.





Benefits

The natural gas hybrid system provides a viable option for vehicle operators whose operating range requirements exceed the 80-100 mile limit of the battery-electric drive system.

For operators whose range requirements exceed 80-100 miles by small increments or who exceed 80-100 miles only occasionally, most operation can still be achieved in a battery-only, zero-emission operating mode and effective fuel economy can be in the many tens to hundreds of miles per gallon-equivalent of natural gas.

For users who regularly require significantly more range than 100 miles, fuel use and emissions with this plug-in hybrid architecture can still be a factor of 2-3 lower than that of a conventional natural gas vehicle with comparable operating requirements.

Why is CNG better than Other fuels?

As gasoline and diesel prices increase, the need for a cleaner and less expensive alternative fuel (cng tanks) becomes even more important. Today, there are several kinds of alternative fuels available to us. New technologies that will power the cars of the future are being developed. However some of these technologies are still in its infancy and are not yet readily available. More and more people all over the world are also looking for an alternative fuel. And among the many options available, compressed natural gas or CNG appears to be the viable option. But the question that needs to be answered is whether CNG is indeed a better fuel and why.

Here are the advantages CNG has over petroleum-based fuels such as gasoline.

Compressed natural gas is a clean-burning fuel. It is actually the cleanest of all fossil fuels. Since natural gas is composed mainly of methane, burning it produces carbon dioxide and water vapor. These are the same compounds we exhale when we breathe. Meanwhile, petroleum produces higher carbon emissions, nitrogen oxides and sulfur dioxide. Burning fuel oil also produces ash particulates that worsen pollution.

Combustion of natural gas releases very small amounts of these compounds. For instance, carbon monoxide emission is reduced by about 80% in CNG-powered cars compared to gasoline-powered vehicles. CNG also produces 45% less hydrocarbons than gasoline. And although natural gas also produces greenhouse gases, it is considerably reduced compared to gasoline or diesel. This helps reduce the harmful effects of greenhouse gases to the environment particularly through global warming.

Since CNG is a clean burning fuel, combusting it leaves little or no residue compared to gasoline or diesel. Thus, the damage to the pipes and tubes of the vehicle's engine is greatly reduced. There is also less particulate matter that can contaminate the motor oil. This results to longer periods in between maintenance procedures such as tune-ups and oil changes. Consequently, owners of CNG-powered cars enjoy bigger savings on maintenance costs.

CNG also has a high ignition temperature of about 1163 degrees Fahrenheit and a flammability rating of approximately 5 to 15% gas in air. This reduces the risk of fire if and when a leak happens. CNG is also lighter than air and will simply dissipate into the atmosphere in the case of leaks. Meanwhile, gasoline or diesel will pool in the ground when there is a leak which results to a very dangerous fire hazard. Lastly, CNG is a non-toxic fuel that does not pose any danger of contamination to ground water.

MODULE VI

VEHICLE INTELLIGENCE

INTRODUCTION

Vehicle intelligence is the application of sensors, mechatronics and artificial intelligence (AI) to enhance vehicles or make them fully autonomous driverless cars.

Vehicle intelligence enhances driving safety and increases engine performance efficiency.

All cars with vehicle intelligence don't necessarily have the capacity for autonomous driving, and may only use this technology for driving comfort safety and convenience. Features that may depend on vehicle intelligence include adaptive cruise control, stability control, accident avoidance systems, navigation and adaptive engine control.

Intelligent features in vehicles can be used to rank vehicles on the U.S. National Highway Traffic Safety Administration's (NHTSA) six levels of automation. These levels of ranking begin with zero, where humans do the driving, through driver assistance technologies up to fully autonomous cars. The five levels that follow zero automation are:

- Level 1: Advanced driver assistance system (ADAS) aid the human driver with either steering, braking or accelerating, though not simultaneously. ADAS includes rearview cameras and features like a vibrating seat warning to alert drivers when they drift out of the traveling lane.
- Level 2: An ADAS that can steer and either brake or accelerate simultaneously while the driver remains fully aware behind the wheel and continues to act as the driver.
- Level 3: An automated driving system (ADS) can perform all driving tasks under certain circumstances, such as parking the vehicle. In these circumstances, the human driver must be ready to re-take control and is still required to be the main driver of the vehicle.
- Level 4: An ADS is able to perform all driving tasks and monitor the driving environment in certain circumstances. In those circumstances, the ADS is reliable enough that the human driver needn't pay attention.
- Level 5: The vehicle's ADS acts as a virtual chauffeur and does all the driving in all circumstances. The human occupants are passengers and are never expected to drive the vehicle.

VISION BASED AUTONOMOUS ROAD VEHICLES

Introduction

Today the concept of autonomous driving is a very active field of research and first solutions of more and more advanced driver assistance systems are already available in recent models of commercial cars. As mentioned in, “the majority of the technologies required to create a fully autonomous vehicle already exist. The challenge is to combine existing automated functions with control, sensing and communications systems, to allow the vehicle to operate autonomously and safely”. That report also presents a classification of the level of autonomy based on the capabilities provided by an autonomous system. The simplest system includes the human driver along with an electronic stability and cruise control, which is available in most of the new car models. The next level adds a driver assistance in which steering and/or acceleration is automated in specific situations like parking assistance and adaptive cruise control. The classification then continues with partial autonomy, in which the driver does not control the steering and/or acceleration, but can take over control again if it is required like in lane keeping. After that, there is the level of high autonomy in which the car system is able to operate autonomously in different sections of the journey and only gives the control back to the human driver in some specific dangerous situations. Finally, there is the level of full autonomy in which the vehicle is capable of driving an entire journey without human intervention. Herein, the vehicle must be able to provide all the following specific capabilities:

1. Self-localization in a map or on a predefined path.
2. Sensing the surrounding and identification of potential collisions.
3. Control the basic driving functions, *i.e.*, breaking, accelerating and steering.
4. Decision making, path planning and following while respecting the regulations of traffic.
5. Information collection and exchange, such as maps, traffic status and road incidences.
6. Platooning with other vehicles.

The work presented in this paper is build on the authors previous work [2] which considers a visual line guided system to control the steering of on-board Autonomous Guided Vehicle (AGV) *that pursue a guided path*. This work was initiated with a project done in collaboration with Siemens Spain S.A. focusing on the development of a driver assistance system for buses in the city center using a vision-based line guided system. The main idea was that the driver should still be able to actuate the brake pedal in order to avoid any potential collisions, but has no longer a steering wheel to manually guide the vehicle. Following the previously mentioned level of autonomy, the system presented in this paper could be assigned to a level somewhere between the levels of partial or high autonomy. The presented control system approach takes over the complete control of the steering wheel which corresponds to a high level of autonomy. However, the speed is controlled as an assistance cruise control by keeping the user's desired speed under the limitation of the maximum speed in each section of the predefined path even if the user pushes the gas pedal to exceed this limit. The speed assistance control also allows to stop the vehicle in case of an emergency, such as the detection of an absence of the line, the push of an emergency button or if a specific localization mark on the road occurs.

The localization of the vehicle on the predefined path was implemented with the help of specific visual localization marks. In cases of a false or missing detection of one or more localization marks, the localization is supported by an odometry approach, i.e. the integration of the speed of the vehicle. These marks were not only used to localize the vehicle, but also to provide additional information to the control system and to the assistance cruise control. This additional information noticeably improves the behavior of the system, such as allowing to reach higher speeds and improving the robustness of the system. Regarding the previous list of the capabilities of a full autonomous system, we are here focusing on Point 1 and partially Point 3. The collision avoidance control is out of scope of this work. Various and potentially adverse conditions of the road such as on rainy days are also not considered in the work at hand. Therefore, the main focus is to find a low cost solution for a vision-based control approach including (I) the steering of an autonomous vehicle using a line guide, (II) a speed control assistance and (III) the localization of the vehicle, while preserving robustness against brightness variations in inner-city environments.

Related Works

Autonomous guided vehicles (AGVs) are generally used in manufacturing and logistic systems inside warehouses, but their acceptance inspired many other applications such as guided buses in city transportation. They were introduced during 1950s and, by 1960s the Personal Rapid Transit (PRT) began to advent. Different guidance systems were introduced for AGVs such as systems based on optical distance measurements, wires, magnetic tapes or computer vision. Each type is based on own design requirements and comes with own related advantages and disadvantages. For instance, in wire guidance systems, a wire is installed below the floor on which the AGV is moving. The wire emits a radio signal which can be detected by a sensor on the bottom of AGV close to the ground. The relative position to the radio signal is applied by the AGV to follow the path. In magnetic tape guidance system, a flexible tape of magnetic material is buried in the floor or road like in the case of the wire guidance system. The advantage of this method with respect to the wire guidance system is the fact that it remains unpowered or passive. In laser navigation systems, the AGV is equipped with a laser transmitter and receives the reflection of the laser from a reflective tape installed on the surrounding walls. The localization and navigation is done using the measurements of the angles and distances to the reflectors. However, this method is generally only used in indoor environments . A vision based navigation system uses a vision sensor to track landmarks in the environment which means that no magnets, no induction wires and also no laser technique is required to let the AGV follow a specified path.

On the other hand, the motivation to reduce traffic jams, to improve the fuel economy and to reduce the number of vehicle accidents in transportation leads to the introduction of different levels of automated driving. Many research institutes and automotive manufacturers worldwide are introducing their automated driving solutions, based on proprioceptive sensors such as the Anti-lock Brake System or the Electric Stability Program, or based on exteroceptive sensors such as radar, video, or LiDAR. The very first experiments on autonomous vehicles have been started in 1920s1920s and promising steps have been conducted in the 1950s. The research in autonomous driving in Europe started within the PROMETHEUS project (program for a European Traffic with Highest Efficiency and Unprecedented Safety) which was one of the largest research projects in fully automated driving in 1986. The obtained results of this project are regarded as milestones in the history of vehicular and robotic systems. Two of the vehicles were ARGO by VisLab and VaMoRs tested in 1998. Both of them used two cameras to detect road lanes and to avoid obstacles, but the implemented algorithms and strategies were different. In 1995 the NAHSC project (National Automated Highway System Consortium) started in the United States within the California PATH (Partners for Advanced Transit and Highways) program. In 1997, the important Demo'97 was developed in San Diego in which some cars were guided by a magnetic guided line inside the asphalt. An array of different sensors had been installed in those cars to execute self-driving tests and to form automated platoons of 8 cars.

In the last decade many authorities around the world introduced plans to promote the development and establishment of automated vehicles. Numerous commercial vehicles offer some levels of automation, such as adaptive cruise control, collision avoidance, parallel parking system, lane keeping assistance, *etc*. Research on this topic got a strong impulse by the challenging test-bed of DARPA in the grand and the urban challenge in 2005 and 2007 with impressive results obtained by Sebastian Thrun and his team from the Stanford University in

2005 and 2008 , or by the Braunschweig University in 2009 . All of these works tried to cover all the capabilities listed for a fully autonomous system, which is also the case for the recent Google Car . In this specific case, the obtained results of this approach should enforce legal changes to achieve the first license for a self-driving car. The European Union also has a long history of contributing to automated driving such as the Vehicle and Road Automation (VRA) program, the GCDC (Grand Cooperative Driving Challenge), and others. Many countries plan to develop sensors, control systems and services in order to have competitive autonomous driving systems and infrastructures . A considerable number of studies and projects have been funded or are still continuing within the new HORIZON2020 research framework in the European Union.

For instance, a Mercedes-Benz S-Class vehicle equipped with six radar sensors covering the full 360° angular range of the environment around the vehicle in the near and far range has been introduced in 2013. The vehicle drove completely autonomous for about 100 km from Mannheim to Pforzheim, Germany, in normal traffic.

Moreover, there are also some works focusing on the sixth point of the list of autonomous capabilities (*i.e.*, the platoon formation). In 2010, the multidisciplinary European project SARTRE used new approaches in platoon formations and leader systems to successfully present an autonomous platooning demo traveling 120 miles. The platoon comprised one human-driven truck followed by four cars equipped with cameras, laser sensors, radar and GPS technology. A complete test of different systems of leader following, lane and obstacle detection and terrain mapping has been done by the VisLab. In 2010, the laboratory directed by Alberto Broggi covered the distance of 15.92615.926 km from Parma to Shanghai with a convoy of four motor homes. All of them were equipped with five cameras and four laser scanners, no road maps were used. The first vehicle drove autonomously in selected sections of the trip while the other vehicles were 100%100% autonomous, using the sensors and the GPS way-points sent by the leader vehicle. The control of speed and/or steering of autonomous vehicles with a localization system based on GPS information is also presented in the literature, see, e.g.,. Herein, a cruise control approach for an urban environment comprising the control of the longitudinal speed based on the speed limits, the curvature of the lane and the state of the next traffic light is proposed. In , control tests of a high-speed car running the Pikes Peaks rally drive are presented. The work in shows a localization system without GPS, based on the detection of intersections and the use of a virtual cylindrical scanner (VCS) to adapt the vehicle speed.

Highly automated levels of driving require a very wide range of capabilities like sensing the environment, figuring out the situation and taking proper action for the driver. The design of a cost-effective solution for such highly automated driving systems is challenging and most of the time leads to an expensive multi-sensor configuration like the way introduced in. Vision-based systems are considered to be a cost-effective approach for automated driving systems. Vision-based systems can be categorized in different research areas and applications in the field of automated driving such as distance estimation using stereo vision or monocular vision data. A review of the literature in on-road vision-based vehicle detection, tracking, and behavior understanding is provided in . From an algorithmic point of view, computationally more complex algorithms require an understanding of the trade-off between computational performance (speed and power consumption) and accuracy. For instance, an offline-online strategy has been introduced in to overcome this trade-off. Furthermore, vision-based systems have many applications in automated driving, such as road detection which is one of the key issues of scene understanding for Advanced Driving Assistance Systems (ADAS). In road geometries for road detection are classified, and introduces an improved road detection algorithm that provides a pixel-level confidence map. The paper describes a neural network road and intersection detection. Another vision-based application for ADAS is lane keeping assistance, where a technique for the identification of the unwanted lane departure of a traveling vehicle on a road is presented in.

Despite some new and improved computer vision algorithms which have been introduced in recent years such as , it has to be noted that the variation in the lighting conditions, occlusions of the lane marking or road shoulders, and effects of shadows make the current vision-based solutions not reliable for the steering control of an autonomous car. Furthermore, these algorithms are still not completely real-time capable to be used in the closed control loop. Based on that and the specific constraints of our project mentioned in the previous section, this work focuses on a vision-based line guided system approach. To the author's best knowledge, a vision-based line-guided system has not been presented to control the steering of an autonomous car under the maximum speed constraints of urban environments.

System Description and working

In this section the system description of the automated car is presented, which can be divided in the general system architecture, the vehicle automation and the human-machine interface.

General System Architecture

The system architecture comprises several components as depicted in Figure 1. The first component is the computer vision system, also called “Visual processing”, which generates the information of the local position of the vehicle with respect to the path to follow (painted as a line). In addition it is able to detect binary visual marks painted on the road, which have the encoded information of its global positioning on the track as well as the maximum speed inside this section and the curvature radius. This information is stored in a data base.

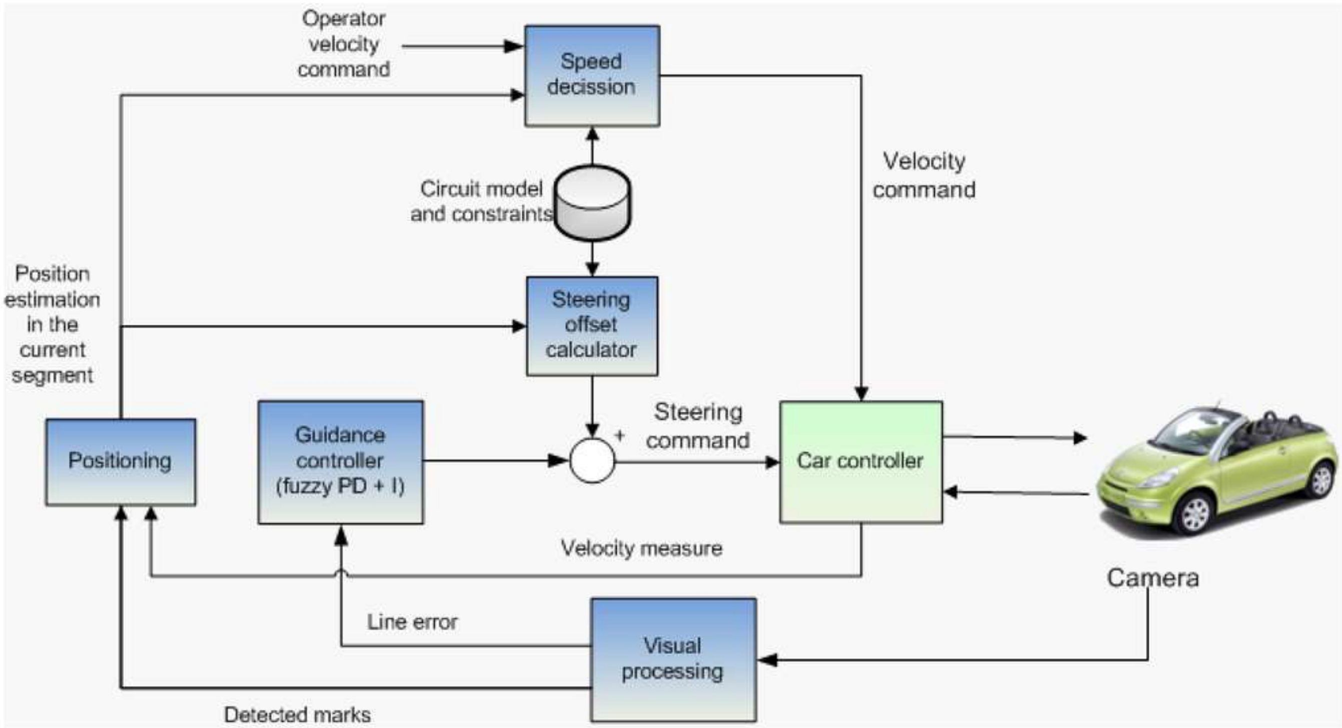


Figure 1. Full system architecture.

The lateral control system includes the “guidance controller”. These are two feedback controllers which have to keep the vehicle on the path by minimizing the deviation from the path. This component also includes the “Steering Offset”.

A “positioning” system allows to calculate the position of the vehicle on the track. The odometry information is generated by integrating the vehicle’s speed and updated with the absolute information obtained by reading the visual marks. In case a mark is not detected at the begining of one section, the odometry position estimation is used to change from one section of the track to another.

The “speed decision” system limits the speed of the vehicle by taking its position on the circuit into account. Herein the human driver is not permitted to overwrite this information either manually or using the Human-Machine Interface.

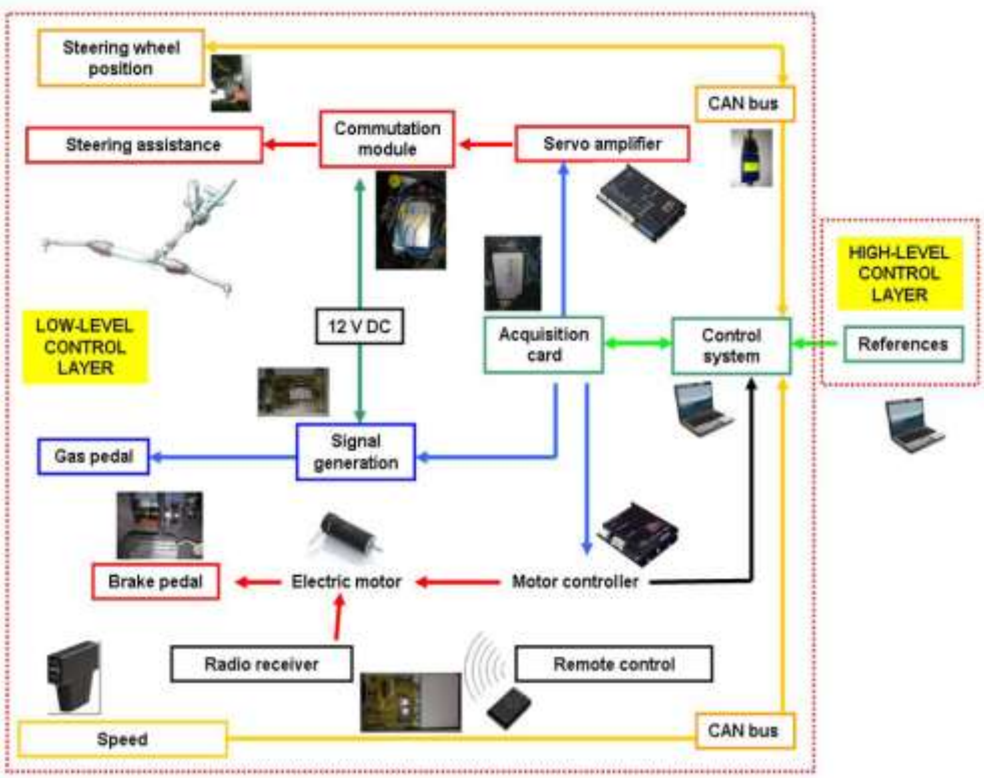
Both velocity and turning commands are sent to the “car controller” system, which actuates directly with the motors installed in the vehicle and reads the measured speed of the vehicle.

Vehicle Automation: Car Controller System

Within the project considered in this paper, a passenger car (shown in Figure 2a) has been fully automated. A detailed description of the vehicle automation is included in and the steering and speed fuzzy controllers were described and tested in . The automation includes a control unit that communicates with a data acquisition card that provides signals to the electronic accelerator pedal and to a servo amplifier operating on the vehicle steering assistance motor. This solution is applicable in case of vehicles with an electric steering assistance system. In the case of hydraulic assistance, solutions as shown in could be used. Moreover, the control unit sends commands to the electric motor controller which operates the brake pedal. As a safety measure, a remote control could operate on this motor so that any control signal is blocked and an emergency braking signal is provided from the power source. The fuzzy controllers allow, firstly, a vehicle behavior similar to that of a human driver. In addition, functions such as emergency manoeuvres (emergency brake and steering avoidance manoeuvres respecting conditions of stability) which are generated if an obstacle is detected on the route have been implemented in the decision module. Figure 2b shows the assembly of the electronic control units of the automated vehicle. Moreover, this low-level control layer receives the desired signals of steering wheel angle and vehicle speed from a high-level control layer and Figure 2c shows an overview of the architecture of the internal automatic control of the vehicle.

(a)

(b)



Steering wheel position
CAN bus
Commutation module
Steering assistance
Servo amplifier
HIGH-LEVEL CONTROL LAYER
LOW-LEVEL CONTROL LAYER
12 V DC
Acquisition card
Control system
References
Gas pedal
Signal generation
Brake pedal
Electric motor
Motor controller
Radio receiver
Remote control
Speed
CAN bus

(c)

Figure 2. Passenger vehicle automation. (**a**) Autonomous vehicle; (**b**) electronic deployment of the control system; (**c**) internal architecture for vehicle control.

This architecture allows the implementation of different types of applications such as a GPS-trajectory guided vehicle, line tracking, collision avoidance applications, remote control from a mobile device like a smartphone, *etc*.

Human-Machine Interface for the Driver Supervision

In this work, an autonomous driving system is presented which is always under the supervision of a driver, either a remote external operator or a driver inside the vehicle. For that reason the presented HMI for the supervision task was designed, see Figure 3. It shows the current information of the vehicle ("*vehicle info*"), comprising the desired user speed ("*user speed*") that can be changed in real time, the current desired speed ("*last speed command*"), the current speed ("*current speed*"), the maximum speed reached during all the experiment ("*maximum speed*"), and the distance traveled in the current section of the track ("*distance traveled*"). Below this information, the information related to the current section of the track in which the vehicle is traveling ("*track section info*") is shown. The first line shows the id of the current section ("*current section*"), followed below by the curvature radius of the current section of the track ("*curvature radius*"), the speed limit inside the section ("*speed limit*"), and the limit for the transition between the previous section and this section ("*transition speed limit*"). Any system messages appear at the bottom of the HMI as a state of the system ("*System status*"), e.g., a message indicating a breakdown of the communication or any camera error is shown in this field. On the right side of this bottom part of the HMI, an emergency stop button (yellow and red button) was also installed. Once this button is pushed, the vehicle will stop whatever its state is. A real-time image feedback of the camera is also shown in the HMI. Over the image feedback, the id of the last mark detected ("*last code detected*"), the state of the camera, and control communications ("*communication status: video, control*") is shown, respectively. Both communications are managed with a specific software daemon to reconnect autonomously after the detection of a communication breakdown.

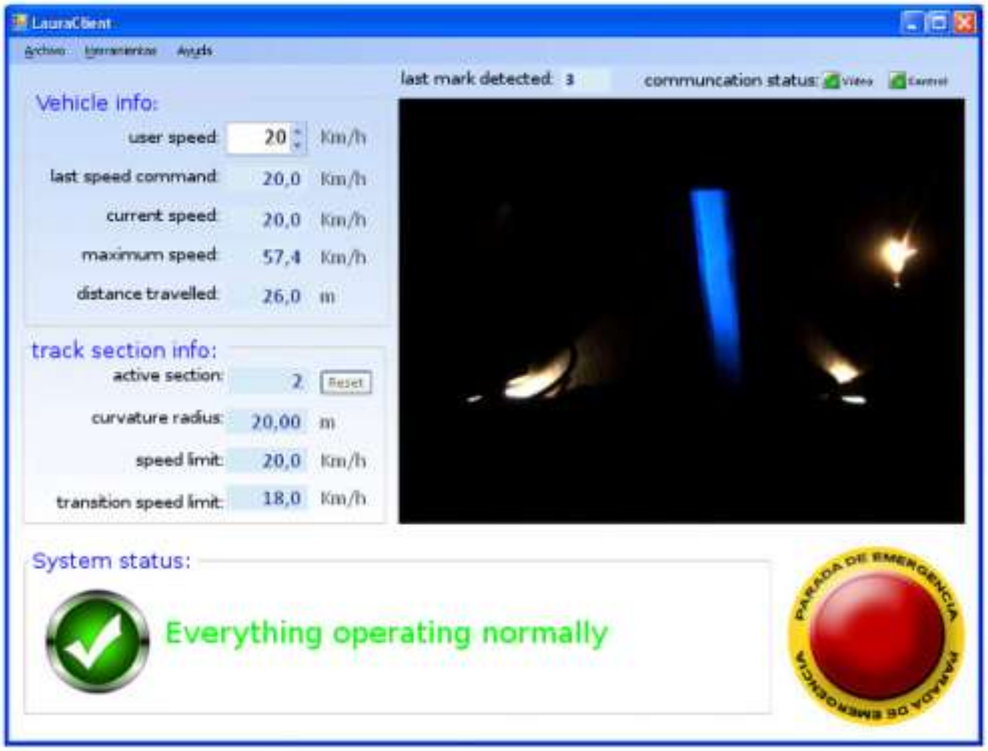


Figure 3. Developed human-machine interface.

Computer Vision System

A computer vision algorithm processes in real time the images captured by a monocular camera under illumination with ultraviolet (UV) light. This camera is placed in the front part of the vehicle, looking downwards and isolated from the sunlight by a black box. A similar approach with a looking downward camera at the bottom of the car is presented in. In this work the car structure was used to avoid that the illumination changes affect the image acquisition. The camera was used to get information from the road to do a localization matching between vision based ground features and the global localization done with a RKT-GPS system. No control of the steering wheel was presented in this work. We, in the presented work, have to set the camera on the front of the vehicle since we are controlling the steering wheel in an Ackermann model vehicle. The mentioned approach could be used in our case to get the information from the visual marks painted on the road but not to guide the vehicle.

The presented algorithm detects both the line to be followed by the vehicle, as well as visual marks painted on the road. The visual marks provide a coded information associated to forward path properties like curvature, maximum allowed speed, *etc.*, which is used by the controller to anticipate changes and react faster.

Two kinds of paint were used for the line and the visual marks. Due to their different pigments, the line is seen as blue while the marks seen as yellow in the images captured by the camera under illumination with UV light. The rest of the image remains black, as depicted in Figure 4.

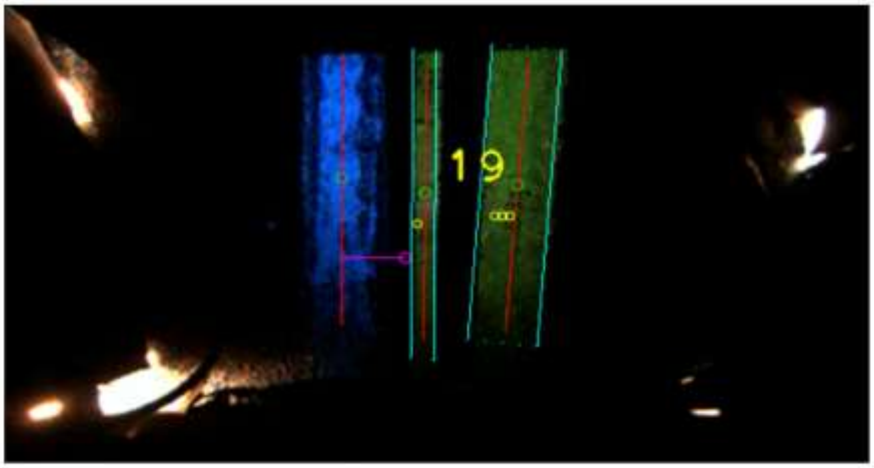


Figure 4. Line and mark detection by the computer vision algorithm.

The visual algorithm has been designed with a special focus on robustness and thus being able to detect fragmented lines due to occlusions or small irregularities on the road. The full system has been tested under different weather conditions including sunny and cloudy days as well as sparkling days. To evaluate the robustness of the system it is important to know the exactly speed at which the system is able to see every single cm of the track by the camera installed. To know this value it has to be taken into account that the frame rate of the camera is equal to 29 fps and the size of the camera system (the metallic box) is 30×5030×50 cm. The distance covered by the system is equal to 29 fps×30×30 cm=870=870 cm/s, and 870 cm/s are equal to 31.3231.32 km/h. That means that at this speed the captured frames cover all the track without losing any single cm of the road. When the speed of the vehicle is higher than 31.3231.32 km/h the system will lose some distance covered by the vehicle in between each frame captured. In the case of 40 km/h, which is equal to 1131 cm/s, the system cover a distance of 39 cm per frame, and for 50 km/h (1388.81388.8 cm/s) the system cover a distance of 47 cm per frame. That means that the system can not see 9 cm and 17 cm in between each frame for the speed of 40 and 50 km/h respectively. Despite this limitation of the vision system the vehicle was able to detect the line and visual marks covering successfully long distance at different speeds. The computer vision algorithm has two different parts which will be described in the following sections.

Line Detection

This first part of the visual algorithm processes the current acquired image to obtain information about the line to be followed by the vehicle. If there is a line in the analyzed image, the line angle and distance are determined with respect to the image center.

The first step for the line detection is color segmentation on YUV space that exploits the blue appearance of the line in the image. Some other color spaces were tested, but YUV provided better results under different light conditions. A rectangular prism inside the YUV space is defined so that only the pixel values inside this volume are considered part of the line. The output of this first step is a binary image in which only the line pixels are set. This method proved to be robust in detecting lines of different blue tones and brightnesses.

To reduced the noise, a second step is performed. In the binary image, every 8-connected pixel group is marked as a blob. Blobs having an area outside a defined range are discarded. Then, for every survivor the centroid, the dominant direction and the maximal length are computed. Those blobs with a too short maximal length are ignored. The remaining blobs are clustered according to proximity and parallelism, so each cluster becomes a candidate line. The centroid and dominant direction of each candidate line are calculated from the weighted sum of the features of its component blobs, where the weight of each blob is proportional to its relative area. In this way the algorithm can accurately detect lines that are fragmented because of the aging of the paint.

The last step consists of the choice of the winning detected line from the whole set of candidate lines. The decision is achieved by using temporal information between the current and the previous frame, *i.e.*, the candidate closer to the last frame winner in terms of centroid distances will be selected as the current frame winner. This rejects false positives because of old line traces along the circuit. In the case that all candidates are far enough from the last frame winner, a bifurcation is assumed and the winner will be the leftmost or rightmost candidate, depending on the information associated to the last detected visual mark.

Mark Detection and Decoding

The second part of the computer vision algorithm includes the detection and decoding of visual marks painted on the road next to the line to follow. The visual marks are detected and decoded even when they appear rotated in the image as a result of vehicle turns.

Each visual mark is labeled through a unique identifier that represents a binary-encoded number, where mark bits are drawn as bars parallel to the line. Because of the reduced visual field of the camera, instead of painting a bar for each bit like in common barcodes where the width of the bar depends on the bit's value, a more compact encoding scheme was chosen. All bits are bars with the same width with no spacing between them. When a bit is one, the bar is painted; when it is zero, the bar space is left unpainted. In the image a mark appears as a set of yellow rectangles. Every painted rectangle is a bit with value one.

A start bar is added at the furthest bit slot from the line to designate the beginning of the mark. The mark specification also defines the number of bits per mark, a fixed bit width, a minimum bit length, and valid ranges for line-mark angle and line-to-start-bit distance. According to the specification, the algorithm will only detect marks that are placed on the right of the line in the direction of motion of the vehicle.

Similarly to the line detection phase, the mark detection algorithm follows a set of steps. First of all, the acquired image is segmented by color in YUV space, extracting the potential mark pixels. The color space boundaries of this segmentation are set so that it admits several yellow tones, ranging from tangerine yellow to bright green, as seen in tests with multiple paints. This makes the color-based filter less restrictive and avoids false negatives. As the probability that any yellow noise present in the image has a valid mark structure is low, the following steps of the algorithm seek for this valid structure in the color-segmented pixels to reduce the false positives.

After the color segmentation, the resulting eight-connected pixels are grouped in blobs. The blobs that do not meet the following criteria are considered as noise and are discarded: the blobs must appear at the right of the line, the blob area must be in a valid range (computed from the visual mark specification), the angular distance between the dominant blob direction and the line must be in the specified range, and the blob length in the dominant direction must be larger than the minimum bit length.

The blobs that pass the filters correspond to a set of bits with value 1. A pattern matching determines the specific ordinal number of bits for each blob. Assuming each mark has a total of N bits (including the start bit), N pattern tests are carried out for each blob, one test for each bit in the range [1,N][1,N]. For every bit i, the pattern Pi,BPi,B is a rectangle with the direction and length of the blob B and a width a equal to i times the bit width in the specification (in pixels). The ordinal number of bits for the blob B will be the value i that minimizes the cost function present in the Equation (1).

$$c(i,B) = f(i,B) + \hat{g}(i,B)$$

$$f(i,B) = 1 - \frac{a(B \cap P_{i,B})}{a(B)}$$

$$\hat{g}(i,B) = \frac{g(i,B)}{g_{max}}$$

$$g(i,B) = | a(B) - a(P_{i,B})|$$

Function *f* indicates how much the pattern covers the blob. Function *g* evaluates the similarity between the blob and pattern areas. Patterns whose *f* or *g* are above a threshold are discarded. This forces the best solution to have a minimum quality in both indicators. Then, the minimization process favors patterns that cover the blob while having a similar size. The threshold for *g* is gmax and g^ is a normalized version that stays in [0,1][0,1], like *f* does.

After assigning a number of ones to all processed blobs, the rightmost one is interpreted as the start bit. If its distance to the line is in the range allowed by the specification, the mark remains in the detection process, otherwise it is ignored. The mark's dominant direction is computed as the average of all its blobs. The orthogonal vector to this direction defines a baseline that is divided into *N* consecutive fixed-width bit slots, starting from the start bit. All bit slots are set to an initial value of zero. Then, blob centroids are projected on the baseline and each projection falls into one of the slots, an then filled with a one. Adjacent slots are also filled with ones according to the blob's number of bits. Finally, the slot values define the binary-encoded mark identifier whose least significant bit is the closest to the start bit.

The final detection step of the visual mark identifier that is going to be passed to the control system is elected with a two different voting process. The first voting process evaluates the detected visual mark id in each frame. Working under the assumption that the code is always located on the right of the line, this part of the image is divided in nine horizontal sections. In each of these section the system tries to identify a visual mark. The final result comes from the most detected code. An example of this voting process is shown in the Figure 5.

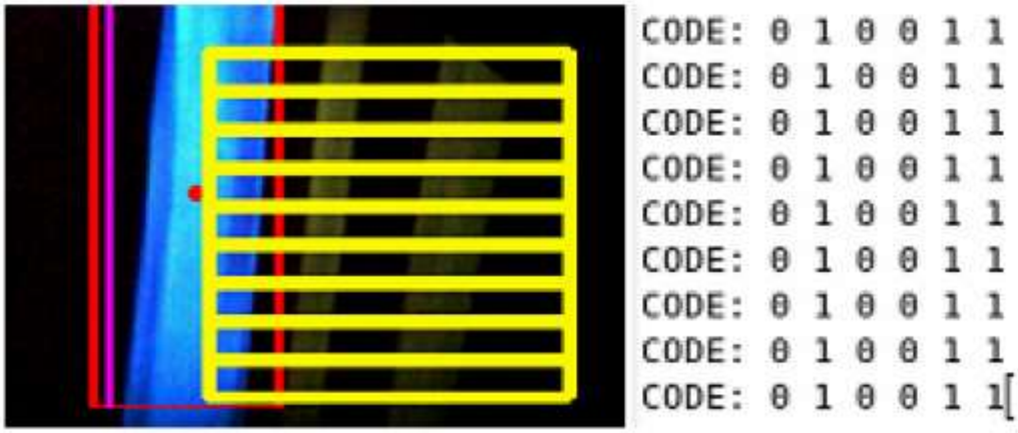


Figure 5. Single frame voting process for the detection of visual marks.

The second voting process evaluates the code detection among the last *M* frames. Large values of *M* produce higher detection delays but increase detection robustness, as more image samples are taken into account. In our experiments, M=3M=3 gave good results. Besides the detected mark identifier, the algorithm provides an estimation of the number of frames and time lapse since the mark was last seen. This information is especially useful at high speeds and high values of *M*, when the decision is delayed until *M* frames have been captured, but the mark was only seen on the first few frames. In addition, an estimation of the mark quality is given based on its average luminance. Figure 4 shows the detection of the line and the mark which represent the number 19.

Once the mark detection stage provides a visual mark identifier, the decoding stage starts. The information encoded in these marks is the current location of the marks on the track, the size and the curvature of the following section of the track, and the maximum permitted speed on it.

The detection of a mark is always checked with a database of available marks, avoiding false detections that could localize the vehicle in another section of the track.

Lateral Control System: A Vision-Based Fuzzy-Logic Controller

The steering control system of the vehicle includes three additive components: The first one is a fuzzy-logic feedback controller that acts with a behavior equivalent to a PD controller. The second one is the weighted integral of the error (distance between the line reference and the measured line position). The third component is the steering offset that acts like a feedforward controller, by changing the operating point of the fuzzy-logic controller to improve its performance, based on the track information given by the detected mark. All the three components are added at the end of the control loop to generate the output of the control system, making a structure of Fuzzy+I+OffsetFuzzy+I+Offset, as shown in Figure 6.

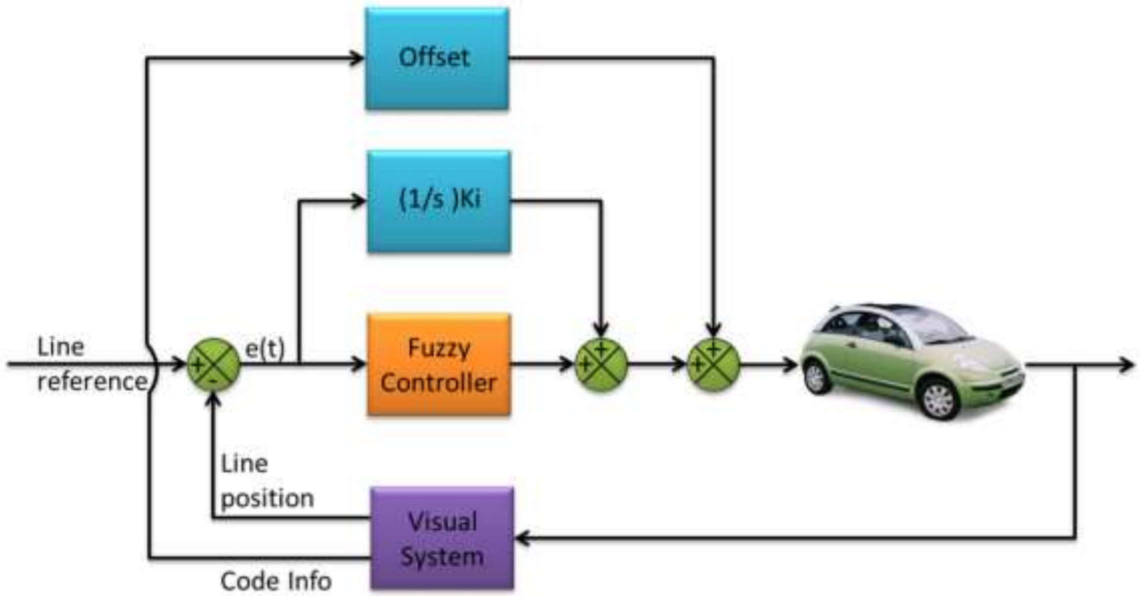


Figure 6. Simplified control loop of the visual control system.

The objective of this work is to develop a controller for a track with small radius curves. In such conditions the speed of the car is not allowed to be very high (less than 50 km/h).

From several real experiments with the vehicle, the authors can confirm that it is practically impossible for a human pilot using just the information received from the down-looking camera to drive faster than 10 km/h while keeping the line-following error low enough to meet the requirements of the application. This is because the pilot only sees 39 cm ahead, and, at that speed, the contents of this area change completely every 0.1080.108 s.

The first and main component, the fuzzy-logic feedback controller was implemented using a software called MOFS (*Miguel Olivares' Fuzzy Software*). This C++ library has been previously successfully used to implement fuzzy-logic control systems with other kind of robotic platforms such as an unmanned helicopter for autonomous landing or quadrotors for avoiding collisions. Thanks to this software, a fuzzy controller can be defined by specifying the desired number of inputs, the type of membership functions, the defuzzification model and the inference operator. In , a more detailed explanation of this software is provided.

The fuzzy-logic controller designed with PD-like behavior has two inputs and one output. Triangular membership functions are used for the inputs and the output. The first input is called the error and is the difference between the line reference and the measured line position in pixels, with respect to the center of the image (Figure 7a). The second input is the derivative of this error (Figure 7b). The output of the controller is the absolute turn of the steering wheel in degrees to correct this error (Figure 7c).

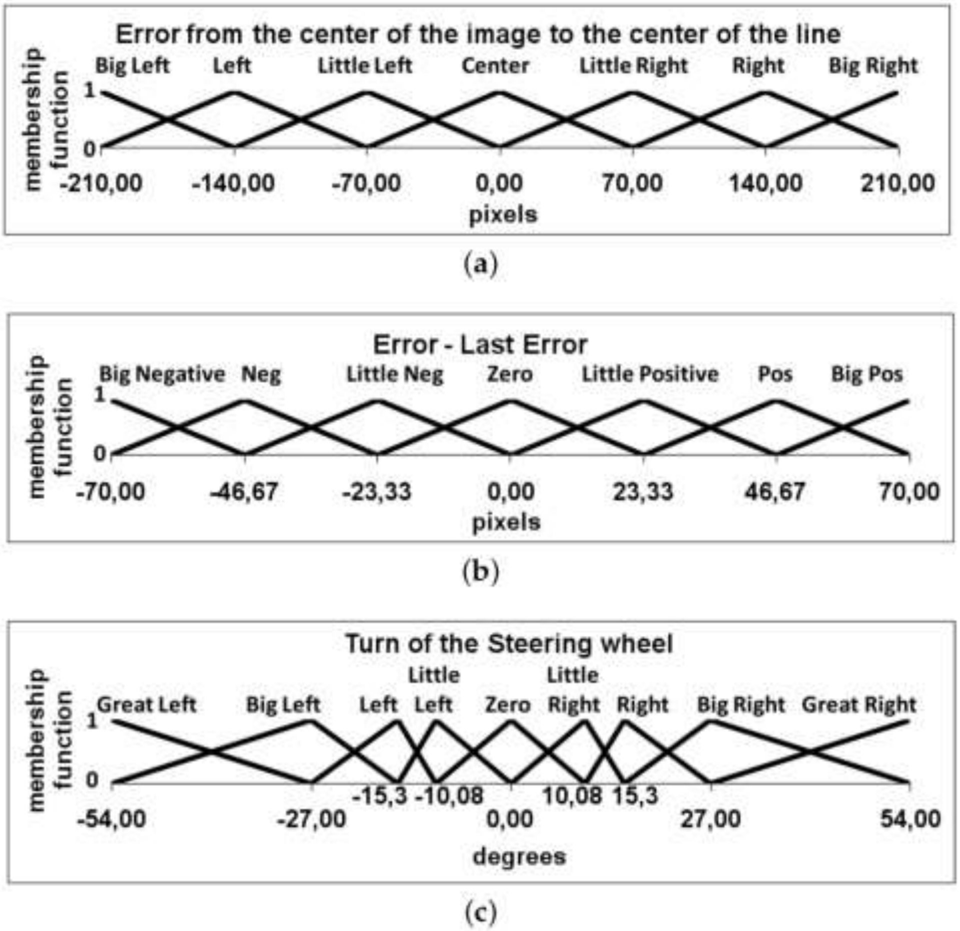


Figure 7. Definition of the two inputs and the output of the fuzzy controller. (a) First input variable of the fuzzy controller: Difference between the line reference and the measured line position with respect to the center of the image, in pixels; (b) second input variable of the fuzzy controller: The difference between the last error and the actual, in pixels; (c) Output variable of the fuzzy controller: The steering wheel angle, in degrees.

The rule base of the presented fuzzy control component is formed by 49 if-then rules. Heuristic information has been used to define the output of each rule as well as for the definition of the range and set of each variable. The developed fuzzy system is a Mamdani-type controller that uses a height defuzzification model with the product inference model as described in Equation (2).

$$y = \frac{\sum_{l=1}^{M} \bar{y}^{l} \prod_{i=1}^{N} \left(\mu_{x_i^l}(x_i)\right)}{\sum_{l=1}^{M} \prod_{i=1}^{N} \left(\mu_{x_i^l}(x_i)\right)}$$

Herein *N* and *M* represent the number of input variables and the total number of rules, respectively. μxliμxil denotes the membership function of the *l*-th rule for the *i*-th input variable. y¯ly¯l represent the output of the *l*-th rule.

To tune the fuzzy-logic controller, a driving session performed by a human driver at 10 km/h provided the necessary training data to modify the initial base of rules of the controller and the size of the fuzzy sets of its variables. For the definition of the initial fuzzy sets, a heuristic method was used based on the extraction of statistical measures from the training data. For the initial base of rules, a supervised learning algorithm implemented in MOFS has been used. This algorithm evaluates the situation (value of input variables) and looks for the rules that are involved in it (active rules). Then, according to the steering command given by the human driver, the weights of these rules are changed. Each time the output of an active rule coincides with the human command its weight will be increased. Otherwise, when the output differs from the human command its weight will be decreased by a constant. Anytime the weight of a rule becomes negative the system sets the output of the rule to the one given by the human driver.

Since the velocity of the vehicle is not included in the fuzzy controller, this is taken into account by multiplying the output of the fuzzy-logic controller by 10v10v, where *v* is the current velocity of the vehicle. The definition of the numerator value of this factor is based on the velocity, in km/h, obtained during a driving session with a skilled human driver, in which data was acquired to tune the rule base of the fuzzy controller.

The second component of the presented control system is the weighted integral of the error. The objective of this component is to ensure that the error converges to zero in every kind of track. The output of this component follows Equation (3).

$$I_t = I_{t-1} + e \times \frac{1}{t} \times Ki$$

Herein *e* is the current error between the center of the line and the center of the image, *t* is the frame rate, and KiKi is a constant that appropriately weights the effect of the integrator. In the presented control approach this constant KiKi has a value equal to 0.60.6.

Finally, the third component of the lateral control system is a steering offset component. It behaves like a feedforward controller that offsets the effect of the change of the curvature of the circuit in every different track, updated each time that a new mark has been detected. It is theoretically calculated using the equations of the Frenet-frame kinematic model of a car-like mobile robot. More detailed information about this control component can be found in.

DYNAMIC VISION

<u>What is "Dynamic vision"?</u>

- More than just active control of gaze and attention ('active vision');
- Expectations of visual appearance are computed in real-time and used for more efficient feature extraction and understanding of fast sequences of images.
- This requires

+ internal representation of models for motion in 3-D space and time (including control activities), and

+ modeling of perspective mapping as nonlinear measurement process, approximated by a linearization for short time intervals to arrive at a least squares recursive model fit for all states and parameters involved.

- Time delays between the different sensory modalities and control output are taken into account; interpretation is synchronized.
- For different elements of perception (inertial, visual, auditory, odometry, ..) the best signals available have to be used! For example, due to delay times and motion blur for vision, fast (short-term) egomotion and gaze stabilization should be derived from inertial signals, while long term stability of interpretation is better served by visual feedback (drift problems with integration of inertial signals).
- Temporally extended maneuver elements and maneuvers are part of the knowledge base for understanding motion processes and for situation assessment(very important, often neglected in CS- or AI-approaches).
- For animals and humans their behavioral capabilities are essential parts of the knowledge base; behaviors should be recognizable from small fractions of temporal action elements in certain situations (intent recognition).
- Perceptual and behavioral capabilities are represented in corresponding networks that

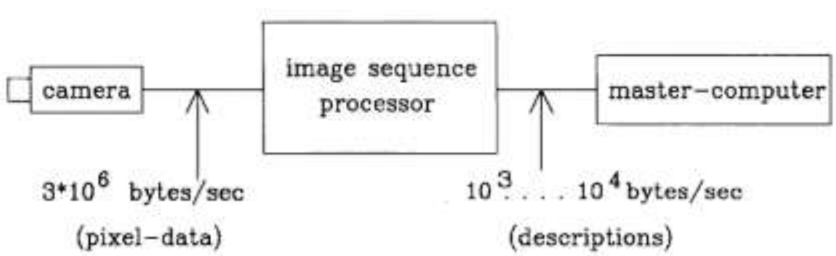
show the interdependences across the levels down to the actual hardware components needed.

- Dynamic vision copes with
  - Moving or changing objects (size, structure, shape)
  - Changing illumination
  - Changing viewpoints
- Input: sequence of image frames
  - Frame: Image at a particular instant of time
  - Differences between frames: due to motion of camera or object, illumination changes, changes of objects
- Output: detect changes, compute motion of camera or object, recognize moving objects etc.

ARCHITECTURE OF DYNAMIC VISION

The design of vision hardware was never considered an end in itself but rather a necessary prerequisite for studying dynamic vision in real-world experiments. The initial approach was, therefore, to minimize the design effort by using available minicomputers to the greatest possible extent and build only a peripheral device enabling such a computer to process image data in real time. Accordingly, the first member of the BVV family of vision systems, the BVV 1, was initially intended to be such a peripheral device, and it was often referred to as a preprocessor in relation to an associated minicomputer.

Figure A.1 shows the overall structure of a vision system based on these considerations. An image sequence processor is inserted between the camera and a conventional computer. From a general point of view, the task of the image sequence processor is data reduction. This is done by extracting relevant information from the pixel data and converting it into a compact symbolical form, well suited for transmitting it to the master computer. According to this concept, the bulk of the computation was to be performed by a conven-



tional minicomputer (master computer), while a specialized image sequence processor was used only for relieving the master computer from the task of inputting pixel data at high speed. The master computer is, thus, free to do what it can do best: computation on relatively small sets of data.

The underlying idea behind this structure was that the minicomputer, which was to be used as the master computer, was a much more powerful computer than the image sequence processor, which was based on one of the 8-bit microprocessors available at that time.

With the advent of ever stronger microprocessors, and eventually the PC, this view has changed. Later BVV systems, while still utilizing commercial hardware as much as possible (e.g., single board computers), are completely self-contained vision systems, except that an additional PC is used for mass storage and as a human interface. The reason is that, at least in not-too-complex situations as they have been studied up to date, the bulk of the processing actually occurs in the lower levels of a vision system (feature extraction, 2-D object modeling [14]) for which the BVV 1 was originally intended. The task originally assigned to the master computer (dynamical object model and assessment of a relatively simple situation) is comparatively small and may, therefore, be performed by the image sequence processor as an additional task, using only a fraction of that system's resources. In fact, it was soon discovered that even the BVV 1, in spite of its weak processing elements, could be used quite effectively without a master computer. General-purpose computers, including minicomputers, by themselves are not suited for dynamic vision. One obvious reason is the fact that they do not have an input channel capable of feeding them continuously with data from a TV camera. If a camera signal is digitized, a data stream of 4×10^6 to 10×10^6 bytes per second results. Even though some modern computers may have direct memory access, DMA, channels capable of handling such data streams, the continuous inputting of video data at such rates would absorb a large part of the memory access bandwidth, thus reducing the remaining computing power significantly. This was even more evident 13 years ago when the image sequence processor BVV 1 was conceived and when memory access times were about 10 times longer than they are today.

A system, as shown in Figure A.1, was actually built and used for experiments in robot vision. The master computer was, at different times, a DEC PDP 11/60, a VAX 750, and a Perkin Elmer 3220. The image sequence processor was a specially designed multi-microprocessor system, later named BVV 1. It was the first member of the BVV family.

1. To control motion, it is sufficient to interpret only those parts of an image sequence that contain relevant features; it is unnecessary to analyze all other parts of the images, for instance, the background. Since, typically,

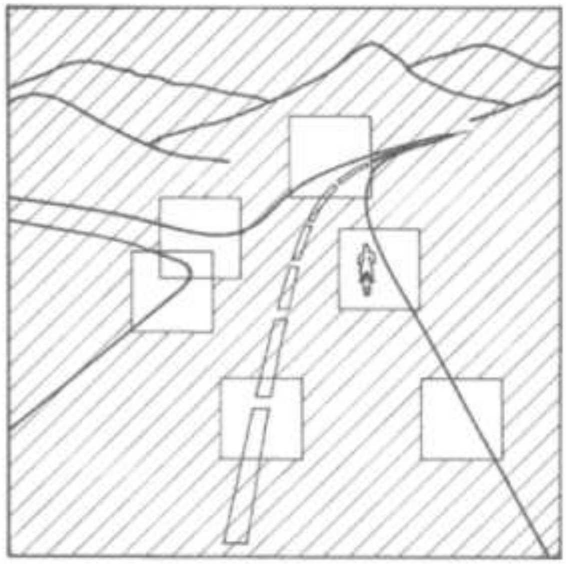


FIGURE A.2. A few small regions of an image contain almost all information relevant for motion control.

only small areas within each image contain relevant features, concentrating all the available processing power on the most relevant parts of each image leads to a significant gain in efficiency. Figure A.2 illustrates this concept, using the task of guiding an autonomous vehicle on a road as an example. Usually, in vision for motion control, the combined area of all regions of interest is less than 10% of the image area. Limiting all processing to these regions thus leads to a very efficient use of resources. Stating it differently, vision systems not limiting their processing to the relevant parts of a scene waste at least 90% of their resources.

2. Controlling motion in real time requires the highest possible processing speed. The task of image interpretation is, therefore, partitioned into several subtasks that are assigned to an equal number of subprocessors (parallel processors) within the system.
3. To prevent communication between subprocessors from becoming a bottleneck for the performance, communication channels with the necessary bandwidth must be provided. Also, the system should be structured in such a way as to minimize the need for interprocessor communication altogether. This may be done by defining the subtasks properly, making them, and thus the subprocessors associated with them, largely independent of each other.
4. Flexibility is a key to the high performance of a vision system. The subprocessors in the BVV 1 have, therefore, free random access to each pixel within their region of interest and they may freely position this region anywhere in the image. Moreover, the internal structure of the image sequence processor is, instead of being fixed, definable by the application programs. It is thus possible for appropriately written application pro-

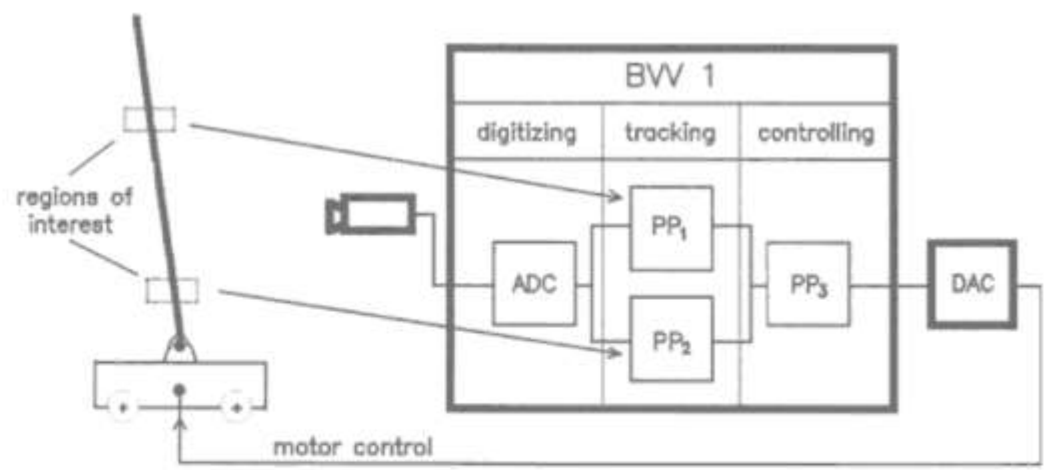


FIGURE A.4. Stabilizing an inverted pendulum using only the BVV 1 without any master computer.

application, an inverted pendulum stabilized by the BVV 1 without a master computer. What had begun as a data reduction unit thus turned into a complete robot vision system.

An important and somewhat surprising lesson learned by working with the BVV 1 was that, *if the system architecture is correct*, four standard 8-bit microprocessors (1 for communication and 3 for image processing) are sufficient for a robot vision task as demanding as the stabilization of an agile mechanical system.

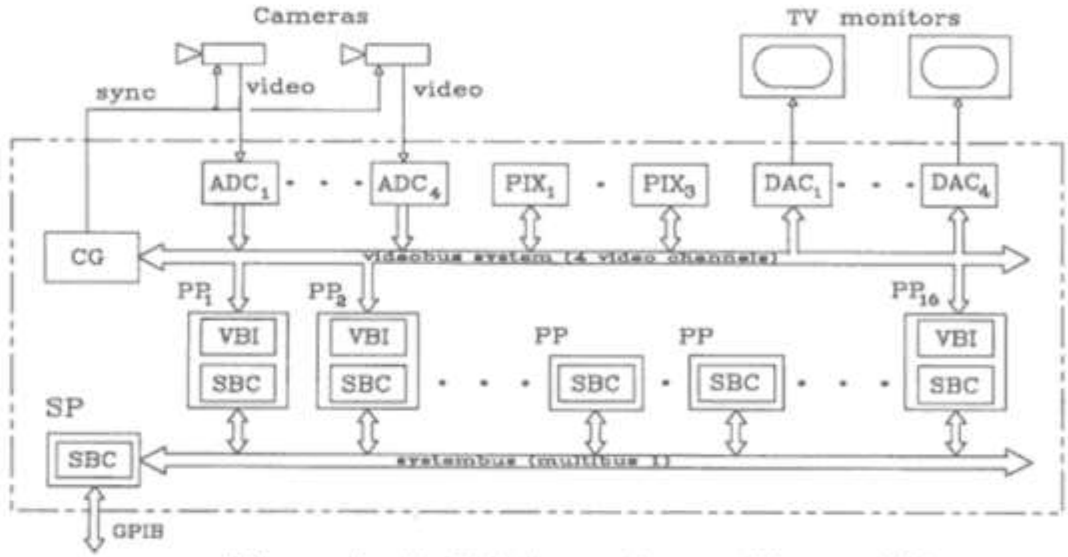
Nevertheless, it became obvious that the computing power of the 8085 A microprocessor was sufficient for the real-time interpretation of visually simple scenes only. In order to be able to interpret more complex scenes, it was decided to develop a more powerful, but otherwise similar, image sequence processor, the BVV 2 [10].

Another vision system, also based on the concepts that had guided the design of the BVV 1, and remarkably similar to the BVV 2, was later built and described by an unrelated Japanese group [21].

THE BVV2

The block diagram (Figure A.5) clearly shows the architectural similarity between the vision system BVV 2 and its predecessor BVV 1. The main difference in a conceptual sense is a videobus system with originally 2, and later 4, channels allowing the simultaneous transmission of up to 4 independent image sequences instead of the simple videobus of the BVV 1. Other differences, not visible in the block diagram, are more powerful microprocessors and much larger memories in all subprocessors.

The multichannel videobus system may be used, for instance, in the following ways:



ADC : analog to digital converter
DAC : digital to analog converter
CG : central clock generator
PIX : pixelprocessor
GPIP : General purpose interface bus connecting the BVV 2 to other equipment, e.g. host computer
PP : parallel processor
SP : system processor
VBI : videobus interface
SBC : single board computer

FIGURE A.5. The real-time vision system BVV 2.

employing two identical cameras simultaneously for stereo vision;
simulating the foveal and the peripheral vision of the eye by using two, or more, identical cameras equipped with lenses of different focal lengths and mounted on a common movable platform;
using an RGB camera for full color vision;
using several cameras pointing into different directions, for instance, the front and rear of a vehicle; and
using fewer than four cameras and, in addition, one or more preprocessing units ("pixelprocessors") to derive "on the fly" from an original image a new image containing, for instance, only edges or only interesting points.

If more than one camera is connected to the system, they must run synchronously. A central clock generator in the BVV 2 provides the control signals necessary to synchronize the cameras and all other parts of the system. In the BVV 1, where only one camera could be used, the camera provided the synchronization signals.

Each parallel processor consists typically of a single-board computer, SBC, and a videobus interface, VBI. The SBCs are standardized commercial products. They were originally based on Intel's 16-bit microprocessor 8086. This processor is generally more powerful and faster than the 8085 A, but, what is most important in the context of image processing, it is much more efficient in addressing two-dimensional arrays of data. In this respect, the 8085 A is quite weak because of its insufficient number of index registers. For typical tasks in feature extraction the 8086 is about 10 times faster than the 8085 A.

Each one of the original parallel processors has between 40 and 148 kBytes of memory. The greater speed of the 8086, in combination with the larger memory of each parallel processor, makes it possible to run more complex programs in real time and to use more refined methods for the extraction of features from the image than with the older BVV 1.

Communication between the subprocessors within the BVV 2 is organized in a manner similar to the one used in the BVV 1, using FIFO buffers to decouple the subprocessors from each other. However, since the SBCs of the BVV 2 are provided with dual-port memories, they have direct access to each other's memory. Messages within the BVV 2 are, therefore, transferred by the system processor reading them from, or writing them into, a parallel processor's memory. The FIFO buffers, which physically exist in the BVV 1, are thus simulated by software in the BVV 2. This made the interprocessor communication slightly slower than with hardware FIFOs, but it allowed commercially available single board computers to be used for all PPs and the SP without modification. This had the advantage that later some of the SBCs could be replaced by even more powerful ones based on the microprocessors 80286 and 80386.

The VBI is a custom-made printed circuit board containing all those parts of the PP that are unavailable on a standard SBC. Its main task is to select from the videobus those pixels that belong to the selected window and make them available to the parallel processor. Since the data rate on the videobus is much higher than on the local processorbus, the video data must be temporarily stored in a buffer memory before being placed in the parallel processor's main memory.

In the BVV 1, a 32-byte FIFO buffer had been used for this purpose (Figure A.6). Therefore, the number of pixels within one row of the window has been limited to 32. This restriction turned out to be inconvenient at times, and a

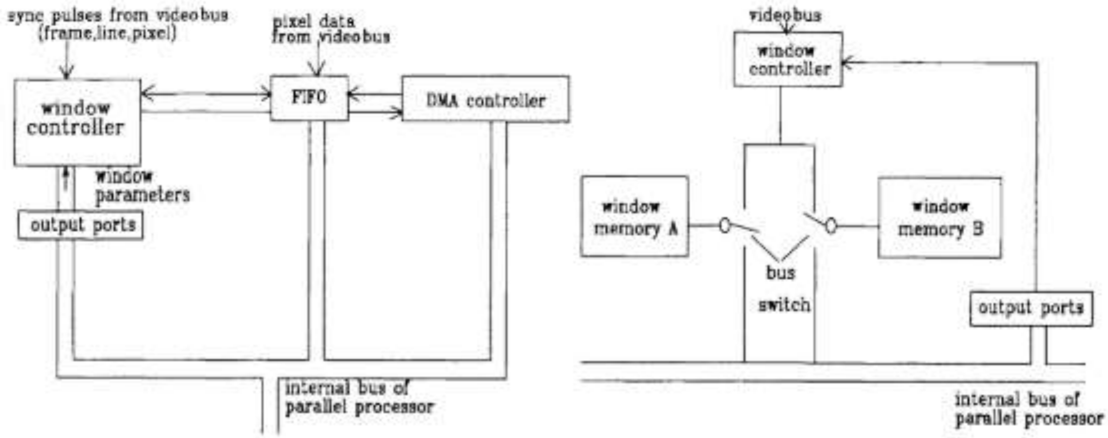


FIGURE A.6. Videobus interfaces of the BVV 1 (left) and the BVV 2 (right).

better solution was desired for the BVV 2. Another restriction was that the window parameters controlling shape, size, and position of the window could only be changed during the interframe gap of the video signal. This could cause an unnecessary increase of the vision system's response time by as much as 20 ms in the worst case.

The videobus interface of the BVV 2 avoids these restrictions. It contains two window memories with a capacity of 4 kBytes each. The window memories are connected through bus switches to the videobus and to the local processor bus in such a way that always one of them is connected to the videobus and the other one to the processorbus. The switches are controlled by the parallel processor's CPU. In operation, the window controller selects, according to the window parameters set by the processor, those pixels that belong to the window and stores their gray levels in the window memory connected to the videobus. As soon as all data belonging to the window have been stored, the processor may, by sending a command to the bus switches, exchange the two window memories. This means that the window memory, which has just been loaded with pixel data, is now connected to the local bus, thus becoming part of the processor's main memory, while the other image memory, which had been connected to the processor up to this moment, is now connected to the videobus, ready to receive the next set of pixel data. In this way, no time is lost in transferring data from the window memory to the parallel processor's main memory.

The BVV 2 has proven to be an efficient hardware basis for dynamic computer vision. Among the applications studied with it are autonomous vehicles, including a highway vehicle [6, 7, 44], and a vision-guided autonomous indoor vehicle to be used in factories and warehouses [27].

The ability to process image sequences at a high rate (50 to 60 images per second) was essential for allowing the experimental vehicle VaMoRs to run autonomously at its maximum speed of 96 km/h on highways, limited only by the power of its engine, not by the vision system.

Again, the main reason for the relatively good system performance, as evidenced in the applications, is not the sheer computing power of the processors of the BVV 2 but rather its flexibility, which allows the entire power of the system to be concentrated on the relevant regions of the image.

After having worked with the BVV 2 for some time, it became clear that certain types of algorithms were particularly useful for feature extraction in dynamic scenes (e.g., controlled correlation [23]) and that the parallel processors spent a significant amount of time executing a fairly limited variety of operations (e.g., addition, subtraction, maximum detection, and, surprisingly, data conversion from the 8-bit format used on the videobus to the 16-bit format used in computing). Also, it was found that in a typical program algorithms from two distinct classes changed over and over again: (1) schematic application of operators on groups of pixels and (2) more or less complex

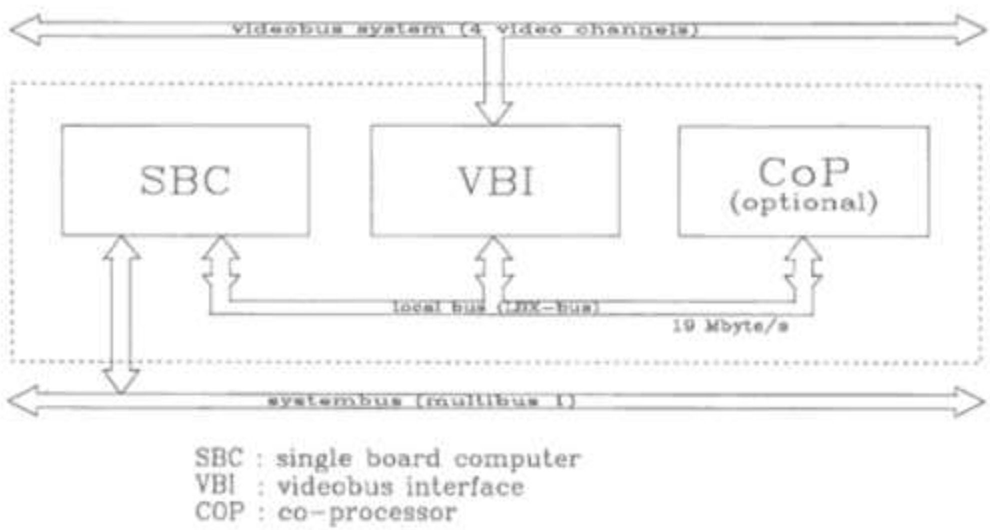


FIGURE A.7. The parallel processor of the BVV 3.

decisions in analyzing the results of the more schematic processing and determining which operator to apply next [28].

A standard microprocessor appeared to be well suited for the analysis and decision part, but it seemed likely that special hardware, similar to a signal processor, would be much more effective for the schematic part. It was, therefore, decided to develop the special hardware and implement it as a coprocessor, to be tightly coupled to an associated standard microprocessor.

If such a coprocessor is used in combination with a microcomputer, a very powerful device for feature extraction results. In fact, its performance would probably be limited by the quantity of pixel data (4*K*) available in a window of the videobus interface of the BVV 2. Fortunately, in the meantime, prices for memory chips were reduced to a point where it seemed justified to design a new videobus interface that would store an entire image rather than only a selected window of limited size.

Figure A.7 shows the structure of the new parallel processor. It connects to the same videobus and to the same systembus as its predecessor in the BVV 2. In fact, the overall architecture of both vision systems is exactly the same; they differ only by the improved performance in feature extraction of the parallel processors of the BVV 3.

The adherence to commercial standards had been very beneficial in the past, having permitted some of the single-board computers of the BVV 2 to be replaced by more modern ones with the newer and more powerful microprocessors Intel 286 or 386 as they became available. These same SBCs are initially being used in the BVV 3, possibly to be replaced again by even more powerful ones at a later time. They are connected to the VBI and coprocessor (COP) via a semistandardized LBX bus having a theoretical bandwidth of 19 MB/s.

The videobus interface is similar in its function to the one of the BVV 2, but instead of the two window memories, it has two full image memories. Among

VISION BASED MOBILE ROBOTS NAVIGATION

Navigation of Mobile Robots is a broad topic, covering a large spectrum of different technologies and applications. It draws on some very ancient techniques, as well as some of the most advanced space science and engineering.

While the human-machine interface is not yet at a transparent level (with robots accepting and following spoken instructions; a problem in the realm of Natural Language Processing), the degree of autonomy available after a machine has been program is now approaching that once considered purely science fiction.

This document draws together, and builds upon, a lot of what is written in the authors' four preceding articles in Mobile Robot Navigation. For completeness, some sections of those articles have been included here; however, the reader is referred back to them for a more detailed analysis of some of the systems discussed here.

Macro- to Micro- Scale Navigation

Overview

"Mobile Robot Navigation" covers a large spectrum of different systems. requirements and solutions. The aim of the first half of this document is to study this range of requirements, identify the major areas within the scale which are most commonly used, and to discuss appropriate systems for meeting these requirements.

Physical Scales

The physical scale of a device's navigation requirements can be measured by the accuracy to which the mobile robot needs to navigate - this is the resolution of navigation. These requirements vary greatly with application, however a first order approximation of the accuracy required can by taken from the dimensions of the vehicle it self. Any autonomous device must be able to determine its position to a resolution within at least its own dimensions, in order to be able to navigate and interact with its environment correctly.

At the small end of the scale there are robots just a few centimetres in size, which will require high precision navigation over a small range (due to energy supply constraints), while operating in a relatively tame environment. At the other end of the scale there are Jumbo jet aircraft and ocean going liners, each with some sort of auto-pilot navigation, which requires accuracy to a number of metres (or tens of metres), over a huge (i.e. global) range, in somewhat more rugged conditions.

To help in categorising this scale of requirements, we use three terms:-

- *Global* navigation, which is the ability to determine one's position in absolute or map-referenced terms, and to move to a desired destination point.
- *Local* navigation, the ability to determine one's position relative to objects (stationary or moving) in the environment, and to interact with them correctly.
- *Personal* navigation, which involves being aware of the positioning of the various parts that make up oneself, in relation to each other and in handling objects.

With the jet auto-pilot example Global navigation is the major requirement, for cruising between continents. Local navigation becomes necessary were the aircraft is expected to fly autonomously in crowded airways, or on approach to the runway on landing. Personal navigation is not an issue, as the vehicle is, fundamentally, one object, and should (hopefully) never come into contact with any other significant objects while under autonomous control.

The "micro" robot on the other hand, is almost exclusively interested in Personal and Local navigation. Such devices are rarely concerned with their position globally, on any traditional geographic scale. Instead their requirements are far more task based - the are concerned with their immediate environment, in particular relative to any objects relevant in the successful completion of their task. This involves Personal navigation, when it is in contact with other objects, and Local navigation for actual movement.

In general, the main focus of the scales of navigation are as follows,

- *Global*: getting between end locations,
- *Local*: carrying out a task while at a location
- *Personal*: monitoring of the individual robot and anything in contact with it.

Navigation Reference

Following on, and going in hand with, the scale of navigation requirements, is the frame in which position fixing is performed relative to. The two terms used here are, understandably, Absolute and Relative. What isn't so obvious, however, is what Relative is relative to, and where

Absolute is absolute from; this is because these terms are somewhat context sensitive.

In terms of position fixing, absolute implies finding ones position relative to an absolute origin; a fixed stationary point common to all position fixes across the range of navigation. Hence in Global navigation, there should be one such point on the planet which all fixes are relative to. In Local navigation the absolute origin is some fixed point in the robot's environment, and in Personal navigation the origin can be viewed as the centre of the robot itself.

A Relative position fix when navigating Globally, taken relative to some other reference point (environment-relative), is analogous to the absolute position fix in Local navigation. Likewise, a position fix taken relative to the same robot's own position at some other point in time (self-relative), is like the personal absolute position fix. Through knowledge of the absolute reference frame (typically using a map), absolute position fixes in one navigation domain can be transformed into position fixes in another. Indeed, almost all global absolute position fixing is carried out by finding either an environment- or a self- relative position fix, and then converting this into a global position (see Beacon Navigation and Dead-Reckoning respectively).

Two Contemporary Systems

The technology employed in mobile robot navigation is rapidally developing. Here two relatively modern systems are studied, satellite based Global Positioning Systems and image based Vision Positioning Systems, which have the common feature of being under continual development. Between the two, a large scale of naivgational requirements can be met.

Summary of GPS

In 1973 the American Defence Navigation Satellite System was formed, as a joint service between the US Navy and Air Force, along with other departments including the Department of Transport, with the aim of developing a highly precise satellite based navigation system - the *Global Positioning System.* In the 24 years since conception GPS has established itself firmly into many military and civilian uses across the world, here it will be considered in the context of a device for navigating of mobile robots.

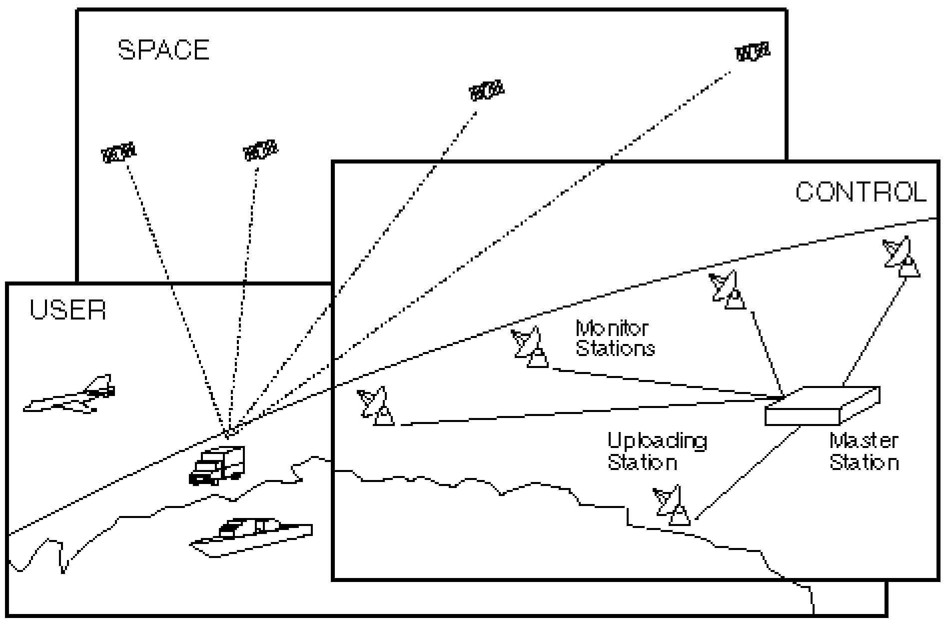
When GPS was released by the US DoD (Department of Defence), it superseded several other systems, however it was designed to have limited accuracy available to non-military (US) users.

Several methods of improving the performance have been developed as a result of this, which greatly increase the usefulness of the system for robots.

Further reading on the technical aspects of GPS is given in the appendix.

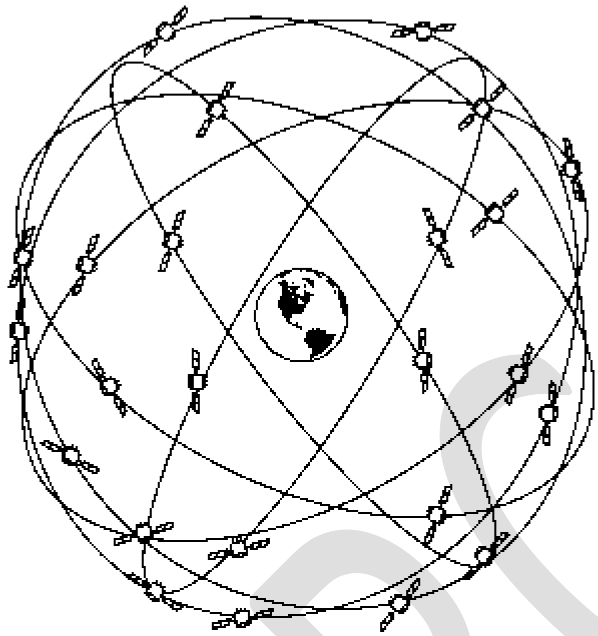
GPS Segments

There are three segments which make up the GPS system.



The Navstar *Global Positioning System* consists of three fundamental segments: Space, Control, and User. (Adapted from [Getting, 1993].)

The *space segment* of GPS is 24 satellites (or *Space Vehicles* - SVs) in orbit about the planet at a height of approximately 20 200 km, such that generally at least four SVs are viewable from the surface of the Earth at any time. This allows the instantaneous user position to be determined, at any time, by measuring the time delay in a radio signal broadcast from each satellite, and using this and the speed of propagation to calculate the distance to the satellite (the *pseudo-range*). As a 'rule-of-thumb', one individual satellite needs to be received for each dimension of the user's position that needs to be calculated. This suggests 3 satellites are necessary for a position fix of the general user (for the *x*, *y*, and *z* dimensions of the receiver's position), however, the user rarely knows the exact *time* which they are receiving at - hence 4 satellite pseudo-ranges are required to calculate these 4 unknowns.



The satellite data is monitored and controlled by the GPS *ground segment* - stations positioned globally to ensure the correct operation of the system.

The *user segment* is the mobile user and their GPS reception equipment. These have advanced considerably in recent years, to allow faster and more accurate processing of received data. They typically contain pre-amplification, an analogue to digital converter, between 5 and 12 digital signal processor (DSP) channels (each one is able to track a separate satellite transmission), and processor for navigational data. Other elements that might be incorporated are differential GPS receiver/ processing capability, received phase information processing, and reception capability for the second (L2) GPS frequency.

Uses of GPS

GPS provides an accuracy of 100 m (95 % of the time) to *Standard Positioning Service* (SPS) users, due to the Selective Availability (S/A) errors introduced intentionally by the US military, for defence reasons. This can be improved to about 15 m (95 %) for authorised *Precision Positioning Service* (PPS) users [Kaplan, 1996]. The SPS accuracy is not good enough to be individually useful for mobile robot navigation. However, when augmented by the benefits of Differential techniques, GPS does become a viable method for global reference navigation.

The DGPS system operates by having reference stations receive the satellite broadcast GPS signal at a known site, and then transmit a correction according to the error in received signal, to mobile GPS users. So long as the mobile user is in the proximity of the stationary site, they will experience similar errors, and hence require similar corrections. Typical DGPS accuracy is around 4 to 6 m, with better performance seen as the distance between user and beacon site decreases.

DGPS provides the resolution necessary for most Global scale navigation purposes, as well as often being useful at the Local scale. There are a few restrictions on the situations were it can be used however; the following problems can greatly reduces DGPS (or GPS) usability,

- periodic signal blockage due to obstruction,
- multipath interference from large reflective surfaces in the vicinity,
- as a result of both of the above, it will not work indoors.

In situations were the above are only a problem on occasion (e.g. a robot which operates outside as well as indoors), combining DGPS with other navigation technologies can prove very effective.

Another common marriage of technologies uses (D)GPS for the global level navigation, then other systems for precision local navigation. A good example of this is the UK Robotics Road Robot, a construction autonomous device built after the lack of automation in this area was noticed [Dolton, 1997]. This incorporates the *Atlas* navigation control unit, which initially finds its course (global) location using GPS, after which it uses laser trilateration to navigate (locally) while carrying out its task. This was found to produce reliable autonomous operation in testing.

GPS Receivers

When considering positioning systems for mobile robots, there are a large number of variables that must be considered, including

- size of mobile transceiver,
- power requirements of mobile transceiver,
- positioning accuracy,

- cost of mobile units,
- cost of total implementation,
- ability to process Differential GPS data,
- inclusion of integrated data communications for other purposes,
- time to first position fix (from a "cold" start),
- update rate with movement,
- standardisation/ availability of equipment,
- portability / time to set up.

A great number of modern commercial GPS receivers and OEM development modules come with differential correction capability, of which almost all follow the RTCM-104 standard for interfacing with the DGPS receiver and network [RTCM, 1994]. This allows a GPS receiver to be used according to requirements, and DGPS correction signals from any appropriate source to be used by connecting the relevant DGPS receiver.

An example of a commercial DGPS receiver is the Communication System International CSI SBX-1. This is a so called OEM module, designed to be integrated into another manufacturers system: ideal for mobile robot construction. It is rated at less than 1 W at 5 VDC, and has a footprint of 10 cm^2. Coupled with a suitable GPS receiver (typically having somewhat high requirements; e.g. 10 W, 20 cm^2footprint) this would provide a good ground for mobile position fixes.

Summary of Vision-based positioning

Vision based positioning or localisation uses the same basic principles of landmark-based and map-based positioning but relies on optical sensors rather than ultrasound, dead-reckoning and inertial sensors.

The most common optical sensors include laser-based range finders and photometric cameras using CCD arrays. However, due to the volume of information they provide, extraction of visual features for positioning is far from straightforward. Many techniques have been suggested for localisation using vision information, the main components of which are listed below:

- representations of the environment.

- sensing models.
- localisation algorithms.

The environment is perceived in the form of geometric information such as landmarks, object models and maps in two or three dimensions. Localisation then depends on the following two inter-related considerations:

- A vision sensor (or multiple vision sensors) should capture image features or regions that match the landmarks or maps.
- Landmarks, object models and maps should provide necessary spatial information that is easy to be sensed.

The primary techniques employed in vision-based positioning to date are:

- Landmark-Based Positioning
- Model-Based Approaches
  - Three-Dimensional Geometric Model-Based Positioning
  - Digital Elevation Map-Based Positioning
- Feature-Based Visual Map Building

Although it seems to be a good idea to combine vision-based techniques with methods using dead-reckoning, inertial sensors, ultrasonic and laser-based sensors, applications under realistic conditions are still scarce.

Clearly vision-based positioning is directly related to most computer vision methods, especially object recognition. So as research in this area progresses, the results can be applied to vision-based positioning.

Real world applications envisaged in most current research projects, demand very detailed sensor information to provide the robot with good environment-interaction capabilities. Visual sensing can provide the robot with an incredible amount of information about its environment. Visual sensors are potentially the most powerful source of information among all the sensors used on robots to date. Hence, at present, it seems that high resolution optical sensors hold the greatest promises for mobile robot positioning and navigation.

Other Technologies

Sensors for Dead-Reckoning

Dead Reckoning (derived from "deduced reckoning" from sailing) is a simple mathematical procedure for determining the present location of a vehicle by advancing some previous position through known course and velocity information over a given length of time.

At present, the vast majority of land-based mobile robots rely on dead reckoning to form the backbone of their navigation strategy. They use other navigation aids to eliminate accumulated errors.

Odometric Sensors

The simplest form of dead reckoning is often termed as *odometry*. This implies that the vehicle displacement along the path of travel is directly derived from some on-board "odometer." A common means of odometric measurement involves optical encoders directly coupled to wheel axles.

Since a large majority of mobile robots rely on motion by means of wheels or tracks, a basic understanding of sensors that accurately quantify angular position and velocity is an important prerequisite for dead reckoning using odometry.

Some of the common rotational displacement and velocity sensors in use today are given below:

- Brush encoders.
- Potentiometers.
- Optical encoders.
- Magnetic encoders.
- Inductive encoders.
- Capacitive encoders.

The most popular type of rotary encoder for mobile robots is the *incremental* or *absolute* optical encoder.

Optical Encoders

At the heart of an optical encoder today lies a miniature version of the *break-beam proximity sensor*. Here, a focused beam of light aimed at a matched photodetector (eg. a slotted-opto switch) is periodically interrupted by a coded opaque/transparent pattern on a rotating intermediate disk attached to the shaft of interest. The advantage of this encoding scheme is that the output is inherently digital which results in a low-cost reliable package with good noise immunity.

As mentioned above, there are two basic types of optical encoders. The incremental version measures rotational velocity and can infer relative position. The absolute model on the other hand, measures angular position directly and can infer velocity. If non-volatile position information is not a requirement, incremental encoders are usually chosen on grounds of lower cost and simpler interfacing compared to absolute encoders.

Incremental Optical Encoders

The single-channel *tachometer encoder* is the simplest type of incremental encoder. It is basically a mechanical light chopper that produces a certain number of pulses per shaft revolution. Increasing the number of pulses per revolution increases the resolution (and cost) of the encoder. These devices are especially suited as velocity feedback sensors in medium- to high-speed control systems. However, they run into noise and stability problems at very slow velocities due to quantization errors. In addition to these instabilities, the single-channel tachometer encoder is incapable of detecting the direction of rotation and can thus not be used a as position sensor.

To overcome the problems mentioned above a slightly improved version of the encoder called the *phase-quadrature incremental encoder* is used. The modification being that a second channel, displaced from the first, is added. This results in a second pulse train which is 90 degrees out of phase with the first pulse train. Now, decoding electronics can determine which channel is leading the other and hence determine the direction of rotation with the added benefit of increased resolution.

Since the output signal of these encoders is incremental in nature, any resolution of angular position can only be relative to some specific reference, as opposed to absolute. For applications involving continuous 360-degree rotation, such a reference is provided by a third channel as a special index output that goes high once for each revolution of the shaft. Intermediate positions are then specified as a displacement from the index position. For applications with limited rotation, such as back-and-forth motion of a pan axis, electrical limit switches can be used to establish a home reference position. Repeatability of this homing action is often broken into steps. The axis is rotated at reduced speed in the appropriate direction until the stop mechanism is encountered. Rotation is then reversed for a short predefined interval after which the axis is then slowly rotated back to the stop position from this known start point. This usually eliminates inertial loading that could influence the final homing position (This two-step approach can be observed in power-on initialisation of stepper-motor positioners in dot-matrix printer heads).

Interfacing an incremental encoder to a computer is not a trivial task. A simple state-based interface is inaccurate if the encoder changes direction at certain positions, and false pulses can result from the interpretation of the sequence of state changes.

A very popular and versatile encoder interface is the HCTL 1100 motion controller chip made by Hewlett Packard. It performs accurate quadrature decoding of the incremental wheel encoder output and provides important additional functions such as:

- closed-loop position control.
- closed-loop velocity control.
- 24-bit position monitoring.

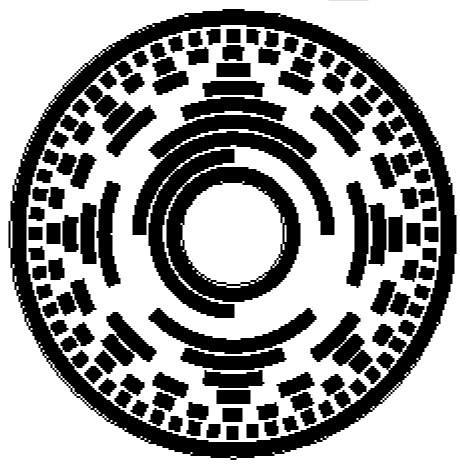
At a cost of only $40 it is a good candidate for giving mobile robots navigation and positioning capabilities.

Absolute Optical Encoders

These are typically used for slower rotational applications that do not tolerate loss of positional information when there is a temporary power interruption. They are best suited for slow and/or infrequent rotations such as steering angle encoding, as opposed to measuring high-speed continuous rotation required for calculating displacement along the path of travel.

Discrete elements in a photovoltaic array are individually aligned in break-beam fashion with concentric encoder tracks, creating in effect, a non-contact implementation of a commutating brush encoder. Having a dedicated track for each bit of resolution results in a larger disk (relative to incremental designs), with a corresponding decrease in shock and vibration tolerance. Very roughly, each additional encoder track doubles the resolution and quadruples the cost.

Instead of the serial bit streams of incremental designs, absolute encoders provide a parallel word output with a unique code pattern for each quantized shaft position. The most common coding scheme is the Gray code. This code is characterised by the fact that only one bit changes at a time, thus eliminating (a majority of the) asynchronous ambiguities caused by electronic and mechanical component tolerances.



A potential disadvantage of absolute encoders is their parallel data output, which requires more complex interface due to the large number of electrical leads.

Doppler Sensors

The rotational displacement sensors discussed above derive navigation data directly from wheel rotation. This means that they are inherently subject to problems arising from wheel slippage, tread wear, and/or improper tire inflation. Doppler and inertial navigation techniques are sometimes employed to reduce the effects of such error sources.

The principle of operation is based on the Doppler shift in frequency observed when radiated energy reflects off a surface that is moving with respect to the emitter.

Most implementations used for robots employ a single forward-looking transducer to measure ground speed in the direction of travel. An example of this is taken from the agricultural industry, where wheel slippage in soft freshly plowed fields can seriously interfere with the need to release seed at a rate proportional to vehicle advance.

A typical implementation uses a microwave radar sensor which is aimed downward (usually 45 degrees) to sense ground movement as shown in the figure below.

$$V_A = \frac{V_D}{\cos\alpha} = \frac{cF_D}{2F_0\cos\alpha}$$

where

V_A = actual ground velocity along path

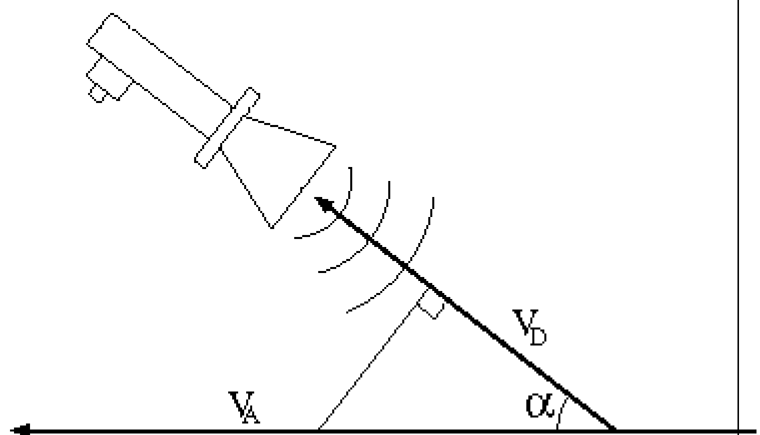
V_D = measured Doppler velocity

α = angle of declination

c = speed of light

F_D = observed Doppler shift frequency

F_0 = transmitted frequency.



A Doppler ground-speed sensor inclined at an angle α as shown measures the velocity component V_D of true ground speed V_A. (Adapted from [Schultz, 1993].)

Errors in detecting true ground speed can arise from vertical velocity components introduced by vehicle reaction to the ground surface and uncertainties in the angle of incidence. An interesting scenario resulting in erroneous operation would involve a stationary vehicle parked over a stream of water.

Accelerometers and Gyroscopes

Fundamentally, gyroscopes provide angular rate and accelerometers provide velocity rate information. Dynamic information is provided through direct measurements.

For accelerometers, there is a very poor signal-to-noise ratio at lower accelerations (ie. during low-speed turns). They also suffer from extensive drift, and they are sensitive to uneven grounds, because any disturbance from a perfectly horizontal position will cause the sensor to detect the gravitational acceleration *g*. Even tilt-compensated systems indicate a position drift rate of 1 to 8 cm/s, depending on the frequency of acceleration changes. This is an unacceptable error rate for most mobile robot applications.

The main problem with gyroscopes is that they are usually very expensive (if they are to be useful for navigation) and they need to be mounted on a very stable platform.

Active Beacons

Navigation using active beacons has been with us for many centuries. Using the stars for navigation is one of the oldest examples of global referenced navigation; technology has brought forward many other systems, such as lighthouses and, more recently, radio navigation.

Types of Beacons

For mobile robotics, laser, sonar and radio (or microwave) are common media for navigational beacons. Because of this, most methods are "line-of-sight" dependant: there must be no obstructions between the mobile user and the beacons. This means they have a limited range of use for a given number of beacons, and are mostly suited for Local area navigation. However, they might well provide position fixes in a global frame of reference, by transforming the users position according to the relation between the local and global reference frames. The (longer wave-length) radio beacon systems tend to be more useful for global scale navigation, due to the greater propagation distances available, and less suitable for indoor use, where multipath reflections from walls can introduce large inaccuracies.

There are two principle methods for determining the user's position:

- *triangulation* measures and uses the bearing between the user's heading and a number of beacons,
- *trilateration* uses a measurement of distance between a number of beacons and the user.

Almost all electronic navigation beacon systems used trilateration, as it is generally possible to measure time delays (and hence distances) more accurately than incident angles.

Most beacon systems can be sub-categorised into one of the following transmission schemes:

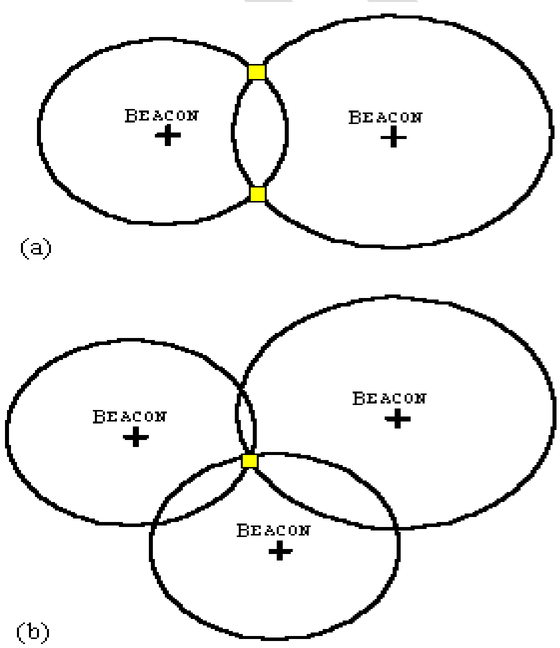
1. Scanning *detectors* with fixed active *transmitting* beacons,
2. Rotating *emitters* with fixed *receiving* beacons,

3. Scanning *emitter/detectors* with passive *reflective* beacons,
4. Scanning *emitter/detectors* with active *receiver/transmitter* beacons.

Radio Beacons

Global Scale Radio beacon systems (e.g. Omega, Loran, as well as GPS [Dixon, 1997]) tend to use the first of these schemes, as it allows for an unlimited number of users from a finite number of beacons. All transmitters are synchronised so that they transmit a continuous wave in phase, however, the receiver is not synchronised to this. This means the user can only measure differences in the time taken for signals to arrive from the various transmitters, not the absolute time. To calculate their position, the user finds the intersection of hyperbolic line-of-positions constructed using the difference in phase of signals received from two pairs of continuously broadcasting transmitters [Tetley, 1991].

Available commercially are more localised beacon systems, which may use either scheme 1, 2, or 4. The first two allow many users in one area; the first being more suitable for autonomous mobile robot control, as the position information is calculated at the mobile end. The second is more suited to tracking applications, such as motor cars around a racetrack. With scheme 4 the round trip propagation delay time from user to beacon and back to user (or vice-versa; generally in position monitoring rather than navigation situations) is measured - analogously to radar operation - to determine range. Using this exact range data it is a simple method to calculate position, by the intersection of circles around, ideally, at least 3 beacons.



Possible user positions at the intersect of circles when range to (a) two, and (b) three, transmitters is known.

Ultrasonic Beacons

Ultrasonic systems generally use one of the first two schemes, again, the first allows many more robots to operate concurrently.

Ultrasonics are frequently used under water situations, as sound has a much higher velocity here (1500 ms^{-1} c.f. 330 ms^{-1} in air). Also, it is possible to measure the incident angle of received signals much more accurately, allowing triangulation methods to be employed [Larcombe, 1994].

Ultrasonics are widely used for proximity detection (see the next section). Occasionally it is possible to combine the two, by introducing distinctive passive sonic beacons with unique reflection properties. By using trilateration against these beacons, a mobile robot can perform an absolute position fix, as well as finding its position relative to any non-unique objects in the vicinity.

Optical Beacons

Optical and laser systems often use the scheme 3, with passive retroreflective beacons, as these are very cheap. Laser energy is really the only form of transmission the can usefully be reflected without some form of intermediate amplification.

A great deal of successful laser navigation systems have been demonstrated, an early example of which was the mobile *Hilare* robot, developed at the *Laboratoire d'Automatique et d'Analyse des Systemes*, France [Borenstein et al., 1996]. This used groups retroreflective beacons, arranged in recognisable configurations to minimise errors from reflections from other surfaces. Two rotating laser heads then scanned the area to determine the bearing to these beacons.

Other methods employed in laser include passive receiver beacons (scheme 2), by Premi and Besant, Imperial College of Science and Technology, London. Here a vehicle-mounted laser beam rotating creates a plane which intersects three fixed-location reference receivers. These then use an FM data link to relay the time of arrival of laser energy back to the mobile vehicle, so that it can determine distances to each beacon individually. A similar system is now commercially available MTI Research, Inc., Chelmsford, MA. This "Computerised Opto-electrical Navigation and Control" (CONAC) system has been proven to be a relatively low-cost, high precision positioning system, working at high speeds (25 Hz refresh), with an accuracy of a few cm [MTI].

Environment Ranging Sensors

Most sensors used for the purpose of map building involve some kind of distance measurement. Below are the three distinct approaches to measuring range:

- Sensors based on measuring the *time of flight* (TOF) of a pulse of emitted energy travelling to a reflecting object, then echoing back to a receiver.
- The *phase-shift measurement* (or *phase-detection*) ranging technique involves continuous wave transmission as opposed to the short pulsed outputs used in TOF systems.
- Sensors based on frequency-modulated (FM) radar. This technique is somewhat related to the (amplitude-modulated) phase-shift measurement technique.

Time of Flight Range Sensors

The measured pulses used in TOF systems typically come from an ultrasonic, RF or optical energy source. The parameters required to calculate range are simply the speed of sound in air or the speed of light. The measured time of flight is representative of travelling twice the separation distance and must therefore be halved in order to give the actual target range.

The advantages of TOF systems arise from the direct nature of their straight-line active sensing. The returned signal follows essentially the same path back to a receiver located in close proximity to the transmitter. The absolute range to an observed point is directly available as output with no complicated analysis requirements.

Potential error sources for TOF systems include the following:

Variation in propagation speed

This is particularly applicable to acoustically based systems, where the speed of sound is significantly influenced by temperature and humidity changes.

Detection uncertainties

This involves determining the exact time of arrival of the reflected pulse. Errors are caused by the wide dynamic range in returned signal strength due to varying reflectivness of target surfaces. These differences in returned signal intensity influence the rise time of the detected pulse, and in the case of fixed-threshold detection will cause the more reflective targets to appear closer.

Timing considerations

Due to the relatively slow speed of sound in air, compared to light, acoustically-based systems make less timing precision demands than light-based systems and are less expensive as a result. TOF systems based on the speed of light require sub-nanosecond timing circuitry to measure distances with a resolution of about 30cm (a resolution of 1mm requires a timing precision of 3 picoseconds). This capability is very expensive to realise and may not be cost effective for most applications, particularly at close range where high accuracies are required.

Surface interaction

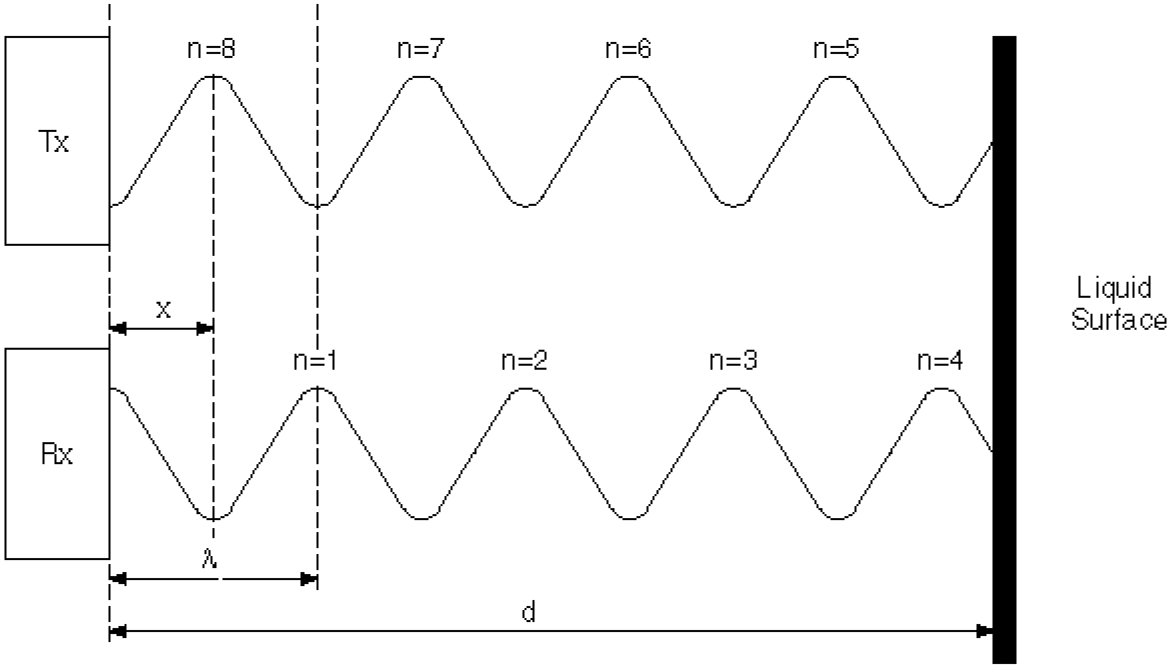
When light, sound or radio waves strike an object, any detected echo represents only a small portion of the original signal. The remaining energy is scattered or absorbed depending on surface characteristics and the angle of incidence of the beam. If the transmission source approach angle exceeds a certain critical value, the reflected energy will be deflected outside the sensing envelope of the receiver. In cluttered environments, sound waves can reflect from (multiple) objects and can then be received by other sensors ("crosstalk").

Ultrasonic TOF Systems

This is the most common technique employed on indoor mobile robots to date, which is primarily due to the ready availability of low cost systems and their ease of interface. Over the past decade, much research has been conducted investigating applicability in areas such as world modelling, collision avoidance, position estimation and motion detection. More recently, their effectiveness in exterior settings has been assessed. For example, BMW now incorporates four piezo-ceramic transducers on both front and rear bumpers in its Park Distance Control system.

Phase-Shift Measurement

Here a beam of amplitude-modulated laser, RF or acoustical energy is directed towards the target. A small portion of the wave (potentially up to six orders of magnitude less in amplitude) is reflected by the target's surface back to the detector along a direct path. The returned energy is compared to a simultaneously generated reference that has been split off from the original signal, and the relative phase shift between the tow is measured as illustrated below.



Relationship between outgoing and reflected waveforms, where x is the distance corresponding to the differential phase. (Adapted from [Woodbury et al., 1993].)

The relative phase-shift expressed as a function of distance to the reflecting target surface is:

$$\phi = \frac{4\pi d}{\lambda}$$

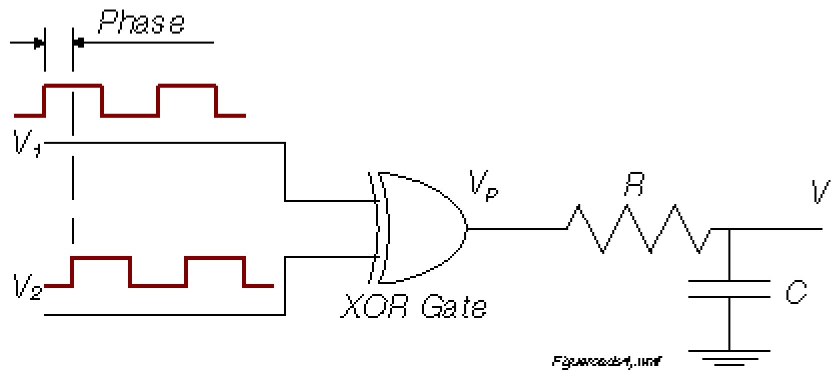
where

ϕ = phase shift

λ = modulation wavelength

d = distance to target

For square-wave modulation at the relatively low frequencies of ultrasonic systems (20 to 200kHz), the phase difference between incoming and outgoing waveforms can be measured with the simple linear circuit shown below. The output of the *exclusive-or* gate goes high whenever its inputs are at opposite logic levels, generating a voltage across the capacitor that is proportional to the phase-shift.



At low frequencies typical of ultrasonic systems, a simple phase-detection circuit based on an *exclusive-or* gate will generate an analog output voltage proportional to the phase difference seen by the inputs. (Adapted from [Figueroa and Barbieri, 1991].)

Advantages of continuous-wave systems over pulsed time of flight methods include the ability to measure the direction and velocity of a moving target in addition to its range (using the *Doppler* effect). Range accuracies of laser-based continuous-wave systems approach those of pulsed laser TOF methods. Only a slight advantage is gained over pulsed TOF range finding however, since the time-measurement problem is replaced by the need for sophisticated phase-measurement electronics.

Algorithms and Methods for Navigation

Dead-Reckoning

Odometry provides good short-term accuracy, is inexpensive and allows very high sampling rates. However, the fundamental idea of odometry is the integration of incremental motion information over time, which leads inevitably to the accumulation of errors. Particularly the accumulation of orientation erro00rs will cause large position errors which increase proportionally with the distance travelled by the robot. Nevertheless, it is widely accepted that odometry is a very important part of a robot navigation system and that navigation tasks will be simplified if odometric accuracy can be improved.

Below are some of the reasons why odometry is used for mobile robots:

- Odometry data can be fused with absolute position measurements (using other techniques) to provide better and more reliable position estimation.

- Odometry can be used in between absolute position updates with landmarks. Given a required positioning accuracy, increased accuracy in odometry allows for less frequent absolute position updates. As a result, fewer landmarks are needed for a given travel distance.
- In some cases, odometry is the only navigation information available. For example when there are insufficient landmarks in the environment or when another sensor subsystem fails to provide useable data.

Systematic and Non-Systematic Odometry Errors

Odometry is based on the assumption that wheel revolutions can be translated into linear displacement relative to the surface. This assumption is only of limited validity since displacement errors can easily be caused by wheel slippage. Below are a number of error sources grouped into two distinct categories:

Systematic Errors

- Unequal wheel diameters.
- Actual wheelbase differs from nominal wheelbase.
- Misalignment of wheels.
- Finite encoder resolution.
- Finite encoder sampling rate.

Non-Systematic Errors

- Travel over uneven floors.
- Travel over unexpected objects on the floor.
- Wheel slippage due to:
    - slippery floors.
    - overacceleration.
    - fast turning (skidding).
    - external forces (interaction with external bodies).

- internal forces (castor wheels).

Making a clear distinction between these two error categories is of great importance for the effective reduction of odometry errors. On most smooth indoor surfaces systematic errors contribute much more to odometry errors than non-systematic errors. However, on rough surfaces with significant irregularities, non-systematic errors are dominant. The problem with non-systematic errors is that they appear unexpectedly and can hence cause large position errors.

Measurement of Odometry Errors

Measurement of Systematic Errors

One widely used but fundamentally unsuitable method is the Unidirectional Square-Path Test. To conduct this test, the robot must be programmed to traverse the four legs of a square path. The path will return the vehicle to the starting area but, because of odometry and controller errors, not precisely to the starting position. The systematic error is then calculated from the end position error. An improved version of this is the Bi-directional Square-Path Test which involves the robot travelling around a square path in both clockwise and anti-clockwise directions.

Measurement of Non-Systematic Errors

Due to the unpredictable nature of these errors, it is very difficult (perhaps impossible) to design a generally applicable quantitative test procedure for them. One proposed approach is to compare the susceptibility to non-systematic errors of different vehicles. This method uses the bi-directional square-path test but in addition, introduces artificial bumps. The robot's susceptibility to non-systematic errors is indicated by the return orientation error and not the return position error. This is because, the return position of this test is sensitive to the exact location where the bumps are placed, whereas the return orientation is not.

Reduction of Odometry Errors

The accuracy of odometry in mobile robots depends to some degree on their kinematic design and on certain critical dimensions. Here are some of the design-specific considerations that affect dead-reckoning accuracy:

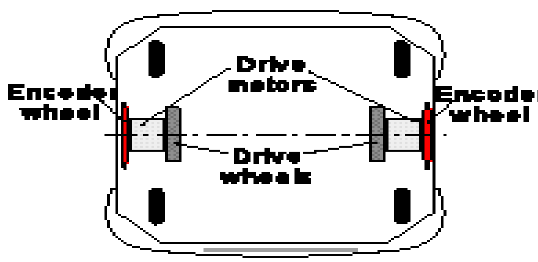
- Vehicles with a small wheelbase are more prone to orientation errors than vehicles with a larger wheelbase. For example, the differential drive *LabMate* robot from TRC has a relatively small wheelbase of 340mm, as a result of which, dead-reckoning is limited to a range of about 10m before a new position "reset" is necessary.

- Vehicles with castor wheels that bear a significant portion of the overall weight are likely to induce slippage when reversing direction (the "shopping trolley effect").
- Wheels used for odometry should be "knife-edge" thin and not compressible. The ideal wheel would be made of aluminium with a thin layer of rubber for better traction. In practice, this is only practical for lightweight robots.

Another general observation is that errors associated to wheel slippage can be reduced by limiting the vehicle's speed during turning, and by limiting accelerations.

Reduction of Systematic Odometry Errors

It is generally possible to improve odometric accuracy by adding a pair of "knife-edge", non-load-bearing *encoder wheels* as shown in the diagram below. Since these wheels are not used for transmitting power, they can be made as recommended above.



Conceptual drawing of a set of *encoder wheels* for a differential drive vehicle.

An alternative approach is the use of an *encoder trailer* with two encoder wheels. This approach is often used for tracked vehicles, since it is virtually impossible to use odometry with tracked vehicles, because of the large amount of slippage between the tracks and the floor during turning.

Another approach to improving odometric accuracy without any additional devices or sensors is based on careful calibration of the mobile robot. Systematic errors are inherent properties of each individual robot and they change very slowly as a result of wear or of different load distributions. This technique of reducing errors requires high precision and accuracy calibration since minute deviations in the geometry of the vehicle or its part may cause substantial odometric errors. As a result, this technique is very time consuming.

Reduction of Non-Systematic Odometry Errors

Mutual Referencing is a method whereby two robots measure their positions mutually. When one of the robots moves to another place, the other remains still, observes the motion, and determines the first robot's new position. In other words, one robot localises itself with reference to a fixed object (the stationary robot). However, this limits the efficiency of the robots.

A unique way for reducing odometry errors even further is *Internal Position Error Correction*. Here, two mobile robots mutually correct their odometry errors on a continuous basis. To implement this method, it is required that both robots can measure their relative distance and bearing continuously. Conventional dead reckoning is used by each robot to determine its heading and direction information which is then compared to the heading and direction observed by the other robot in order to reduce any errors to a minimum.

Inertial Navigation

This is an alternative method for enhancing dead reckoning. The principle of operation involves continuous sensing of minute accelerations in each of the three directional axes and integrating over time to derive velocity and position. A gyroscopically stabilised sensor platform is used to maintain consistent orientation of the three accelerometers throughout this process.

Although this method is simple in concept, the specifics of implementation are rather demanding. This is mainly caused by error sources that affect the stability of the gyros used to ensure correct attitude. The resulting high manufacturing and maintenance costs of this method have usually made it impractical for mobile robot applications. For example, a high-quality *Inertial Navigation System* (INS) such as would be found in a commercial airliner will have a typical drift of about 1850m per hour of operation, and cost between $50,000 to $70,000. High-end INS packages used in ground applications have shown performance of better than 0.1 percent of distance travelled, but cost up to $200,000. However, since the development of laser and optical fibre gyroscopes (typically costing $1,000 to $5,000), INS is becoming more suitable for mobile robot applications.

One advantage of inertial navigation is its ability to provide fast, low-latency dynamic measurements. Also, INS sensors are self-contained, non-radiating and non-jammable. The main disadvantage however, is that the angular rate data and the linear velocity rate data must be integrated once and twice (respectively), to provide orientation and linear position, respectively.

Landmark-Based Navigation

Natural Landmarks

The main problem in natural landmark navigation is to detect and match characteristic features from sensory inputs. The sensor of choice for this task is computer vision. Most computer vision-based natural landmarks are long vertical edges, such as doors and wall junctions. For a more detailed description of this please refer to Vision-Based Positioning.

When range sensors are used for natural landmark navigation, distinct signatures, such as those of a corner or an edge, or of long straight walls, are good feature candidates. Proper selection of features will also reduce the chances for ambiguity and increase positioning accuracy. A natural landmark positioning system has the following basic components:

- A sensor (usually vision) for detecting landmarks and contrasting them against their background.
- A method for matching observed features with a map of known landmarks.
- A method of computing location and localisation errors from the matches.

Artificial Landmarks

Detection is much easier with artificial landmarks, which are designed for optimal contrast. In addition, the exact size and shape of artificial landmarks are known in advance. Many artificial landmark positioning systems are based on computer vision and some examples of typical landmarks are black rectangles with white dots in the corners, a sphere with horizontal and vertical calibration circles to achieve three-dimensional localisation from a single image.

The accuracy achieved by the above methods depends on the accuracy with which the geometric parameters of the landmark images are extracted from the image plane, which in turn depends on the relative position and angle between the robot and the landmark.

There are also a variety of landmarks used in conjunction with non-vision sensors. Most often used are bar-coded reflectors for laser scanners. For an example of this, please refer to the *Mobile Detection Assessment and Response System* (MDARS) which uses retroreflectors.

Line Navigation

This is another type of landmark navigation that has been widely used in industry. Line navigation can be thought of as a continuous landmark, although in most cases the sensor used in this system needs to be very close tot he line, so that the range of the vehicle is limited to the immediate vicinity of the line. These techniques have been used for many years in industrial automation tasks and vehicles using them are generally called *Automatic Guided Vehicles* (AGVs). However, the techniques are not discussed in detail here since they do not allow the vehicle to move freely - the main feature that sets mobile robots apart from AGVs.

The main implementations for line navigation are given below:

- *Electromagnetic Guidance*.
- *Reflecting Tape Guidance* or *Optical Tape Guidance*.
- *Ferrite Painted Guidance*, which uses ferrite magnet powder.
- *Thermal Marker Guidance.*

Summary

Artificial landmark detection methods are well developed and reliable. By contrast, natural landmark navigation is not sufficiently developed yet for reliable performance under a variety of and dynamic conditions.

The main characteristics of landmark-based navigation are given below:

- Natural landmarks require no modifications to the environment.
- Artificial landmarks are inexpensive and can have additional information encoded on them.
- The maximal distance between robot and landmark is significantly shorter than in active beacon systems.
- The positioning accuracy depends on the distance and angle between the robot and the landmark.

- Substantially more processing is necessary than with active beacon systems.
- Ambient conditions (such as lighting) can cause problems such as landmarks not being recognised or other objects being mistaken for landmarks.
- Landmark navigation requires the robot to know its approximate starting location so that it knows where to look for landmarks. If this requirement is not met, very time consuming searching processes have to be employed.
- A database of landmarks and their location in the environment must be maintained.

Map-Based Navigation

Map-based positioning (also known as "map matching"), is a technique in which the robot uses its sensors to create a map of its local environment. This local map is then compared to the global map previously stored in memory. If a match is found then the robot can compute its actual position and orientation in the environment. The prestored map can be a CAD model of the environment, or it can be constructed from prior sensor data.

The main advantages of map-based positioning are given below:

- It uses naturally the naturally occurring structure of typical indoor environments to derive position information without modifying the environment.
- It can be used to generate an updated map of the environment. Environment maps are important for other mobile robot tasks, such as global path planning.
- It allows a robot to learn about a new environment and to improve positioning accuracy through exploration.

Disadvantages of map-based positioning arise because it requires that:

- There be enough stationary, easily distinguishable features that can be used for matching.
- The sensor map be accurate enough (depending on the task at hand) to be useful.
- A significant amount of sensing and processing power is available.

Map Building

As map building problem is very closely related to its sensing abilities, it could be defined as, "Given the robot's position and a set of measurements, what are the sensors seeing?"

Error and uncertainty analyses play an important role in accurate estimation and map building. It is vital to take explicit account of the uncertainties by for example, modelling the errors by probability distributions. The representation used for the map should provide a way to incorporate newly sensed information into the map. It should also provide the necessary information for path planning and obstacle avoidance.

The three main steps of sensor data processing for map building are:

- Feature extraction from raw sensor data.
- Fusion of data from various sensor types.
- Automatic generation of an abstract environment model.

Map Matching

This is one of the most challenging aspects of map-based navigation. In general, matching is achieved by first extracting features, followed by determination of the correct correspondence between image and model features. Work on map matching in the computer vision arena is often focused on the general problem of matching an image of arbitrary position and orientation relative to a model.

Matching algorithms can be classified as either *icon-based* or *feature-based*. The icon-based algorithm differs from the feature-based one in that it matches very range data point to the map rather than corresponding the range data into a small set of features to be matched to the map. The feature-based estimator, in general, is faster than the iconic-based estimator and does not require a good initial heading estimate. The iconic-based estimator can use fewer points than the feature-based estimator, can handle less-than-ideal environments and is more accurate.

As with Landmark-Based navigation, it is advantageous to use an approximate position estimation based on odometry to generate an estimated visual scene (from the stored map) that would be "seen" by the robot. This generated scene is then compared to the one actually seen. This procedure dramatically reduces the time taken to find a match.

One problem with feature-based positioning systems is that the uncertainty about the robot's position grows if there are no suitable features that can be used to update the robot's position.

The problem is particularly severe if the features are to be detected with ultrasonic sensors which suffer from poor angular resolution.

Geometric and Topological Maps

In map-based positioning there are two common representations, namely geometric and topological maps. A geometric map represents objects according to their absolute geometric relationships. It can be a grid map, or a more abstract map such as a line or polygon map. The topological approach on the other hand, is based on recording the geometric relationships between the observed features rather than their absolute position with respect to an arbitrary co-ordinate frame of reference. Unlike geometric maps, topological maps can be build and maintained without any estimates for the position of the robot. As a result, this approach can be used to integrate large area maps since all connections between nodes are relative, rather than absolute.

Summary

Map-based positioning is still in the research stage. Currently, this technique is limited to laboratory settings and good results have been obtained only in well-structured environments. It is difficult to estimate how the performance of a laboratory robot scales up to a real world application. The relevant characteristics of map-based navigation systems are given below:

- They require a significant amount of processing and sensing capabilities.
- Processing can be very intensive depending on the algorithms and resolution used.
- An initial position estimate is required from odometry (or other source) to limit the initial search for features.

The critical research areas are:

- Sensor selection and fusion.
- Accurate and reliable algorithms for matching local maps to the stored map.
- Good error models of sensors and robot motion.

Multiple Robot Communications and Co-ordination

There are a number of issues introduced when more than one robot is present in a given locale concurrently. Without prior knowledge of each other's existence, they could well interfere with one another. However, if correctly programmed, and if the necessary communication network exists between them, they can co-operate in carrying out some task.

Two advantages of co-operation will be considered here; improving speed and improving accuracy.

Improving Speed

When using local area navigation, mobile robots are generally carrying out some other set task (i.e. the navigation is the means, not an end). If there are a number of robots co-operating in carrying out this task, then they will have to communicate positional data to each other to achieve this end.

When communicating positional information, a common reference should be used in order to compare positions. This means that an absolute global or local positioning system should be used.

The communication link used between robots should ideally allow bi-directional transfers, with multiple access - allowing 'A' to talk to 'B', without interference from 'C' talking to 'D'.

Given these conditions, considerable algorithmic advances can be made; these lie mostly in the higher level "guidance" processing of the robot ("what should I do next?"), rather than the navigational side ("where am I?"). This means these improvements are mostly task dependant.

As an example, consider a number of robots searching a given area for some proximity detectable object (e.g. using metal detectors). The main criteria dictating where a robot should look are:

- have all of the objects already been found?
- have all places already been searched?
- am I within the area bounds?
- have I already searched here?
- has any other robot already searched here?

These questions can either be answered by either

- continual polling of the other robots
- each one carrying a complete current search state of the field, updated by events as they occur,
- querying a central search state database.

The method chosen would aim to minimise both the amount of communication (and hence bandwidth) required, and also minimise the amount of redundant (potentially outdated) information in the system, the exact choice depending on the dynamics of the search.

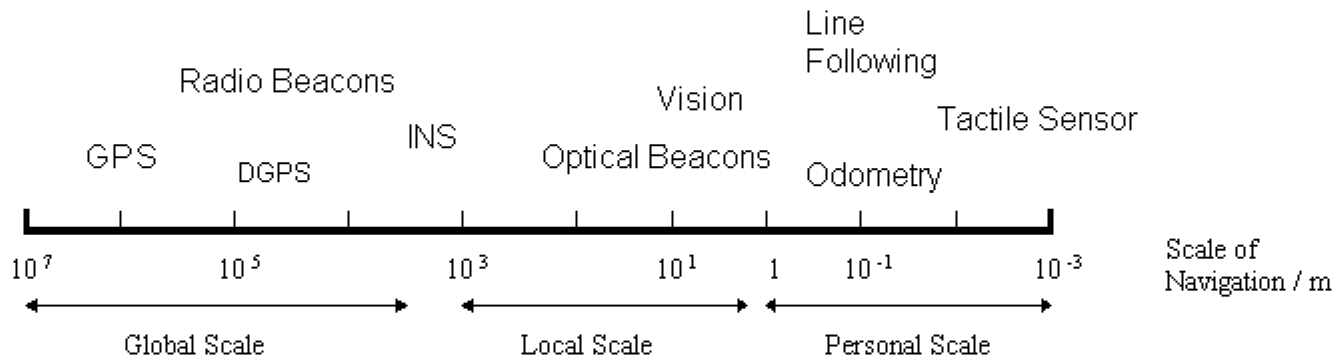
Improving Accuracy

While carrying out a navigational task, a co-operating robots can provide augmentation for each others navigational system, in order to provide an accuracy better than the sum of their individual systems.

A good example of this is the Non-line-of-sight Leader/Follower (NLOSLF) DGPS method [Motazed, 1993]. This involves a number of vehicles in a convoy that autonomously follow a lead vehicle driven by a human operator or otherwise. The technique employed is referred to as "intermittent stationary base differential GPS", where the lead and final vehicle in the convoy alternate as fixed-reference DGPS base stations. As the convoy moves out from a known location, the final vehicle remains behind to provide differential corrections to the GPS receivers in the rest of the vehicles, via a radio data link. After travelling a predetermined distance in this fashion, the convoy is halted and the lead vehicle assumes the role of DGPS reference station, providing enhanced accuracy to the trailing vehicle as it catches up. During this stationary time, the lead vehicle can take advantage of on site dwell to further improve the accuracy of its own fix. Once the last vehicle joins up with the rest, the base-station roles are reversed again, and the convoy resumes transit.

This ingenious technique allows DGPS accuracy to be achieved over large ranges, with minimal reliance on out side systems. Drawbacks of this approach include the need for intermittent stops, the reliance on obtaining an initial high-accuracy position fix (for the initial reference station), and accumulating ambiguity in actual location of the two reference stations.

Summary of the Scales of Navigation



Case Studies

Miniature Maze-Solving Robots

This case study analyses the requirements for navigating miniature mobile robots around a walled maze.

The aim is for the robot to navigate about in order to solve the maze by finding a pre-determined exit.

Specification

Vehicle	Dimensions	Cross-sectional diameter 12cm
		Height multiple 3cm modules
	Weight	< 2kg
	Power Supply	6V, 500mAh
	Intended Environment	Level, non-rugged terrain
Navigation Requirements	Navigation-Space	Two dimensions of movement
		Position fix, heading and velocity
	Accuracy	< 10cm

Range	approx. 10m
Refresh	> 1Hz
Processing	Onboard, autonomous control
System dimensions	within vehicle specification

Analysis

Scale of Navigation

The first stage in providing a navigation system for a mobile robot is to identify what scale of navigation is required.

Here there is no requirement for global referenced position fixing, as the robot is only concerned with its position within the maze, and not with the absolute position of the maze on a larger scale.

On a local scale, the robot is concerned with its current position in the maze, and mapping all places visited in order to progress in solving the maze. At this level actual maze solving processing is not considered, merely producing the navigational and tracking information for the next level of processing to provide vehicle guidance information from.

This local navigation has two distinct parts:

- detection and categorisation of walls and obstacles in the maze,
- determination of current position in maze.

In mapping the maze, either walls or the path taken can be recorded. Depending on which of these is chosen, the requirements of the navigation system vary slightly.

If mapping walls, as well as sensing their position around the robot, the distance travelled by the robot must also be measured. If mapping the path travelled, this must be measured and recorded by some other means; the detection of walls is still necessary, however, in order to take a central path through the corridors.

The detection of walls can occur at either a local or personal level, depending on the technology used (proximity or contact). The path travelled can likewise be measured in a locale- of self-relative reference frame (local area position fix or dead-reckon method).

Viable Systems

Due to the large constraints of the robot specification, in terms of physical attributes and power consumption, not all applicable navigation systems can be used.

Wall Detection

For wall detection the following techniques are available:

- (Ultra)sonic ranging,
- Light-based ranging,
- Tactile (contact) sensors,
- Vision based sensing,
- Absolute position referenced onto a (previously recorded) map.

Clearly this last method is not possible, as having a pre-made map would nullify the aim of the robot. Vision also is no use, as it would currently require too large (physically and electrically) an amount of processing for this application.

Of the other three, the technology for the application would largely depended on the maze construction. The robot is circular - if *all* corridors are known to be of an equal width to the robot's diameter, then the tactile sensor would be the simplest and most reliable method. If, however, the maze is constructed from larger corridors or rooms, this method might miss exploration of areas, and another method should be used.

Ultrasonic transceivers tend to be the more reliable in detecting large surfaces (as light sensors suffer greatly from ambient light interference) and are available in quite small packages. Hence a number of these placed on the robot would provide a fairly reliable wall detection system. A contact sensor at the front of the robot might also be included for detection of collision with objects invisible to the ultrasound.

Position Determination

As discussed, knowing the position of walls about the robot is not sufficient for determining its position in the maze; some other distinguishing information is required. The walls themselves can not provide this, as each one is not necessarily unique to the robot.

In determining position, the following could be used:

- An active beacon system working above the level of the walls,
- Dead-reckoning, giving a position relative to the starting location,

The active beacon system is a viable option, as quite small, low powered devices are available. There are two considerable drawbacks with this, however. Most commercial systems are quite expensive, as they require a fair number (at least three) of beacons to be purchased, along with the processing power for their co-ordination in the environment. They are also quite intrusive, which reduces the autonomy of the robot. While this could be justified, a more self-contained solution would be preferred.

Dead-reckoning, using odometry sensors, can provide a good enough accuracy over short distances, and easily meets the physical constraints. Dead-reckoning does, however, suffer from cumulative error, which requires periodic correction. Due to the nature of maze solving, there is a great deal of back-tracking; the corrections could be incorporated into this process, by continuously comparing actual position of walls sensed to expected position according to the map made on the outward journey. By this, the accumulated error becomes a function of net displacement in the solution of the maze, rather the total distance travelled throughout the mapping process.

Conclusions

The two main objectives of the case study have been met:

- A final solution for the specified application has been identified,
- The method of arriving at a solution system has been demonstrated.

The system arrived at meets all of the requirements for navigation of this mobile robot. Only generalised classes of hardware have been identified, namely ultrasonic detectors coupled with odometric sensors. Exact devices, and the necessary software algorithms for processing the raw data from these devices would have to be researched further.

COLLISION WARNING AND AWARENESS SYSTEM

Not so long ago, it would have seemed incredible that your car would be able to "see" other vehicles or pedestrians, anticipate collisions, and automatically apply the brakes or take corrective steering actions. But more and more cars can do that to some degree, thanks to a growing list of collision-avoidance systems.

Some of these capabilities, such as forward-collision warning systems, have been around for a few years, mostly on high-end luxury cars. Others, like steering assist, are just getting ready for prime time. The good news is that the collision-avoidance systems are getting better and are spreading to mainstream cars.

The potential for these systems is so great that the Insurance Institute for Highway Safety has added collision-avoidance system testing to its suite of safety evaluations. The IIHS has determined that some of these collision-avoidance systems could prevent or mitigate many crashes. Now, to win top overall safety scores from the IIHS, a car needs to have a forward-collision warning system with automatic braking. In addition, any autobrake system has to function effectively in formal track tests that the IIHS conducts.

The federal National Highway Traffic Safety Administration is also on board, with an eye to making some collision-avoidance systems mandatory. NHTSA's 5-Star Safety Ratings note which systems are available on cars they crash-test. Their presence doesn't affect the Star ratings yet, though.

The cost of collision-avoidance systems can still be an obstacle. Most advanced systems today come only as part of a large options package or on a model's higher, more expensive trim versions. Jumping to the trim line where the safety goodies are offered can add thousands of dollars to a vehicle's price.

Lasers, Radar, and Cameras

These cutting-edge active safety systems rely on a number of sensors, cameras, lasers, and short- and long-range radar. They monitor what is going on around the vehicle—vehicles, pedestrians, cyclists, and even road signs—as well as the vehicle itself. Inputs are processed by computers, which then prompt some action from the car or the driver. Those actions may start with attention-grabbers, such as a beep, a flashing dashboard icon, a tug from the seatbelt, or a vibration in the seat or steering wheel. If the driver doesn't respond, the more advanced systems then apply partial or full braking force.

In our ongoing evaluations we've found that there's a fine line between a helpful electronic co-pilot and a computerized backseat driver. If a warning system emits too many inappropriate alerts, then there is an increasing temptation to switch it off.

Not every system on the market today is top-notch. The IIHS has found that some autonomous braking systems are more effective than others. But they conclude there's a net benefit regardless.

A 2009 study conducted by the IIHS found a 7 percent reduction in crashes for vehicles with a basic forward-collision warning system, and a 14 to 15 percent reduction for those with automatic braking.

"Even in the cases where these systems failed to prevent a crash, if there's automatic braking going on, or if the driver does brake in response to a warning, that crash is going to be less severe than it would have been otherwise," says David Zuby, chief research officer at the IIHS.

In the end, these systems can do a lot of good in preventing crashes from happening in the first place. But it's important for drivers to realize that none of these aids reduces the need to stay alert.

Current Active Safety Systems

Manufacturers routinely use unique, marketing-friendly names for their various systems. This makes it confusing to know the system's full capabilities. When you are shopping for a new car, make sure to ask what the safety feature does. For a detailed listing of the available systems for each manufacturer

Rear cross-traffic alert

Cross-traffic alert warns you of traffic approaching from the sides as you reverse. The warning usually consists of an audible chirp and a visual cue in either the outside mirror or the rear camera's dash display. The more advanced systems can also pick out bicycles and pedestrians.

CR's take: Cross-traffic alert systems are especially handy if you have to back into a traffic lane when adjacent parked cars obscure your view.

Forward-collision warning (FCW) and autobrake

Also called a pre-crash warning system, these stand-alone or combined radar-, laser-, or camera-based systems warn drivers of an impending collision by using visual, auditory, or physical cues. Most vehicle systems also pre-charge the brakes and take other steps to prepare for impact. If the driver ignores the warnings, systems with autonomous braking, or autobrake, will apply partial or full braking force. They can be active at anywhere from walking to highway speeds. CR's take: Sometimes you want or need to stay closer to the car ahead of you than at other times, so systems that let you adjust your follow distance have a distinct advantage.

Blind-spot monitoring (BSM) and assist

A blind-spot monitoring system uses radars or cameras to scan the areas beside and behind you, looking for vehicles entering or lurking in your blind zones. When such a vehicle is detected, an illuminated icon appears in or near the appropriate side-view mirror. If you signal a turn while a car is in your blind zone, some systems send a stronger alert, such as a blinking light or louder chirps. More advanced systems help keep you in your own lane by applying the brakes on one side of the vehicle.

CR's take: In general, we like these systems and find them helpful.

Pedestrian detection and braking

Pioneered by Volvo and now offered by others, pedestrian detection can recognize a person straying into a vehicle's path. Some will automatically apply the brakes, if needed, sometimes partially and sometimes to a complete stop. Some newer systems can also detect bicyclists. CR's take: They're a good investment, especially if you often drive in cities or other populous areas.

Adaptive headlights

As you turn the steering wheel adaptive headlights will swivel, which helps illuminate the road when going around curves. A 2014 IIHS study found that adaptive headlights improved drivers' reaction times by about a third of a second. That could be just enough to avoid, say, hitting a parked car on a dark road.

CR's take: Our drivers have mixed feelings about adaptive headlights. The wider view can be helpful, but the swiveling motion of the light path can be a little distracting, especially if the headlight beams' motion isn't exactly synchronized with the steering wheel's.

Lane departure warning (LDW) and assist LDW

These systems use a camera, along with various sensors, to identify lane markers and monitor your distance from them. If you stray over the line without signaling, you'll hear a warning tone or perhaps a physical alert like a vibration in the steering wheel or seat. More advanced "lane keeping assist" (LKA) systems selectively apply brakes or nudge the steering to guide you back if you're wandering.

CR's take: We've found LDW more useful on highways than on narrow, winding country roads where they can beep at you too often. We also prefer systems that make corrections using the steering rather than the brakes.

Drowsiness detection

Various methods are used to detect if a driver is tired or falling asleep. Mercedes-Benz pioneered one of the first, which uses a computer algorithm that compares a driver's steering behavior with those recorded at the start of the trip. Other systems monitor the car's position within its lane of travel, looking for erratic maneuvers indicative of inattention. Some also track the driver's eye movements with an in-car camera, noting rapid or prolonged eye blinks. Alerts may include a chime, a dab on the brakes, a tug on the shoulder belt, and/or an illuminated cup-of-coffee icon on the instrument panel.

CR's take: Anything that keeps a driver from falling asleep is probably a good idea. We haven't experienced any problems, such as false alarms, on cars we've tested with the feature. In addition to drowsy-driving, these systems can tell you to look sharp if you're wandering around in your lane. Some may even keep drivers from looking down to text or answer emails.

Automatic park assist

The system will identify a parallel or perpendicular parking space your car can fit into. Once found, the system steers the car into the space; some can also exit from parallel parking spaces. The driver still does the braking and has to follow commands from the system. **CR's take:** These can be awkward to initialize. The driver has to activate the system and then drive by an open space for the system to recognize the spot. It may not recognize the parking space the first time. But most do a good job at steering the car into the spot.

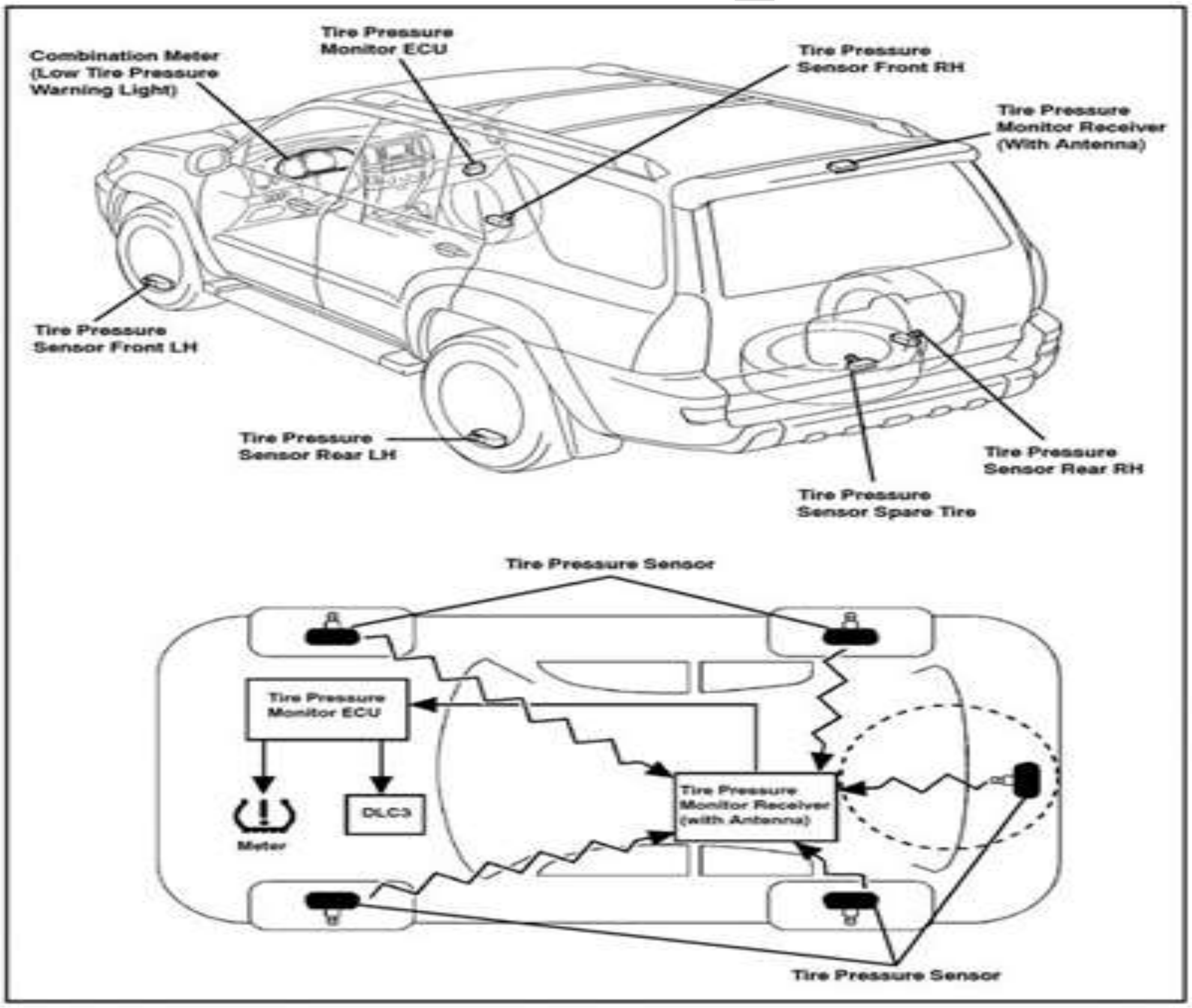
Rear cameras and parking assist

Rear-view cameras will be mandatory with the 2018 model year. They can help prevent a back-over accident, such as hitting a child who wanders behind your car. Parking assist sensor systems notify you with progressively louder and quicker beeps as you close in on an obstacle. CR's take: These are a must-have on SUVs and pickups, which often have large blind zones behind them. In addition, rear cameras are great when backing into tight parking spaces or lining up a trailer.

TIRE PRESSURE MONITORING SYSTEM(TPMS)

Tire Pressure Monitoring System

Tire Inflation Pressure Monitor Systems (TPMS) are being used on more and more new vehicles. Low tires are potentially dangerous, especially if a vehicle is heavily loaded and traveling at highway speeds during hot weather. A low tire under these conditions is a blowout waiting to happen. The inflation pressure of the tires should be checked regularly, but many motorist do not check their tires. That is why Tire Pressure Monitor Systems are coming into use.



Tires are designed to operate within a certain pressure range. The recommended inflation pressure can usually be found in the vehicle owner's manual and on a decal that may be located in the glove box or door jam. The recommended inflation pressure is designed to give the best combination of ride comfort, load carrying capacity and rolling resistance.

Increasing the tire inflation pressure reduces rolling resistance (which helps fuel economy). It also increases the load carrying capacity of the tire. But it also increases ride harshness. The maximum inflation pressure (which can be found on the sidewall of the tire) should never be exceeded because too much pressure may overstress the tire and increase the risk of tire failure.

Decreasing the inflation pressure improves ride quality by making the tire softer. Under certain circumstances this may help improve traction a bit. But lowering the pressure also reduces the tire's ability to carry weight and increases rolling resistance (which hurts fuel economy). A low tire also wears faster. Why? Because increased rolling resistance and flexing in the tread scrubs away the tread. As the miles add up, so does the wear and eventually the tread is down to the wear bars. Once the wear bars are flush with the surface of the tread, the tire needs to be replaced.

DIRECT AND INDIRECT TIRE PRESSURE MONITORING SYSTEMS

Direct tire pressure monitoring systems use individual sensors inside each tire, and sometimes a full-size spare, to transmit information to a central control module. The sensors read internal pressure, and sometimes temperature. The information received at the module is analyzed, and any issues with any of the tires are sent to the car's vehicle information system, or low-pressure light.

Information is most often sent wirelessly as a radio signal. While some aftermarket systems are mounted outside the tire, most manufacturers use a sensor mounted inside the tire. This is where the expense for the consumer comes in. Each sensor has a battery with a life of about a decade. On most, the battery is not serviceable, and the entire sensor must be changed. The sensor stem is also subject to damage, as is the sensor itself, when the tire hits a curb or the car gets into an accident. And each time a sensor is changed, it generally has to be reprogrammed into the control module so it can be recognized.

The wireless system is also prone to problems and challenges, as well as being integrated with other car systems that can fail or become corrupted over time. Added to this mix is the often-proprietary technology used by each manufacturer, making the range of sensors out there a confusing mix for shops and consumers.

Indirect tire pressure monitoring systems don't rely on sensors to do the work, or at least not pressure sensors. The systems rely on wheel speed sensor data to interpret the size of a tire based on how fast it rotates -- a small tire would rotate faster than a larger tire, and an underinflated tire is smaller than one with proper inflation. All of this data can be gleaned by electronic monitors within in the car, and then interpreted using advanced programming and processing.

This system is less prone to the vagaries of direct sensors, but more attention must be paid to it. For instance, imagine that a driver fills up his tires with air at a gas station and checks the pressure before heading out on a long trip. An indirect system needs to be reset every time the tires are inflated, or it will see the newly inflated tires as a possible hazard. In this case, if it isn't reset, the system will see bigger tires and may warn the driver of over inflation.

APPENDIX I

CONTENT BEYOND THE SYLLABUS

ENGINE ELECTRONICS

Automotive engine electronics originated from the need to control engines. The first electronic pieces were used to control engine functions and were referred to as engine control units (ECU). As electronic controls began to be used for more automotive applications, the acronym ECU took on the more general meaning of "electronic control unit", and then specific ECU's were developed. Now, ECU's are modular. Two types include engine control modules (ECM) or transmission control modules (TCM).

A modern car may have up to 100 ECU's and a commercial vehicle up to 40.

Automotive electronics or automotive embedded systems are distributed systems, and according to different domains in the automotive field, they can be classified into:

1. Engine electronics
2. Transmission electronics
3. Chassis electronics
4. Active safety
5. Driver assistance
6. Passenger comfort
7. Entertainment systems
8. Electronic Integrated Cockpit systems

One of the most demanding electronic parts of an automobile is the engine control unit. Engine controls demand one of the highest real time deadlines, as the engine itself is a very fast and complex part of the automobile. Of all the electronics in any car the computing power of the engine control unit is the highest, typically a 32-bit processor.

It controls such things as:

In a diesel engine:

- Fuel injection rate

- Emission control, NOx control
- Regeneration of oxidation catalytic converter
- Turbocharger control
- Cooling system control
- Throttle control

In a gasoline engine:

- Lambda control
- OBD (On-Board Diagnostics)
- Cooling system control
- Ignition system control
- Lubrication system control (only a few have electronic control)
- Fuel injection rate control
- Throttle control

Many more engine parameters are actively monitored and controlled in real-time. There are about 20 to 50 that measure pressure, temperature, flow, engine speed, oxygen level and NOx level plus other parameters at different points within the engine. All these sensor signals are sent to the ECU, which has the logic circuits to do the actual controlling. The ECU output is connected to different actuators for the throttle valve, EGR valve, rack (in VGTs), fuel injector (using a pulse-width modulated signal), dosing injector and more. There are about 20 to 30 actuators in all.

1.1.2 TRANSMISSION ELECTRONICS

These control the transmission system, mainly the shifting of the gears for better shift comfort and to lower torque interrupt while shifting. Automatic transmissions use controls for their operation, and also many semi-automatic transmissions having a fully automatic clutch or a semi-auto clutch (declutching only). The engine control unit and the transmission control exchange messages, sensor signals and control signals for their operation.

1.1.3 CHASIS ELECTRONICS

The chassis system has a lot of sub-systems which monitor various parameters and are actively controlled:

- ABS - Anti-lock Braking System
- TCS – Traction Control System
- EBD – Electronic Brake Distribution
- ESP – Electronic Stability Program

1.1.4 SAFETY

These systems are always ready to act when there is a collision in progress or to prevent it when it senses a dangerous situation:

- Air bags
- Hill descent control
- Emergency brake assist system

1.1.5 DRIVER ASSISTANCE

- Lane assist system
- Speed assist system
- Blind spot detection
- Park assist system
- Adaptive cruise control system
- Pre-collision Assist

1.1.6 PASSENGER COMFORT

- Automatic climate control
- Electronic seat adjustment with memory
- Automatic wipers
- Automatic headlamps - adjusts beam automatically
- Automatic cooling - temperature adjustment

1.1.7 INFOTAINMENT SYSTEM

- Navigation system
- Vehicle audio
- Information access

All of the above systems forms an infotainment system. Developmental methods for these systems vary according to each manufacturer. Different tools are used for both hardware and software development.

1.1.8 ELECTRONICS INTEGRATED COCKPIT SYSTEMS

These are new generation hybrid ECUs that combine the functionalities of multiple ECUs of Infotainment Head Unit, Advanced Driver Assistance Systems (ADAS), Instrument Cluster, Rear Camera/Parking Assist, Surround View Systems etc. This saves on cost of electronics as well as mechanical/physical parts like interconnects across ECUs etc. There is also a more centralized control so data can be seamlessly exchanged between the systems.

There are of course challenges too. Given the complexity of this hybrid system, a lot more rigor is needed to validate the system for robustness, safety and security. For example, if the infotainment system's application which could be running an open source Android OS is breached, there could be possibility of hackers to take control of the car remotely and potentially misuse it for antisocial activities. Typically so, usage of a hardware + software enabled hypervisors are used to virtualize and create separate trust and safety zones that are immune to each other's failures or breaches. Lot of work is happening in this area and potentially will have such systems soon if not already.

1.1.9 FUNCTIONAL SAFETY REQUIREMENTS

In order to minimize the risk of dangerous failures, safety related electronic systems have to be developed following the applicable product liability requirements. Disregard for, or inadequate application of these standards can lead to not only personal injuries, but also severe legal and economic consequences such as product cancellations or recalls.

The IEC 61508 standard, generally applicable to electrical/electronic/programmable safety-related products, is only partially adequate for automotive-development requirements. Consequently, for the automotive industry, this standard is replaced by the existing ISO 26262, currently released as a Final Draft International Standard (FDIS). ISO/DIS 26262 describes the entire product life-cycle of safety related electrical/electronic systems for road vehicles. It has been published as an international standard in its final version in November 2011. The implementation of this new standard will result in modifications and various innovations in the automobile electronics development process, as it covers the complete product life-cycle from the concept phase until its decommissioning

1.1.10 SECURITY

As more functions of the automobile are connected to short- or long-range networks, cyber security of systems against unauthorized modification is required. With critical systems such as engine controls, transmission, air bags, and braking connected to internal diagnostic networks, remote access could result in a malicious intruder altering the function of systems or disabling them, possibly causing injuries or fatalities. Every new interface presents a new "attack surface". The same facility that allows the owner to unlock and start a car from a smart phone app also presents risks due to remote access. Auto manufacturers may protect the memory of various control microprocessors both to secure them from unauthorized changes and also to ensure only manufacturer-authorized facilities can diagnose or repair the vehicle. Systems such as keyless entry rely on cryptographic techniques to ensure "replay" or "man-in-the-middle attacks" attacks cannot record sequences to allow later break-in to the automobile.

In 2015 the German general automobile club commissioned an investigation of the vulnerabilities of one manufacturer's electronics system, which could have led to such exploits as unauthorized remote unlocking of the vehicle

ENGINE MANAGEMENT SYSTEM

An **engine control unit** (**ECU**), also commonly called an **engine control module** (**ECM**), is a type of electronic control unit that controls a series of actuators on an internal combustion engine to ensure optimal engine performance. It does this by reading values from a multitude of sensors within the engine bay, interpreting the data using multidimensional performance maps (called lookup tables), and adjusting the engine actuators accordingly. Before ECUs, air-fuel mixture, ignition timing, and idle speed were mechanically set and dynamically controlled by mechanical and pneumatic means.

If the ECU has control over the fuel lines, then it is referred to as a **Electronic Engine Management System** (EEMS). The fuel injection system has the major role to control the engine's fuel supply. The whole mechanism of the EEMS is controlled by a stack of sensors and actuators.

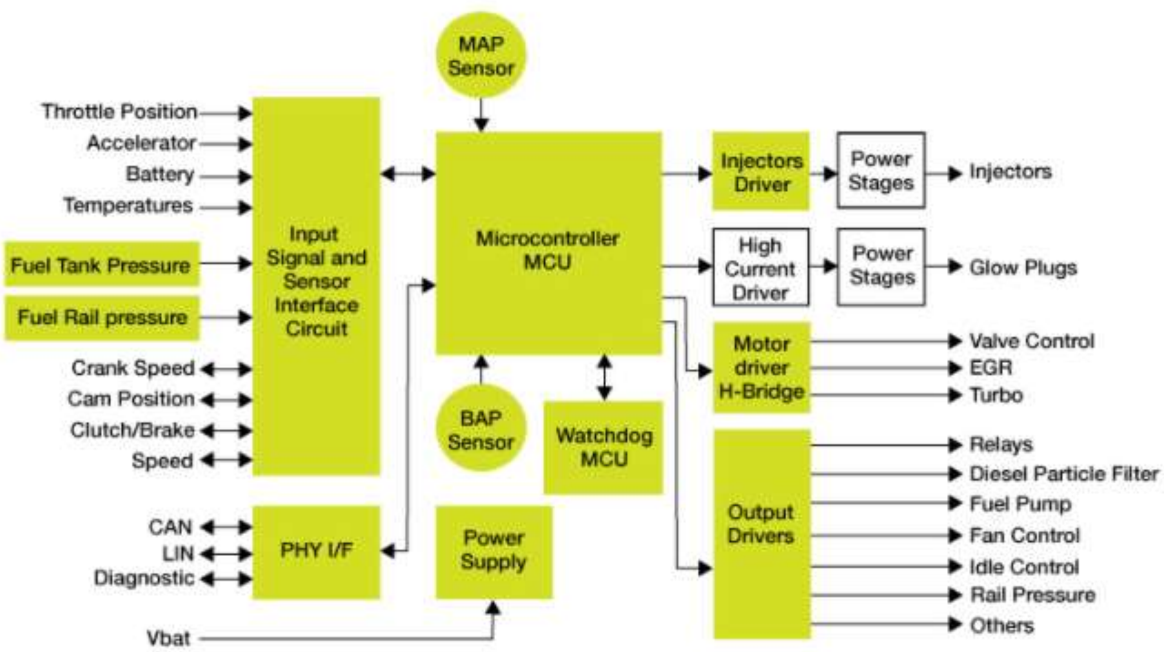
Modern engine management systems do a fine job of ensuring that engines run cleanly and efficiently in a wide variety of conditions, they are for the most part reliable and require little or no maintenance. However they seem from the outside to be fearsomely complicated systems which defy all attempts at understanding. Amidst all this apparent hokum it is easy to lose sight of the two basic functions performed by an EMS.

1. To provide a spark at the right time.

2. To meter fuel to the engine in the right quantity.

WHAT IS AN ENGINE MANAGEMENT SYSTEM?

Basic Engine Management System or EMS is a self contained custom built computer which controls the running of an engine by monitoring the engine speed, load and temperature and providing the ignition spark at the right time for the prevailing conditions and metering the fuel to the engine in the exact quantity required.



There are two discrete subsystems in operation within the Engine Management System, the fuel or injection system and the ignition system. It is possible to run an engine management system which just provides one of these subsystems, for example just the ignition system. It is much more common to use the mapped ignition within an Engine Management System in isolation than it is to use just the injection.

What is a fuel map or ignition map:

Most of us have heard the term "Mapped ignition" and programmed or mapped injection but may not understand what this actually is. Whilst the engine is running its requirements for fuel and ignition timing will vary according to certain engine conditions, the main two being engine speed and engine load. A "map" is no more than a look up table by engine speed and load, which gives the appropriate fuel or timing setting for each possible speed and load condition. There will normally be a map for the injector timings (fuel map) and a separate map for the ignition timing settings (ignition map) within the Engine Management System.

Each map has entries for a pre-determined range of engine speeds (called speed sites) and a predetermined range of engine load conditions (called load sites) which generally indicate how far open the throttle is. The Engine Management System knows the engine speed (derived from the crank sensor or distributor pickup) and the engine load (from the Throttle Position Sensor or airflow meter) and will use these two values to "look-up" the appropriate fuel and timing settings in each map.

If the current engine telemetry falls between the sites in the map then the value is interpolated between the nearest two sites. Normally there will be speed sites every 500 or so RPM and 8 to 16 load sites between closed and open throttle. In the example below speed sites are spaced every 1000 RPM and the 8 load sites are numbered 0 to 7.

Simple Example of an Ignition Map

[redacted]	0	1000	2000	3000	4000	5000	6000	7000	8000
0	8	25	20	35	38	38	38	40	40
1	8	15	20	32	34	35	35	38	38
2	8	12	20	26	32	33	32	34	36
3	8	12	19	26	30	31	32	32	34
4	8	12	18	25	30	30	30	32	32

5	8	12	18	25	30	30	30	30	31
6	8	12	18	25	30	30	30	30	31
7	8	12	18	25	30	30	30	30	31

In this example the engine load increases as the load site numbers in the left column increase. If the engine were running at 3000RPM, load site 3, then the value looked up would be 26, I.E. 26 degrees of advance. If the engine were running at 3500RPM, load site 3 then the Engine Management System would interpolate between the value for 3000RPM (26) and the value for 4000RPM (30) and calculate a value of 28 degrees.

Note: how ignition advance falls as load increases, this is because cylinder filling is much better when load increases and therefore the mixture burns faster, necessitating less advance.

PROGRAMMABLE ECU VS. NON-PROGRAMMABLE ECU.

Most Engine Management System's fitted to production vehicles are not programmable, that is to say that the maps within the Engine Management System which determine the fueling and ignition settings are fixed and cannot be varied by the owner. This makes good sense from a manufacturers point of view since the engine then runs within the permitted parameters which keeps the engine emissions and economy within known limits.

There is a burgeoning market for "chip tuning" where the chip containing the maps is replaced by another which has revised map settings providing better performance from the engine, the gains to be had here are fairly small except with turbo-charged engines where the EMS controls the boost. Chip changes on these engines can yield quite large increases in engine power. Some manufacturers go to great lengths to stop after market tuners from decoding the maps within their Engine Management System with varying degrees of success. Notable EMS which are difficult if not impossible to "chip" are the Rover MEMS and the Ford EECIV system.

All after-market Engine Management System are programmable since they have to be fitted to a variety of different engine installations in a variety of states of tune. If the map values could not be changed then the EMS would be useless for after market applications. Some manufacturers of these systems discourage home mapping and will only allow authorized dealers to undertake the mapping.

For clarity sake we will examine each of the two sub-systems within an Engine Management System separately, in practice there is a great deal of interaction between the two, both systems will utilize information from the various engine sensors.

OPERATION OF THE ENGINE MANAGEMENT SYSTEM.

The way the EMS manages injection is quite simple, the sensors and triggers on the engine relay information to the EMS about engine speed and load. The EMS uses these to extract the appropriate injector time from the injection map and then fires the injector(s) for this length of time. If the system uses batched injection then all of the injectors are fired at the same time once per engine revolution. With grouped injection the injectors are grouped together in pairs which are fired at an optimal point in the engines cycle which best suits those two cylinders, again once per revolution. Where the engine sensors are able to determine the engines cycle position (usually from a cam phase sensor) it is possible to fire the injectors at the optimum time for each individual cylinder; this is known as sequential injection. Rather than firing once per revolution, each injector is fired for twice the pulse width at the optimum time in the engines cycle; E.G. Immediately before the inlet valve opens. There are minor benefits in economy and emissions to be had from using sequential or grouped injection, but power wise there is little or no difference.

As we can see information from these two main input sources allows the EMS to orchestrate the engines fueling so that the engine runs happily in normal conditions. There are times however when the engine is not running under these ideal conditions and it is at these times that other vital feedback is required to allow the EMS to run the engine properly. Generally under these conditions the EMS makes adjustments or “corrections” to the fuel map according to what it knows about the prevailing conditions. The main environmental conditions that are monitored by the EMS are as follows.

Engine temperature.

When an engine starts from cold it is well below its normal operating temperature, this causes some of the fuel injected into the engine to condense rather than atomizing and being drawn in efficiently. Combustion chamber temperatures are also low which leads to incomplete and slow combustion. These affects cause the engine to run weak and require that extra fuel be supplied to the engine to compensate. In a conventional system the “choke” on the carburetor performs this function, on an injection system a coolant temperature sensor provides the EMS with the engines temperature and enables it to “correct” the fuelling. This correction involves adding a percentage of extra fuel according to a pre-determined correction profile by temperature, up to the normal operating temperature of the engine. The amount of extra fuel will vary from engine to engine and according to engines temperature and RPM since the affects of condensing are less when air speeds are higher.

Air temperature.

When air temperatures are high, the density of the air being inducted falls off, thereby lessening the volume of Oxygen available for combustion, if the fuel that is injected remains constant then the mixture will become too rich. To compensate for this the EMS applies a correction to the base map according to a predetermined correction profile. As the air temperature rises so air density will continue to fall and hence the fueling will be reduced. Information about air temperature is relayed to the EMS by an air temperature sensor. To an extent air flow meters can compensate for lower density air since depending on their type they may show less volume of air inducted.

Battery voltage.

If the voltage of the vehicles battery varies then it is likely that the time taken to open the injectors will vary. Since the EMS times the overall injector pulse if the injector takes longer to open then the time it remains open will be that much shorter and therefore the fuel introduced to the engine will be correspondingly less. Some EMS’es have a correction applied to the base map of injector times for variations in voltage; the corrections are usually small but during shorter injector times (idle and cruise) they can be very significant to the efficient running of the engine.

Mixture strength.

Some EMS'es make use of a Lambda sensor that sits in the exhaust of an engine and measures the "strength" of the mixture while the engine is running. During conditions of steady state running the EMS is able to tell from this sensor whether the mixture is rich or lean and can make real-time adjustments to bring the mixture back to chemically correct. This generally happens only when in steady state, E.G. at idle or when cruising and is known as "closed loop running". Over a period of time the EMS can "learn" whether the mixture is rich or lean and make long term adjustments.

Knock sensing.

A knock sensor is an acoustic sensor that listens for pre-ignition more commonly known as "knocking" or "pinking/pinging". It is most likely eradicated by adjusting the timing but there are circumstances where the mixture needs trimming as well. When this is detected the EMS is able to adjust the fueling if required in order to help eradicate the problem.

There are some additional corrections that the EMS can apply intuitively by examining changes in state or other derived conditions, the most common are.

Acceleration fueling.

When the throttle is opened suddenly there is generally a weakening affect on the induction since air is lighter than fuel and is drawn in more rapidly. Weakening on throttle opening transients is also caused by the fact that the fuel has already been injected and the inlet valve is open before changes in the inlet manifold can take place due to a throttle

Transient, this is only a transitory affect but it can cause the engine to stumble or stutter on initial acceleration. To counteract this tendency the EMS can keep track of sudden changes in throttle position or load and add a percentage of extra fuel when this happens. The extra fuel is only added for a short period and is then decayed over another short period; this is normally a number of engine revolutions rather than a period of time. This is known as "accelerator clamp".

Deceleration fuel.

When the throttle is closed suddenly and the engine is being over-drive the hydrocarbon levels in the exhaust can rise dramatically. It is also possible for unburned fuel to ignite in the exhaust system producing the characteristic ?popping? on overrun. To overcome this some Engine Management Systems will either reduce the fuel to the engine on overrun or in some cases cut it off all together.

Cranking fuel.

When the engine is actually being started the cranking speed is quite low (150-200RPM or so) this means that the airspeed in the inlet ports is minimal and may not be sufficient to atomize and draw in all the fuel from the injectors. It is normally necessary to add some extra fuel while cranking to overcome this drawback. The amount of extra fuel to be added can be built into the base map at speed site zero but it is more usual to have a correction to the base map which is a percentage of extra fuel to be added when cranking. This extra fueling can also vary with engine temperature so the correction is normally in a table for each of a range of engine temperatures. This correction normally decays quite quickly once the engine has fired since it is only required at low crank speeds. The percentage of extra fuel required will vary from engine to engine.

Control of air/fuel ratio

Most modern engines use some type of fuel injection to deliver fuel to the cylinders. The ECU determines the amount of fuel to inject based on a number of sensor readings. Oxygen sensors tell the ECU whether the engine is running rich (too much fuel/too little oxygen) or running lean (too much oxygen/too little fuel) as compared to ideal conditions (known as stoichiometric). The throttle position sensors tell the ECU how far the throttle plate is opened when you press the accelerator. The mass air flow sensor measures the amount of air flowing into the engine through the throttle plate. The engine coolant temperature sensor measures whether the engine is warmed up or cool. (If the engine is still cool, additional fuel will be injected.)

Air/fuel mixture control of carburetors with computers is designed with a similar principle, but a mixture control solenoid or stepper motor is incorporated in the float bowl of the carburetor.

Control of idle speed

Most engine systems have idle speed control built into the ECU. The engine RPM is monitored by the crankshaft position sensor which plays a primary role in the engine timing functions for fuel injection, spark events, and valve timing. Idle speed is controlled by a programmable throttle stop or an idle air bypass control stepper motor. Early carburetor-based systems used a programmable throttle stop using a bidirectional DC motor. Early Throttle body injection (TBI) systems used an idle air control stepper motor. Effective idle speed control must anticipate the engine load at idle.

A full authority throttle control system may be used to control idle speed, provide cruise control functions and top speed limitation.

Control of variable valve timing

Some engines have Variable Valve Timing. In such an engine, the ECU controls the time in the engine cycle at which the valves open. The valves are usually opened sooner at higher speed than at lower speed. This can increase the flow of air into the cylinder, increasing power and fuel economy.

Electronic valve control

Experimental engines have been made and tested that have no camshaft, but have full electronic control of the intake and exhaust valve opening, valve closing and area of the valve opening.[1] Such engines can be started and run without a starter motor for certain multi-cylinder engines equipped with precision timed electronic ignition and fuel injection. Such a *static-start* engine would provide the efficiency and pollution-reduction improvements of a mild hybrid-electric drive, but without the expense and complexity of an oversized starter motor.[2]

The first production engine of this type was invented (in 2002) and introduced (in 2009) by Italian automaker Fiat in the Alfa Romeo MiTo. Their Multiair engines use electronic valve control which dramatically improve torque and horsepower, while reducing fuel consumption as much as 15%. Basically, the valves are opened by hydraulic pumps, which are operated by the ECU. The valves can open several times per intake stroke, based on engine load. The ECU then decides how much fuel should be injected to optimize combustion.

At steady load conditions, the valve opens, fuel is injected, and the valve closes. Under a sudden increase in throttle, the valve opens in the same intake stroke and a greater amount of fuel is injected. This allows immediate acceleration. For the next stroke, the ECU calculates engine load at the new, higher RPM, and decides how to open the valve: early or late, wide-open or half-open. The optimal opening and timing are always reached and combustion is as precise as possible. This, of course, is impossible with a normal camshaft, which opens the valve for the whole intake period, and always to full lift.

The elimination of cams, lifters, rockers, and timing set reduces not only weight and bulk, but also friction. A significant portion of the power that an engine actually produces is used up just driving the valve train, compressing all those valve springs thousands of times a minute.

Once more fully developed, electronic valve operation will yield even more benefits. Cylinder deactivation, for instance, could be made much more fuel efficient if the intake valve could be opened on every down stroke and the exhaust valve opened on every upstroke of the deactivated cylinder or "dead hole". Another even more significant advancement will be the elimination of the conventional throttle. When a car is run at part throttle, this interruption in the airflow causes excess vacuum, which causes the engine to use up valuable energy acting as a vacuum pump. BMW attempted to get around this on their V-10 powered M5, which had individual throttle butterflies for each cylinder, placed just before the intake valves. With electronic valve operation, it will be possible to control engine speed by regulating valve lift. At part throttle, when less air and gas are needed, the valve lift would not be as great. Full throttle is achieved when the gas pedal is depressed, sending an electronic signal to the ECU, which in turn regulates the lift of each valve event, and opens it all the way up.

ELECTRONICS CHASSIS MANAGEMENT SYSTEM

A chassis (pronounced TCHA-see or CHA-see) is the physical frame or structure of an automobile, an airplane, a desktop computer, or other multi-component device. *Case* is very similar in meaning, but tends to connote the protective aspect of the frame rather than its structure. People tend to choose one term or the other. The rest of this definition uses *chassis* but applies as well to the term *case* . Both terms (and *casing*) are derived from the Vulgate Latin for *box* . The plural form is also *chassis* .

Modern electronic control systems and chassis components make a major contribution towards enhancing comfort and increasing safety in the vehicle.

The chassis control system involves

- Anti Lock Braking system

- Electronic Damping Control system
- Power Assisted Steering System
- Traction Control Systems

TRACTION CONTROL

prevent drive wheels from wheel spinning during starting or

–accelerating on a wet or icy surface.

avoid reduction of either steering response in front-wheel-drive (FWD) / vehicle stability on rear-wheel-drive (RWD) vehicles.

TCS operates

to maximize adhesion to the road surface during acceleration

Same sensors as in ABS

The actuation uses fuel, ignition and driven wheel braking action

to achieve reduction in driven wheel torque during wheel spin.

maintain the acceleration slip of the driven wheels equal to the mean rotational velocity of the non-driven wheels + a specified speed difference known as the slip threshold.

driven wheels are kept at a faster speed than the non-driven wheels

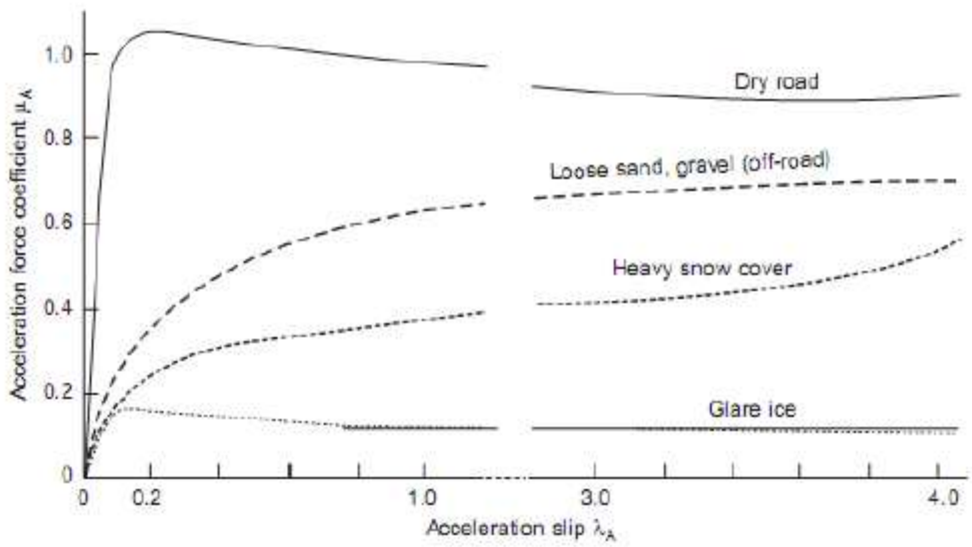
the vehicle accelerates at a constant rate proportional to the difference in the two speeds. (if difference is not in limits (slip threshold), traction needs to be controlled)

Control depends on road surface conditions or adhesion coefficient.

on dry road surfaces, maximum acceleration at slip rates of 10 to 30%.

On glare ice, maximum traction between 2 and 5 percent

so TCS systems designed for a slip rate range between 2 and 20%.



Adhesion force coefficient μ_A as a function of acceleration λ_A(Jurgen, 1995)

on loose sand or gravel and in deep snow the coefficient of adhesion increases continually with the slip rate

TCS systems incorporate slip-threshold switches to allow the driver to select a higher slip threshold or switch off the TCS

The control objectives of TCS are modified by vehicle speed and curve recognition.

Both of these variables can be derived from the speeds of the non-driven wheels.

coefficient of adhesion or friction decided on the basis of acceleration rate and engine torque

The slip threshold is raised in response to higher friction coefficients to allow higher acceleration rates

Curve recognition or cornering detection also affects the control strategy for TCS.

This strategy employs the difference in wheel speeds of the non-driven wheel speeds as a basis for reductions in the slip set point to enhance stability in curves.

High vehicle speeds and low acceleration requirements on low coefficient of adhesion surfaces imply

–a control strategy of progressively lower slip threshold set points as the vehicle speed increases,

–gives maximum lateral adhesion on the surface.

DAMPING CONTROL

The primary function of a shock absorber

–control vehicle movement against roll during turning and pitch during acceleration or braking.

–Requires hard suspension

•secondary role

–To prevent vehicle vibration caused by a poor road surface.

–Requires a soft suspension

•Electronic damping control (EDC) used to attain these twin objectives

•altering the characteristics of spring and oil-filled damper arrangement

–difficult and expensive

•Simple option - Suspensions with at least three settings; ‘soft’, ’medium’ and ‘firm’

•OR electronically controlled suspension systems using air, nitrogen gas and hydraulic oil as a suspension agent.

SENSORS USED IN TRACTION CONTROL

–vehicle speed,

–engine r.p.m.,

–brake system pressure,

–steering angle,

–chassis and wheel acceleration,

–throttle position,

–vehicle load and

–even road surface condition

•Road condition - implied by processing signals from front and rear height sensors rather than direct measurement.

–if the height sensor signals a small high frequency but a large low frequency amplitude

•a heaving or undulating road surface

•Does not require a softening of damper.

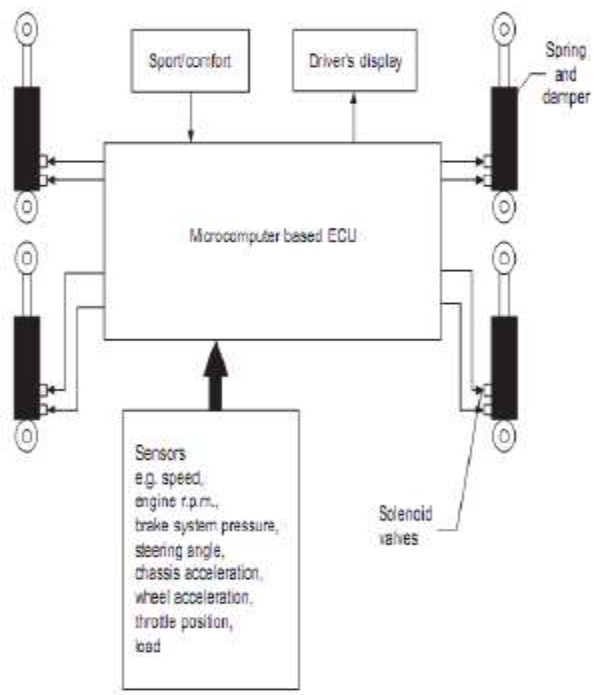
–A large high frequency component would suggest

•a rough road surface and

•Softening of damper action.

•Conflicts with damper requirement to prevent rolling during cornering.

•If the vehicle corners on a rough surface this must be resolved by the ECU.



Electronically controlled damping system

Longitudinal acceleration

•measured directly using an acceleration sensor, or

•inferred from brake system pressure and throttle opening angle.

•Used to control pitching during acceleration / braking

Lateral forces

•inferred by the rate at which the steering wheel is being turned and the vehicle speed.

•used by the ECU to prevent rolling.

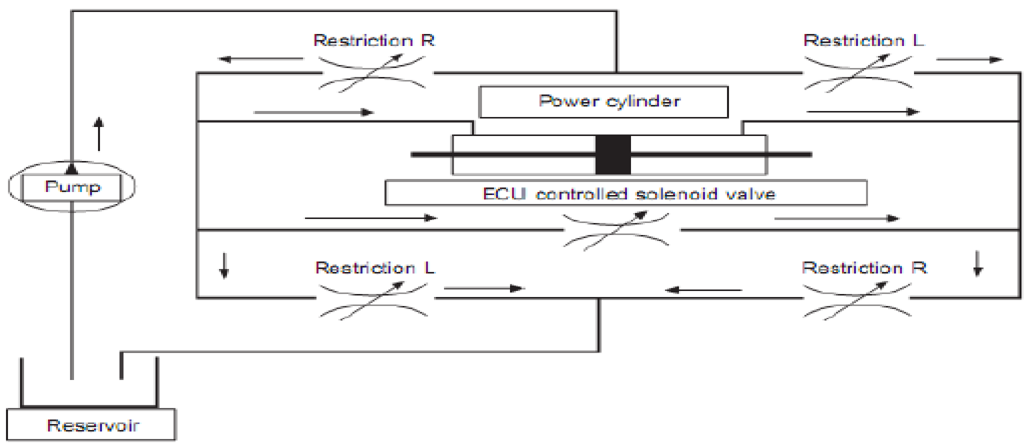
•the actuators are dampers fitted with two ON-OFF fluid control solenoids used to select one of four different damper settings (normal, soft, super-soft and firm).

•Driver can choose sport or smooth ride mode.

•In sport mode soft or super-soft damper settings excluded

•Result in a harder but more stable ride.

ELECTRONICALLY CONTROLLED POWER ASSISTED STEERING



Hydraulic bridge circuit for electronically-controlled power steering showing flow paths

•the ports of a solenoid valve are connected across the rack and pinion steering hydraulic power cylinder.

•with increasing vehicle speed the valve opening is extended

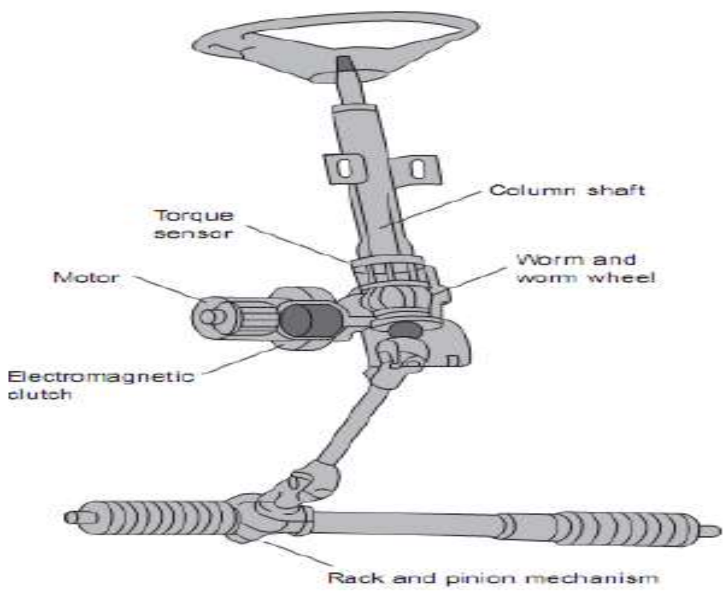
–reducing the hydraulic pressure in the power cylinder

–increasing the steering effort.

•bridge-like restrictions for control of the power cylinder are formed by the paths through the pump to port connections of a rotary valve

•The valve is connected directly to the steering wheel and

–a small movement of this controls the high pressure hydraulic fluid to reach the power cylinder/solenoid valve.



•input to the rack and pinion steering system is from a motor/reduction gearbox

•motor torque is applied directly to either the pinion gear shaft or to the rack shaft.

•The steering effort range is greater than with hydraulic systems,

•installations are cheaper and reliable.

•Power is only consumed when steering wheel moves, (unlike hydraulic system)

•a torque sensor on the column shaft

•The electric motor coupled to the worm wheel mechanism through a reduction gearbox.

•The load torque *TL* on the steering column is the load presented by the worm mechanism and the rack and pinion assembly to which it is attached.

•The amount of motor torque is proportional to the motor current *IM*.

•in a simple armature controlled d.c. motor the average current is given

$$I_M = \frac{V_M - k \times N}{R}$$

–where *R is the armature resistance,*

–*N is the speed of the motor and VM* the motor voltage,

•the set point motor voltage depends on how much control effort is required from the d.c. motor.

•When a driver turning a steering wheel at a constant rate, say in cornering.

–The d.c. motor, must turn at a speed proportional to this rate.

–Controlling term --- motor voltage = k x N

•at high vehicle speeds the assistance given to the driver must decrease in proportion to speed

–i.e., Decrease motor current or voltage as vehicle speed increases.

–Motor voltage component = kT x Tm (Tm is output from Torque sensor)

–Inverse function of vehicle speed

•Add both components to get appropriate control

AIR BAG AND SEAT BELT SYSTEM

systems consist of

–crash detection sensors (typically piezoelectric) with a signal conditioning amplifier

–a microcontroller distinguishing between crashes and normal vehicle dynamics,

–igniter triggering for the pyrotechnic inflator

•used for air-bag deployment and seat belt tightening.

•The allowable forward passenger travel with an air-bag system is 12.5 cm

–with seat belt tensioning systems it is about 1 cm.

•Approximately 30 ms are required to inflate air-bags and

•time required to tension a seat belt with a retractor = ~10 ms.

•triggering must be done by the time forward displacement is reached minus the activation time of the respective restraining device.

•Often multiple sensors and sensor mounting positions

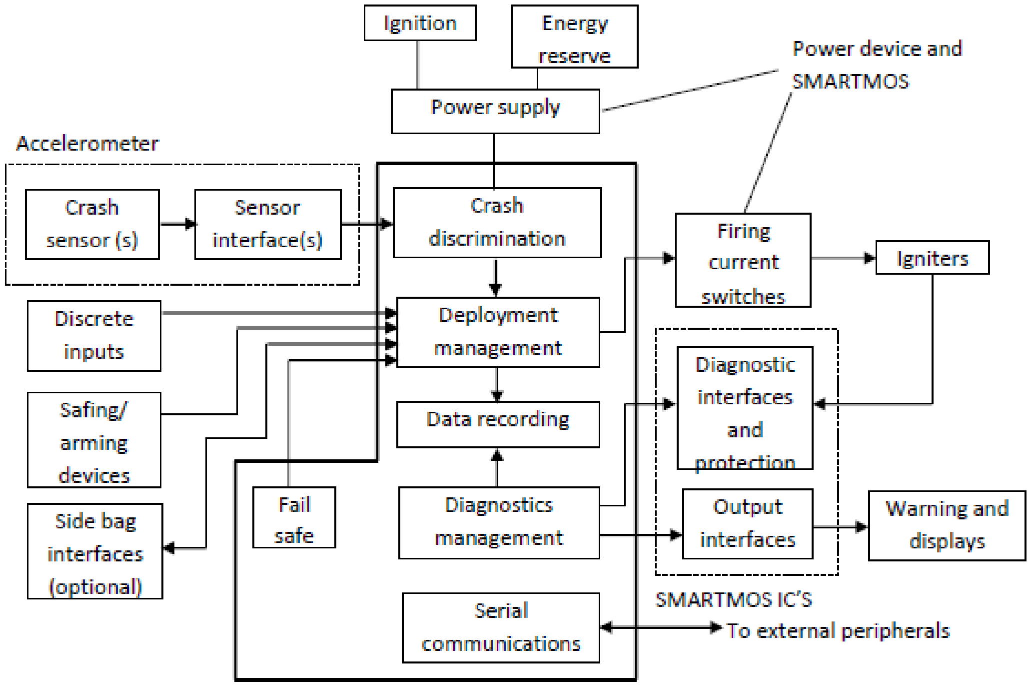
•When airbag is triggered

–ECU turns on the firing current switches,

–allows current through the igniter,

–initiates a gas generation reaction inside the inflation module.

–Capacitance based power maintained even if battery is disconnected


Ignition
Energy reserve
Power supply
Power device and SMARTMOS
Accelerometer
Crash sensor (s)
Sensor interface(s)
Crash discrimination
Firing current switches
Igniters
Discrete inputs
Deployment management
Diagnostic interfaces and protection
Safing/ arming devices
Data recording
Fail safe
Diagnostics management
Output interfaces
Warning and displays
Side bag interfaces (optional)
Serial communications
SMARTMOS IC'S
To external peripherals