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

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE MATERIALS

AU486 NOISE VIBRATION AND HARSHNESS

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: 2002
- Course offered : B.Tech in Mechanical 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

Producing internationally competitive Mechanical Engineers with social responsibility & sustainable employability through viable strategies as well as competent exposure oriented quality education.

DEPARTMENT MISSION

1. Imparting high impact education by providing conductive teaching learning environment.
2. Fostering effective modes of continuous learning process with moral & ethical values.
3. Enhancing leadership qualities with social commitment, professional attitude, unity, team spirit & communication skill.
4. Introducing the present scenario in research & development through collaborative efforts blended with industry & institution.

PROGRAMME EDUCATIONAL OBJECTIVES

PEO1: Graduates shall have strong practical & technical exposures in the field of Mechanical Engineering & will contribute to the society through innovation & enterprise.

PEO2: Graduates will have the demonstrated ability to analyze, formulate & solve design engineering / thermal engineering / materials & manufacturing / design issues & real life problems.

PEO3: Graduates will be capable of pursuing Mechanical Engineering profession with good communication skills, leadership qualities, team spirit & communication skills.

PEO4: Graduates will sustain an appetite for continuous learning by pursuing higher education & research in the allied areas of technology.

PROGRAM OUTCOMES (POS)

Engineering Graduates will be able to:

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

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.

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.

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.

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.

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.

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.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and teamwork**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
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.
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.
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 OUTCOMES (PSO)

PSO1: graduates able to apply principles of engineering, basic sciences & analytics including multi variant calculus & higher order partial differential equations..

PSO2: Graduates able to perform modeling, analyzing, designing & simulating physical systems, components & processes.

PSO3: Graduates able to work professionally on mechanical systems, thermal systems & production systems.

COURSE OUTCOMES

CO1	Understand the basics of noise, vibration, sources of vibration and noise in automobiles.
CO2	Study the effect of noise and vibration on human beings and nature.
CO3	Understand the engine related noises.
CO4	Understand the prediction and control techniques of noise, vibration pertain to an automobile.
CO5	Understand the measurement techniques of noise, vibration pertain to an automobile.
CO6	Know about reduction of noise and vibration from an automobile.

MAPPING OF COURSE OUTCOMES WITH PROGRAM OUTCOMES

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	1	1		1		2			2	1	2	2	1
CO2	1		2	1	1		2								2
CO3		1	1			2	2								
CO4	1	2	1	1		1	1							2	
CO5		1	1	2		1		1				2		2	2
CO6	1	1	2			2	2	1			1	1		2	2

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

SYLLABUS

Course code	Course Name	L-T-P - C	Year of Introduction
AU486	Noise, Vibration and Harshness	3-0-0-3	2016

Prerequisite : NIL

Course Objectives

- To impart the basics of noise, vibration, sources of vibration and noise in automobiles
- To study the effect of noise and vibration on human beings and nature.
- To introduce the methods of measurement of noise and vibration.
- To provide knowhow on various methods to reduce the vibration and noise

Syllabus

Fundamentals of Acoustics and Noise, Vibration - Effects of Noise, Blast, Vibration, and Shock on People- Introduction to Transportation Noise and Vibration Sources – Engine noise - Reduction of noise and vibrations - Noise and Vibration Transducers - Noise and Vibration Measurements - Vibration Data Analysis

Expected outcome.

The students will

i. understand the sources, effects, prediction, control techniques, measurement techniques of noise, vibration pertain to an automobile

ii. know about reduction of noise and vibration from an automobile.

Text Books:

1. Clarence W. de Silva , "Vibration Monitoring, Testing, and Instrumentation ",CRC Press, 2007
2. Colin H Hansen "Understanding Active Noise Cancellation" , Spon Press , London 2003
3. Kewal Pujara "Vibrations and Noise for Engineers, Dhanpat Rai & Sons, 1992.
4. Singiresu S.Rao,"Mechanical Vibrations" - Pearson Education, ISBM –81-297-0179-2004.

References:

1. Allan G. Piersol ,Thomas L. Paez "Harris' Shock and Vibration Handbook" , McGraw-Hill , New Delhi, 2010
2. Bernard Challen and Rodica Baranescu - "Diesel Engine Refrence Book" - Second edition - SAE International - ISBN 0-7680-0403-9 – 1999.
3. David A.Bies and Colin H.Hansen "Engineering Noise Control: Theory and Practice "Spon Press, London, 2009
4. Julian Happian-Smith - "An Introduction to Modern Vehicle Design"- Butterworth-Heinemann, ISBN 0750-5044-3 – 2004
5. Matthew Harrison "Vehicle Refinement: Controlling Noise and Vibration in Road Vehicles ", Elsevier Butterworth-Heinemann, Burlington, 2004

Course Plan

Module	Contents	Hours	End Sem. Exam Marks
I	Fundamentals of Acoustics and Noise, Vibration: Introduction, classification of vibration and noises: Theory of Sound—Predictions and Measurement, Sound Sources, Sound Propagation in the Atmosphere, Sound Radiation from Structures and Their Response to	7	15%

	Sound, General Introduction to Vibration, free and forced vibration, undamped and damped vibration, linear and non linear vibration, response of damped and undamped systems under harmonic force, analysis of single degree and two degree of freedom systems		
II	Effects of Noise, Blast, Vibration, and Shock on People: General Introduction to Noise and Vibration Effects on People and Hearing Conservation, Noise Exposure, Noise-Induced Annoyance, Effects of Infrasound, Low-Frequency Noise, and Ultrasound on People, Effects of Intense Noise on People and Hearing Loss, Effects of Vibration on People, Effects of Mechanical Shock on People, Rating Measures, Descriptors, Criteria, and Procedures for Determining Human Response to Noise.	7	15%
FIRST INTERNAL EXAMINATION			
III	Introduction to Transportation Noise and Vibration Sources, Noise Characteristics of engines, engine overall noise levels, assessment of combustion noise, assessment of mechanical noise, engine radiated noise, intake and exhaust noise, engine accessory contributed noise, transmission noise, aerodynamic noise, tyre noise, brake noise	7	15%
IV	Reduction of noise and vibrations I: Vibration isolation, tuned absorbers, untuned viscous dampers, damping treatments, application dynamic forces generated by IC engines, engine isolation, crank shaft damping, modal analysis of the mass elastic model shock absorbers.	7	15%
SECOND INTERNAL EXAMINATION			
V	Reduction of noise and vibrations: noise dose level, legislation, measurement and analysis of noise, measurement environment, equipment, frequency analysis, tracking analysis, sound quality analysis. Methods for control of engine noise, combustion noise, mechanical noise, predictive analysis, palliative treatments and enclosures, automotive noise control principles, sound in enclosures, sound energy absorption, sound transmission through barriers	8	20%
VI	Noise and Vibration Transducers, Analysis Equipment, Signal Processing, and Measuring Techniques: General Introduction to Noise and Vibration Transducers, Measuring Equipment, Measurements, Signal Acquisition and Processing, Acoustical Transducer Principles and Types of Microphones, Vibration Transducer Principles and Types of Vibration Transducers, Sound Level Meters, Noise Dosimeters, Analyzers and Signal Generators, Equipment for Data Acquisition, Noise and Vibration Measurements, Determination of Sound Power Level and Emission Sound Pressure Level, Sound Intensity Measurements, Noise and Vibration Data Analysis, Calibration of Measurement Microphones, Calibration of Shock and Vibration Transducers.	8	20%
END SEMESTER EXAM			

QUESTION BANK

MODULE I			
Q:NO:	**QUESTIONS**	**CO**	**KL**
1	Write the fundamentals of Acoustics.	CO1	K6
2	Discuss sound and explain its types.	CO1	K2
3	Briefly explain the sources of sound or noise.	CO1	K2
4	How the sounds are predicted? Describe different sound rating scales.	CO1	K2
5	What are the elements of a sound measuring instrument?	CO1	K5
6	Draw a flow chart and describe various sound measuring instruments.	CO1	K1
7	What are the factors affects the propagation of sound?	CO1	K5
8	Write a short note on sound transmission through civil structures.	CO1	K6
9	Describe the term resonance.	CO1	K2
10	Define Vibration and explain the different classifications of Vibration.	CO1	K1
11	Derive the response of undamped vibration under harmonic force.	CO1	K2
12	Derive the response of damped vibration under harmonic force.	CO1	K2
13	Define degrees of freedom and explain in detail with examples.	CO1	K2
MODULE II			
1	Discuss the effects of noise on peoples.	CO2	K4
2	Define sound and explain its effects on human.	CO2	K2
3	Explain the effects of vibration on peoples.	CO2	K6
4	How the sounds are classified? Describe different sound rating scales.	CO2	K2
5	What are the elements depends on the human response to sound?	CO2	K5
6	Draw a neat diagram and describe various shock measuring instruments.	CO2	K1
7	What are the effects on human by blast?	CO2	K5
8	Write a short note on mechanical shock.	CO2	K3
9	Enumerate the term noise induced annoyance.	CO2	K6
10	Define Noise exposure and explain the effects of intense noise.	CO2	K2
11	Discuss vibrometer and accelerometer.	CO2	K4
12	Differentiate WBV and HAV.	CO2	K4
13	Describe the term Hearing Conservation.	CO2	K2
14	How the low frequency noise affects people?	CO2	K2
15	Describe the effect on infrasonic sound on humans.	CO2	K2

16	Discuss the effect on ultrasonic sound on humans	CO2	K4
	MODULE III		
1	Write a short note on Transportation Noise.	CO3	K6
2	Discuss the sources of vibration.	CO3	K4
3	What are the noise characteristics of an engine?	CO3	K5
4	How the engine noise levels are classified?	CO3	K2
5	Enumerate the term Combustion noise in an engine.	CO3	K6
6	Enumerate the term radiated noise in an engine.	CO3	K6
7	Differentiate intake and exhaust noise in engines.	CO3	K4
8	Give an assessment on Mechanical noise.	CO3	K3
9	Explain engine accessory contributed noise.	CO3	K6
10	Explain Tyre noise and Brake noise.	CO3	K6
11	Describe the terms i) Transmission noise and ii) Aerodynamic noise	CO3	K2
	MODULE IV		
1	What you meant by vibration isolation?	CO4	K5
2	Discuss the different types of vibration isolators used.	CO4	K4
3	List out and Explain the factors depends the selection of vibration isolators.	CO4	K1
4	Write the components of tuned mass dampers and explain its types.	CO4	K3
5	Describe the applications of tuned mass dampers.	CO4	K2
6	Differentiate and discuss between tuned and untuned viscous dampers.	CO4	K4
7	Write the different types of damping treatments and its applications.	CO4	K3
8	Explain the dynamic forces generated by IC engines.	CO4	K6
9	Enumerate the term engine isolation.	CO4	K6
10	How the damping was done on crank shaft of an engine?	CO4	K2
11	Describe the modal analysis of mass elastic model of shock absorbers.	CO4	K2
	MODULE V		
1	What you meant by noise dose level?	CO5	K5
2	Discuss on Noise legislation.	CO5	K4
3	Write a short note on measurement environment.	CO5	K3
4	Describe the term frequency analysis of noise.	CO5	K2
5	Write about tracking analysis of noise.	CO5	K3
6	Discuss sound quality analysis.	CO5	K4

7	What are the methods used to control the engine noise, combustion noise and mechanical noise?	CO5	K5
8	Explain predictive analysis.	CO5	K6
9	What are the palliative treatments on noise?	CO5	K5
10	Enumerate the principles of automotive noise control.	CO5	K6
11	Discuss the importance of sound enclosures.	CO5	K4
12	Explain the sound energy absorption and sound transmission through barriers.	CO5	K6
	MODULE VI		
1	How the signal acquisition and processing were done in measuring instruments?	CO6	K2
2	Write the principles of acoustical transducers.	CO6	K3
3	What are the different types of microphones?	CO6	K5
4	Discuss the principles of vibration transducers.	CO6	K4
5	What are the different types of vibration transducers?	CO6	K5
6	Write and explain different types of noise and vibration measuring instruments.	CO6	K3
7	Describe the equipment for data acquisition.	CO6	K2
8	Differentiate between sound power level and sound pressure level.	CO6	K2
9	Discuss the methods to determine i) sound power level , ii) sound pressure level	CO6	K4
10	What you meant by sound intensity measurements?	CO6	K5
11	Enumerate noise and vibration data analysis.	CO6	K6
12	Discuss the calibration of measurement microphones.	CO6	K4
13	Describe the calibration of shock and vibration transducers.	CO6	K2

MODULE 1

Syllabus- Fundamentals of Acoustics and Noise, Vibration: Introduction, classification of vibration and noises: Theory of Sound—Predictions and Measurement, Sound Sources, Sound Propagation in the Atmosphere, Sound Radiation from Structures and Their Response to Sound, General Introduction to Vibration, free and forced vibration, undamped and damped vibration, linear and non linear vibration, response of damped and undamped systems under harmonic force, analysis of single degree and two degree of freedom systems

1.1 NOISE, VIBRATION, AND HARSHNESS

Noise, vibration, and harshness (**NVH**), also known as **noise and vibration** (**N&V**), are the study and modification of the noise and vibration characteristics of vehicles, particularly cars and trucks. While noise and vibration can be readily measured, **harshness** is a subjective quality, and is measured either via "jury" evaluations, or with analytical tools that can provide results reflecting human subjective impressions. These latter tools belong to the field known as "psychoacoustics."

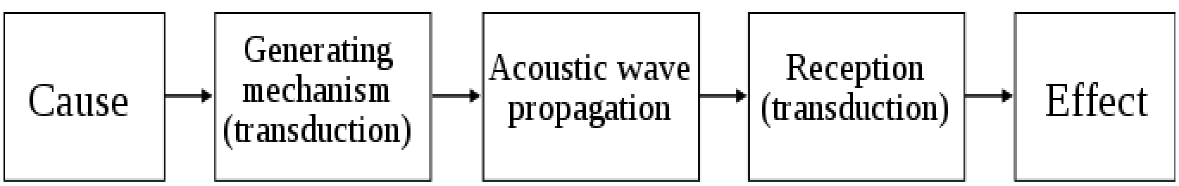
Interior NVH deals with noise and vibration experienced by the occupants of the cabin, while exterior NVH is largely concerned with the noise radiated by the vehicle, and include drive-by noise testing.

Acoustics

Acoustics is the branch of physics that deals with the study of all mechanical waves in gases, liquids, and solids including topics such as vibration, sound.

Fundamentals of Acoustics

The study of acoustics revolves around the generation, propagation and reception of mechanical waves and vibrations.



The steps shown in the above diagram can be found in any acoustical event or process.

1. Cause

There are many kinds of cause, both natural and volitional.

2. Generating Mechanism

There are many kinds of transduction process that convert energy from some other form into sonic energy, producing a sound wave. The wave carries energy throughout the propagating medium. Eventually this energy is transduced again into other forms, in ways that again may be natural and/or volitionally contrived. The five basic steps are found equally well whether we are talking about an earthquake, a submarine using sonar to locate its foe, or a band playing in a rock concert. The most widely used generating mechanisms are electromagnetism, electrostatics and piezoelectricity.

3. Wave propagation

The central stage in the acoustical process is wave propagation. This falls within the domain of physical acoustics. In fluids, sound propagates primarily as a pressure wave. In solids, mechanical waves can take many forms including longitudinal waves, transverse waves and surface waves.

Acoustics looks first at the pressure levels and frequencies in the sound wave and how the wave interacts with the environment. This interaction can be described as either a diffraction, interference or a reflection or a mix of the three. If several media are present, a refraction can also occur. Transduction processes are also of special importance to acoustics.

In fluids such as air and water, sound waves propagate as disturbances in the ambient pressure level. While this disturbance is usually small, it is still noticeable to the human ear. The smallest sound that a person can hear, known as the threshold of hearing, is nine orders of magnitude smaller than the ambient pressure. The loudness of these disturbances is related to the sound pressure level (SPL) which is measured on a logarithmic scale in decibels.

Physicists and acoustic engineers tend to discuss sound pressure levels in terms of frequencies, partly because this is how our ears interpret sound. What we experience as "higher pitched" or "lower pitched" sounds are pressure vibrations having a higher or lower number of cycles per second

The entire spectrum can be divided into three sections: audio, ultrasonic, and infrasonic. The audio range falls between 20 Hz and 20,000 Hz. This range is important because its frequencies can be detected by the human ear. This range has a number of applications, including speech communication and music. The ultrasonic range refers to the very high frequencies: 20,000 Hz and higher. This range has shorter wavelengths which allow better resolution in imaging technologies. Medical applications such as ultrasonography and elastography rely on the ultrasonic frequency range. On the other end of the spectrum, the lowest frequencies are known as the infrasonic range. These frequencies can be used to study geological phenomena such as earthquakes.

4. Reception

A transducer is a device for converting one form of energy into another. In an electroacoustic context, this means converting sound energy into electrical energy (or vice versa). Electroacoustic transducers include loudspeakers, microphones, particle velocity sensors, hydrophones and sonar projectors. These devices convert a sound wave to or from an electric signal. The most widely used transduction principles are electromagnetism, electrostatics and piezoelectricity.

The transducers in most common loudspeakers (e.g. woofers and tweeters), are electromagnetic devices that generate waves using a suspended diaphragm driven by an electromagnetic voice coil, sending off pressure waves. Electret microphones and condenser microphones employ electrostatics—as the sound wave strikes the microphone's diaphragm, it moves and induces a voltage change. The ultrasonic systems used in medical ultrasonography employ piezoelectric transducers. These are made from special ceramics in which mechanical vibrations and electrical fields are interlinked through a property of the material itself.

5. Effect

The final effect may be purely physical or it may reach far into the biological or volitional domains.

1.2 NOISE

Noise is unwanted sound judged to be unpleasant, loud or disruptive to hearing. It is the excessive sound which makes irritation.

Sources of Noise (Sound)

This section describes various sources of noise that can affect a community.

1. Industrial noise:

Mechanized industry creates serious noise problems. It is responsible for intense noise indoors as well as outdoors. This noise is due to machinery of all kinds and often increases with the power of the machines. Sound generation mechanisms of machinery are reasonably well understood. The noise may contain predominantly low or high frequencies, tonal components, 24 be impulsive or have unpleasant and disruptive temporal sound patterns. Rotating and reciprocating machines generate sound that includes tonal components; and air-moving equipment tends also to generate noise with a wide frequency range. The high sound pressure levels are caused by components or gas flows that move at high speed (for example, fans, steam pressure relief valves), or by operations involving mechanical impacts (for example, stamping, riveting, road breaking). Machinery should preferably be silenced at the source.

Noise from fixed installations, such as factories or construction sites, heat pumps and ventilation systems on roofs, typically affect nearby communities. Reductions may be achieved by encouraging quieter equipment or by zoning of land into industrial and residential areas. Requirements for passive (sound insulating enclosures) and active noise control, or restriction of operation time, may also be effective.

2. Transportation noise

Transportation noise is the main source of environmental noise pollution, including road traffic, rail traffic and air traffic. As a general rule, larger and heavier vehicles emit more noise than smaller and lighter vehicles. Exceptions would include: helicopters and 2- and 3-wheeled road vehicles.

The noise of road vehicles is mainly generated from the engine and from frictional contact between the vehicle and the ground and air. In general, road-contact noise exceeds engine noise at speeds higher than 60 km/h. The physical principle responsible for generating noise from tireroad contact is less well understood. The sound pressure level from traffic can be predicted from the traffic flow rate, the speed of the vehicles, the proportion of heavy vehicles, and the nature of the road surface. Special problems can arise in areas where the traffic movements involve a change in engine speed and power, such as at traffic lights, hills, and intersecting roads; or where topography, meteorological conditions and low background levels are unfavourable (for example, mountain areas).

Railway noise depends primarily on the speed of the train, but variations are present depending upon the type of engine, wagons, and rails and their foundations, as well as the roughness of wheels and rails. Small radius curves in the track, such as may occur for urban trains, can lead to very high levels of high-frequency sound referred to as wheel squeal. Noise can be generated in stations because of running engines, whistles and loudspeakers, and in marshaling yards because of shunting operations. The introduction of high-speed trains has created special noise problems with sudden, but not impulsive, rises in noise. At speeds greater than 250 km/h, the proportion of high-frequency sound energy increases and the sound can be perceived as similar to that of overflying jet aircraft. Special problems can arise in areas close to tunnels, in valleys or in areas where the ground conditions help generate vibrations. The long-distance propagation of noise from high-speed trains will constitute a problem in the future if otherwise environment-friendly railway systems are expanded.

Aircraft operations generate substantial noise in the vicinity of both commercial and military airports. Aircraft takeoffs are known to produce intense noise, including vibration and rattle. The landings produce substantial noise in long low-altitude flight corridors. The noise is 25 produced by the landing gear and automatic power regulation, and also when reverse thrust is applied, all for safety reasons. In general, larger and heavier aircraft produce more noise than lighter aircraft. The main mechanism of noise generation in the early turbojet-powered aircraft was the turbulence created by the jet exhaust mixing with the surrounding air. This noise source has been significantly reduced in modern high by-pass ratio turbo-fan engines that surround the high-velocity jet exhaust with lower velocity airflow generated by the fan. The fan itself can be a significant noise source, particularly during landing and taxiing operations. Multi-bladed turbo-prop engines can produce relatively high levels of tonal noise. The sound pressure level from aircraft is, typically, predicted from the number of aircraft, the types of airplanes, their flight paths, the proportions of takeoffs and landings and the atmospheric conditions. Severe noise problems may arise at airports hosting many helicopters or smaller aircraft used for private business, flying training and leisure purposes. Special noise problems may also arise inside airplanes because of vibration. The noise emission from future super jets is unknown.

A sonic boom consists of a shock wave in the air, generated by an aircraft when it flies at a speed slightly greater than the local speed of sound. An aircraft in supersonic flight trails a sonic boom that can be heard up to 50 km on either side of its ground track, depending upon the flight altitude and the size of the aircraft (Warren 1972). A sonic boom can be heard as a loud doubleboom sound. At high intensity it can damage property.

Noise from military airfields may present particular problems compared to civil airports (von Gierke & Harris 1987). For example, when used for night-time flying, for training interrupted landings and takeoffs (so-called touch-and-go), or for low-altitude flying. In certain instances, including wars, specific military activities introduce other intense noise pollution from heavy vehicles (tanks), helicopters, and small and large fire-arms.

3. Construction noise and building services noise

Building construction and excavation work can cause considerable noise emissions. A variety of sounds come from cranes, cement mixers, welding, hammering, boring and other work processes. Construction equipment is often poorly silenced and maintained, and building operations are sometimes carried out without considering the environmental noise consequences. Street services such as garbage disposal and street cleaning can also cause considerable disturbance if carried out at sensitive times of day. Ventilation and air conditioning plants and ducts, heat pumps, plumbing systems, and lifts (elevators), for example, can compromise the internal acoustical environment and upset nearby residents.

4. Domestic noise and noise from leisure activities

In residential areas, noise may stem from mechanical devices (e.g. heat pumps, ventilation systems and traffic), as well as voices, music and other kinds of sounds generated by neighbours (e.g. lawn movers, vacuum cleaners and other household equipment, music reproduction and noisy parties). Aberrant social behavior is a well-recognized noise problem in multifamily dwellings, as well as at sites for entertainment (e.g. sports and music events). Due to predominantly low-frequency components, noise from ventilation systems in residential buildings may also cause considerable concern even at low and moderate sound pressure levels.

The use of powered machines in leisure activities is increasing. For example, motor racing, offroad vehicles, motorboats, water skiing, snowmobiles etc., and these contribute significantly to loud noises in previously quiet areas. Shooting activities not only have considerable potential for disturbing nearby residents, but can also damage the hearing of those taking part. Even tennis playing, church bell ringing and other religious activities can lead to noise complaints.

Some types of indoor concerts and discotheques can produce extremely high sound pressure levels. Associated noise problems outdoors result from customers arriving and leaving. Outdoor concerts, fireworks and various types of festivals can also produce intense noise. The general problem of access to festivals and leisure activity sites often adds to road traffic noise problems. Severe hearing impairment may also arise from intense sound produced as music in headphones or from children's toys.

1.3 SOUND

Sound is a vibration that propagates as an acoustic wave, through a transmission medium such as a gas, liquid or solid. It is an effect produced in human ear by the propagation of waves.

In human physiology and psychology, sound is the reception of such waves and their perception by the brain.[1] Only acoustic waves that have frequencies lying between about 20 Hz and 20 kHz elicit an auditory percept in humans. Sound waves above 20 kHz are known as ultrasound and are not audible to humans. Sound waves below 20 Hz are known as infrasound. Different animal species have varying hearing ranges. Infrasonic waves used for measuring earthquakes. The Ultrasonic sound used for medical applications.

NOISE(SOUND) PREDICTION LEVELS

Basic Aspects of Acoustical Measurements Most environmental noises can be approximately described by one of several simple measures. They are all derived from overall sound pressure levels, the variation of these levels with time and the frequency of the sounds.

SINGLE EVENT MATRIX SOUND LEVEL

1. Sound pressure level (SPL)

The sound pressure level is a measure of the air vibrations that make up sound. All measured sound pressures are referenced to a standard pressure that corresponds roughly to the threshold of hearing at 1 000 Hz. Thus, the sound pressure level indicates how much greater the measured sound is than this threshold of hearing. Because the human ear can detect a wide range of sound pressure levels (10–102 Pascal (Pa)), they are measured on a logarithmic scale with units of decibels (dB).

Sound pressure level, denoted L_p and measured in dB, is defined by

$$L_p = \ln\left(\frac{p}{p_0}\right)\text{ Np} = 2\log_{10}\left(\frac{p}{p_0}\right)\text{ B} = 20\log_{10}\left(\frac{p}{p_0}\right)\text{ dB},$$

Where

- p is the root mean square sound pressure;
- p_0 is the reference sound pressure;

The commonly used reference sound pressure in air is, p_o = 20 µPa.

The sound pressure levels of most noises vary with time. Consequently, in calculating some measures of noise, the instantaneous pressure fluctuations must be integrated over some time interval. To approximate the integration time of our hearing system, sound pressure meters have a standard Fast response time, which corresponds to a time constant of 0.125 s. Thus, all measurements of sound pressure levels and their variation over time should be made using the Fast response time, to provide sound pressure measurements more representative of human hearing. Sound pressure meters may also include a slow response time with a time constant of 1s, but its sole purpose is that one can more easily estimate the average value of rapidly fluctuating levels. Many modern meters can integrate sound pressures over specified periods and provide average values. It is not recommended that the slow response time be used when integrating sound pressure meters are available.

Because sound pressure levels are measured on a logarithmic scale they cannot be added or averaged arithmetically. For example, adding two sounds of equal pressure levels results in a total pressure level that is only 3 dB greater than each individual sound pressure level. Consequently, when two sounds are combined the resulting sound pressure level will be significantly greater than the individual sound levels only if the two sounds have similar pressure levels.

2. Frequency and frequency weighting

The unit of frequency is the Hertz (Hz), and it refers to the number of vibrations per second of the air in which the sound is propagating. For tonal sounds, frequency is associated with the perception of pitch. For example, orchestras often tune to the frequency of 440 Hz. Most environmental sounds, however, are made up of a complex mix of many different frequencies. They may or may not have discrete frequency components superimposed on noise with a broad 22 frequency spectrum (i.e. sound with a broad range of frequencies). The audible frequency range is normally considered to range from 20–20 000 Hz. Below 20 Hz we hear individual sound pulses rather than recognizable tones. Hearing sensitivity to higher frequencies decreases with age and exposure to noise. Thus, 20 000 Hz represents an upper limit of audibility for younger listeners with unimpaired hearing.

Our hearing systems are not equally sensitive to all sound frequencies (ISO 1987a). Thus, not all frequencies are perceived as being equally loud at the same sound pressure level, and when calculating overall environmental noise ratings it is necessary to consider sounds at some frequencies as more important than those at other frequencies. Detailed frequency analyses are commonly performed with standard sets of octave or 1/3 octave bandwidth filters. Alternatively, Fast Fourier Transform techniques or other types of filters can be used to determine the relative strengths of the various frequency components making up a particular environmental noise.

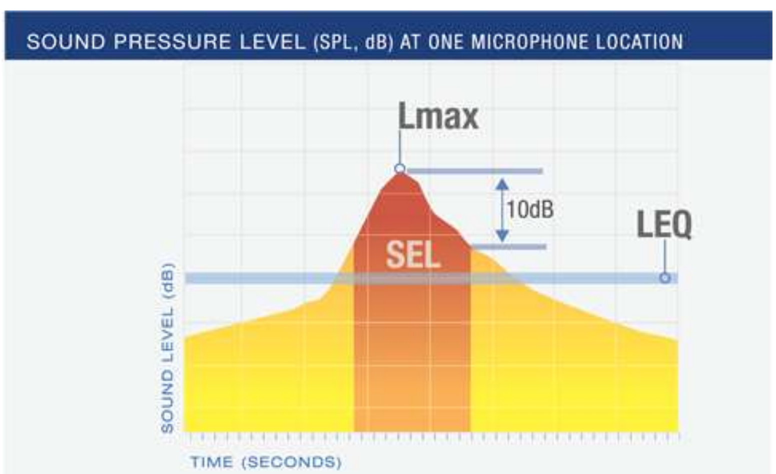
Frequency weighting networks provide a simpler approach for weighting the importance of different frequency components in one single number rating. The A-weighting is most commonly used and is intended to approximate the frequency response of our hearing system. It weights lower frequencies as less important than mid- and higher-frequency sounds. Cweighting is also quite common and is a nearly flat frequency response with the extreme high and low frequencies attenuated. When no frequency analysis is possible, the difference between A-weighted and C-weighted levels gives an indication of the amount of low frequency content in the measured noise. When the sound has an obvious tonal content, a correction to account for the additional annoyance may be used (ISO 1987b).

Because the frequency response of human hearing changes with amplitude, three weightings have been established for measuring sound pressure: A, B and C. A-weighting applies to sound pressures levels up to 55 dB, B-weighting applies to sound pressures levels between 55 dB and 85 dB, and C-weighting is for measuring sound pressure levels above 85 dB.

In order to distinguish the different sound measures a suffix is used: A-weighted sound pressure level is written either as dB_A or L_A. B-weighted sound pressure level is written either as dB_B or L_B, and C-weighted sound pressure level is written either as dB_C or L_C. Unweighted sound pressure level is called "linear sound pressure level" and is often written as dB_L or just L. Some sound measuring instruments use the letter "Z" as an indication of linear SPL.

3. Individual noise events (L_{Amax}) and Sound Exposure Level (SEL)

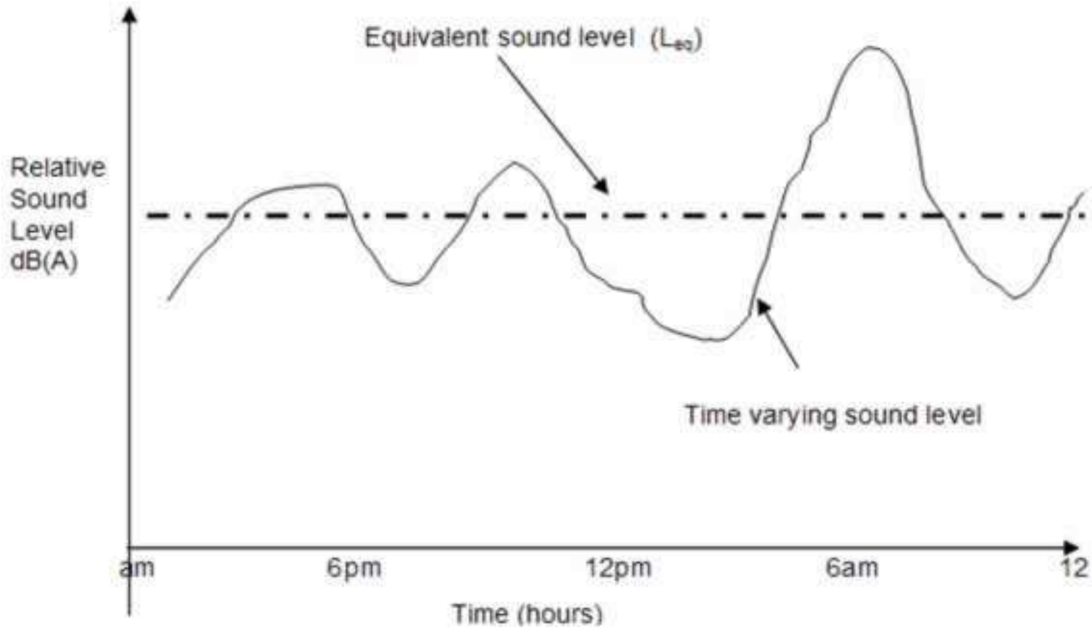
It is often desired to measure the maximum level (LAmax) of individual noise events. For cases such as the noise from a single passing vehicle, LAmax values should be measured using the Fast response time because it will give a good correlation with the integration of loudness by our hearing system. However, for very short-duration impulsive sounds it is often desirable to measure the instantaneous peak amplitude to assess potential hearing-damage risk. If actual instantaneous pressure cannot be determined, then a time-integrated 'peak' level with a time constant of no more than 0.05 ms should be used (ISO 1987b). Such peak readings are often made using the C- (or linear) frequency weightings. Alternatively, discrete sound events can be evaluated in terms of their A-weighted sound exposure level (SEL, for defintion see appendix 5). The total amount of sound energy in a 23 particular event is assessed by the SEL. One can add up the SEL values of individual events to calculate a LAeq,T over some time period, T, of interest. In some cases the SEL may provide more consistent evaluations of individual noise events because they are derived from the complete history of the event and not just one maximum value. However, A-weighted SEL measurements have been shown to be inadequate for assessing the (perceived) loudness of complex impulsive sounds, such as those from large and small weapons (Berglund et al. 1986). In contrast, C-weighted SEL values have been found useful for rating impulsive sounds such as gun shots (Vos 1996; Buchta 1996; ISO 1987b).



CUMULATIVE EVENT MATRIX SOUND LEVEL

1. Equivalent continuous sound pressure level

According to the equal energy principle, the effect of a combination of noise events is related to the combined sound energy of those events. Thus, measures such as the equivalent continuous sound pressure level (LAeq,T) sum up the total energy over some time period (T) and give a level equivalent to the average sound energy over that period. Such average levels are usually based on integration of A-weighted levels. Thus LAeq,T is the average energy equivalent level of the A-weighted sound over a period T.



2. CNEL (Community Noise Equivalent Level)

CNEL is a single number result that is calculated for a complete 24-hour period and usually made up of results taken at shorter intervals such as 5 minutes or 1 hour and then averaged over the whole 24 hours.

CNEL is the average sound level over a 24 hour period, with a penalty of 5 dB added between 7 pm and 10 pm. and a penalty of 10 dB added for the nighttime hours of 10 pm to 7 am.

1.4 SOUND MEASURING INSTRUMENTS

Many types of measuring systems can be used for the measurement of sound depending on the purpose of the study, the characteristics of sound and the extent of information that is desired about the sound.

The various elements in a measuring system are:

a) The transducer; that is, the microphone;

b) The electronic amplifier and calibrated attenuator for gain control;

c) The frequency weighting or analyzing possibilities;

d) The data storage facilities;

e) The display.

Not all elements are used in every measuring system. The microphone can, for instance, be connected to a sound level meter or directly to a magnetic tape recorder for data storage and future measurement or reference.

The two main characteristics are:

1. The frequency response: that is, the deviation between the measured value and the true value as a function of the frequency. As the ear is capable of hearing sounds between 20 Hz and 20 kHz, the frequency response of the sound level meter should be good, with variations smaller than 1 dB, over that range.

2. The dynamic range: that is, the range in dB over which the measured value is proportional to the true value, at a given frequency (usually 1000 Hz). This range is limited at low levels by the electrical background noise of the instrument and at high levels by the signal distortion caused by overloading the microphone or amplifiers.

MICROPHONES

The microphone is the interface between the acoustic field and the measuring system. It responds to sound pressure and transforms it into an electric signal which can be interpreted by the measuring instrument (e.g. the sound level meter). The best instrument cannot give a result better than the output from the microphone. Therefore, its selection and use must be carefully carried out to avoid errors. When selecting a microphone, its characteristics must be known so that its technical performance (e.g. frequency response, dynamic range, directivity, stability), in terms of accuracy and precision, meets the requirements of the measurement in question, taking into account the expected conditions of use (e.g. ambient temperature, humidity, wind, pollution). The microphone can be of the following types: piezoelectric, electromagnetic, and electrostatic.

The Sensitivity of a Microphone: The sensitivity of a microphone is defined as the amplitude (in mV) of the output signal for an incident sound pressure of amplitude 1 Pa (94 dB) at 1000 Hz. It can also be expressed in decibels by the following expression:

$$Sensitivity = 20\log_{10}\frac{Vp_0}{V_0 p} \quad \text{dB}$$

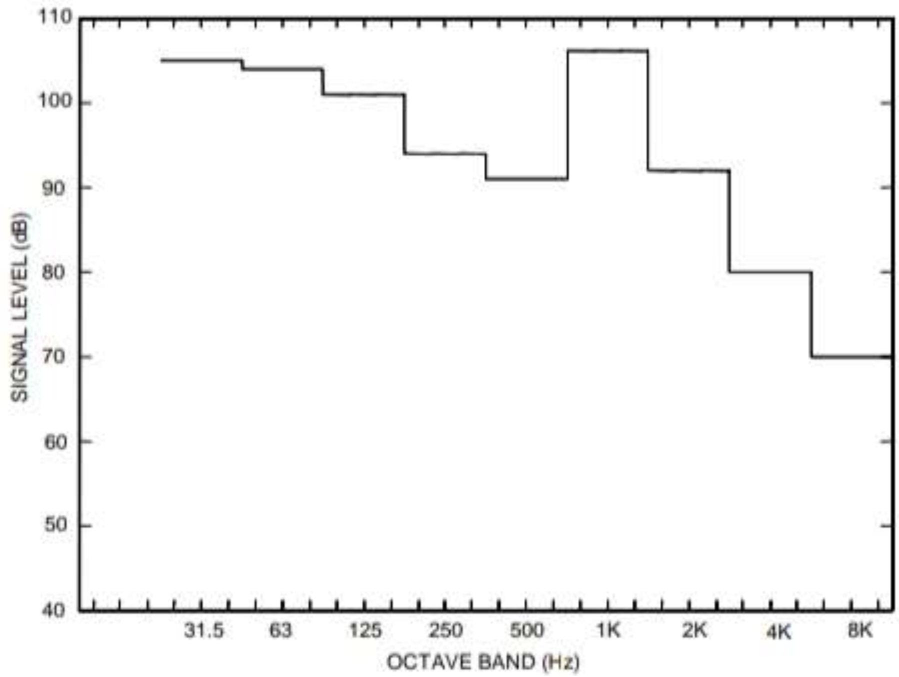
Thus, a microphone giving an output signal V of 10 mV for a pressure signal p of 94 dB has a sensitivity of 10 mV/Pa or -40 dB. Here p0 = 1Pa and V0 = 1 volt.

Frequency Response: Good quality piezoelectric or condenser microphones have usually flat frequency response characteristics from 2 Hz to an upper limit which depends on their size. This limit is about 2 kHz for a 1" diameter microphone, 4 kHz for a 1/2" and 8 kHz for a 1/4" microphone.

Dynamic Range: High sensitivity microphones are needed to measure very low noise levels (lower than 30 dB), and low sensitivity ones have to be used for high noise levels such as for impact noise (above 130 Sound measuring instruments 129 dB). The dynamic range of typical good quality microphones is thus between 100 and 120 dB.

FREQUENCY ANALYZERS

Description The objective of frequency analysis is to determine how the overall level is distributed over a range of frequencies. The most usual analysis for occupational hygiene noise studies is octave band analysis.



RECORDERS

1. Graphic Level Recorder: If the sound level meter has a logarithmic DC output facility, common graphic recorders can be used to obtain a permanent record of the evolution of the sound level, providing that their writing speed is compatible with the SLOW or FAST characteristics of the SLM. If there is no DC output or if this output is not proportional to the dB level but only to the RMS pressure, then a special recorder must be used.

2. Magnetic Tape Recorders: Magnetic tape recorders are used to make a permanent recording of the noise for future analysis or reference. For general surveys, small recorders with a frequency response of + 3 dB in the range 30 Hz to 16 kHz and a dynamic range of 40 dB may be sufficient. For precise measurements and frequency analyses, higher quality instrumentation is needed.

Some of the instruments used are,

I. SOUND LEVEL METERS

The electrical signal from the transducer is fed to the pre-amplifier of the sound level meter and, if needed, a weighted filter over a specified range of frequencies. Further amplification prepares the signal either for output to other instruments such as a tape recorder or for rectification and direct reading on the meter. The rectifier gives the RMS value of the signal. The RMS signal is then exponentially averaged using a time constant of 0.1 s ("FAST") or 1 s ("SLOW") and the result is displayed digitally or on an analog meter.

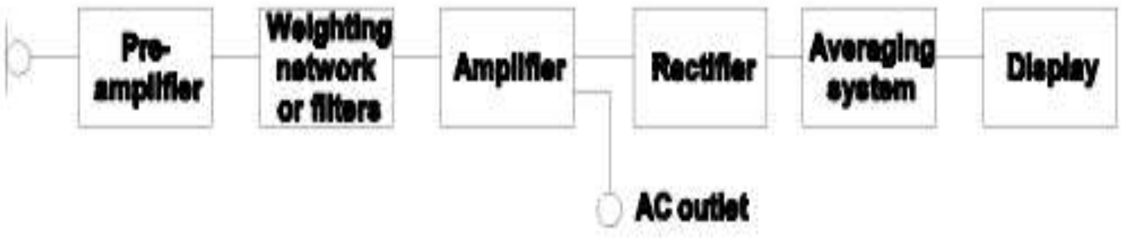


Figure 6.1. Sound level meter block diagram

The specifications of sound level meters are given in IEC 60651 for four types 0, 1, 2, 3 differing by the measurement precision. The type 0 sound level meters is intended as a laboratory reference standard. Type 1 is intended especially for laboratory use and for field use where the acoustical environment has to be closely specified and controlled. The type 2 sound level meter is suitable for general field applications. Type 3 is intended primarily for field noise survey applications.

II. NOISE DOSIMETERS

The need to ascertain the noise exposure of workers during their normal working day, has led to the development of the noise dosimeter. This is a small, light and compact instrument to be worn by the worker. It measures the total A-weighted sound energy received and expresses it as a proportion of the maximum A-weighted energy that can be received per day. This instrument is particularly useful whenever the exposure varies appreciably during the working day.

III. PERSONAL SOUND LEVEL METERS

Personal sound level meters are in fact integrating sound level meters designed as dosimeters in order to be worn by the worker during his regular work. These instruments make it possible to record on almost any increment of time the equivalent level, the peak level or any statistical parameter. Typically it will record the LAeq,T (in dB(A)) and Lpeak (in dB) every second. This is extremely interesting as it makes it possible to analyse the evolution of the noise exposure during the day and to correlate it to the type of work or the location of the worker.

1.5 PROPOGATION OF SOUND

Sound is a vibration that propagates as an acoustic wave, through a transmission medium such as a gas, liquid or solid.

Sound is pictorially represented by a continuous succession of peaks and valleys. The distance between two consecutive peaks or trough is termed as the wavelength of the wave or the period. The number of cycles per unit time is termed as the frequency of the sound. Frequency is measured in cycles per second or Hertz.

The faster an object vibrates, i.e. the higher the frequency, then the higher the pitch of the sound. The difference between a man’s voice and women must be clearly evident to you. The voice of a man has a lower frequency which contributes to the deepness of the bass in the voice. Women, in contrast, have a voice with higher frequency resulting in a higher shrillness or pitch.

Acoustics looks first at the pressure levels and frequencies in the sound wave and how the wave interacts with the environment. This interaction can be described as either a diffraction, interference or a reflection or a mix of the three. If several media are present, a refraction can also occur. Transduction processes are also of special importance to acoustics.

Speed of Sound

The speed of a sound wave is affected by the type of medium through which it travels. Sound waves travel the fastest in solids due to the proximity of molecules. Likewise, sound waves travel slowest in gases because gases are spread far apart from one another. The state of the medium through which sound travels is not the only factor that affects a sound's speed. Speed of a sound wave can also be affected by the density, temperature, and elasticity of the medium through which the sound waves travel. The propagation of the sound wave is not possible through the vacuum. The medium here can be gas, liquid or solid. The speed of sound when it is travelling through a medium depends on the type of medium. The speed of sound when travelling through air is 343 m/s or 1,235 km/h.

Can Sound Travel in Space?

A medium is essential for the propagation of sound. Sound cannot travel through a vacuum due to the fact that there are no molecules that can be compressed and expanded in space. Our voice is produced by the vibration of strings known as the vocal cords which is inside Adam's apple. When you make a sound, its vibration travels through the air and when it reaches your brain through your ears, it is interpreted as sound.

Human Hearing and Speech

Humans can hear sounds ranging from 20 Hz to 20 kHz. Sounds with frequencies above the range of human hearing are called ultrasound. Sounds with frequencies below the range of human hearing are called infrasound. The typical sounds produced by human speech have frequencies in the order of 100 to 1,000 Hz.

Physical factors that affect sound propagation

Following are a few factors that affect the propagation of sound:

1. Velocity Gradient: If the atmosphere in which the sound wave is travelling is turbulent, sound waves would scatter due to velocity fluctuations of the medium.

2. Wind Gradient: Sound propagating along the wind would bend downwards while sound propagating against the wind would bend upwards.

3. Temperature Gradient: Sound waves travel faster in a warm atmosphere near the surface of the earth. Here, there is an upward refraction of sound waves. In case of a decrease in temperature at higher altitudes, the refraction would be downwards.

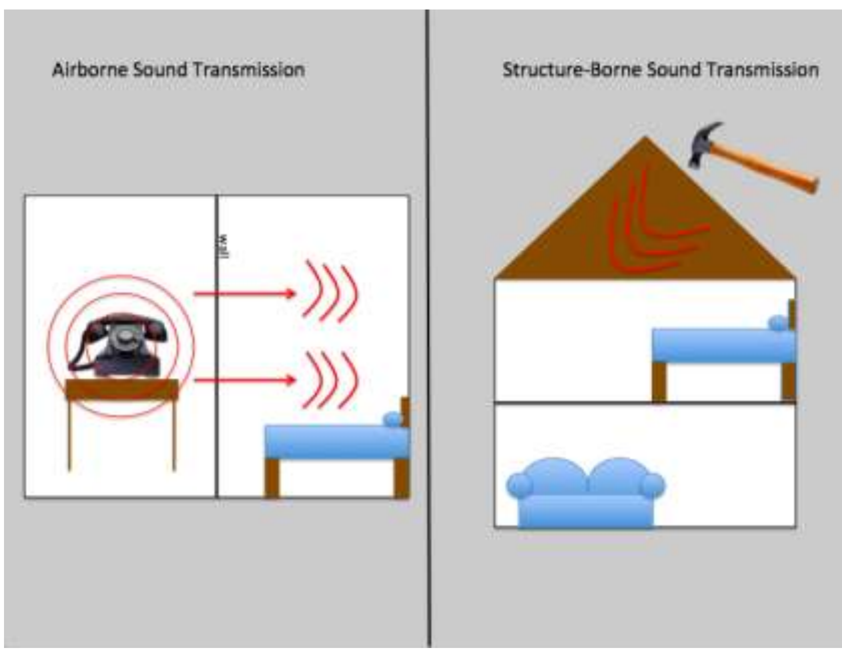
1.6 SOUND TRANSMISSION IN CIVIL STRUCTURES

Airborne Sound

This type of noise is transmitted by air and atmosphere such as the radio, the barking of dogs or people carrying on conversations. When sound waves traveling through the air reach a building element they hit it and cause it to vibrate. These vibrations travel through the structure or building and are radiated out the other side. Have you ever been inside of your quiet home as a loud party takes place next door or even down the street? It may have felt as if the music was reverberating loudly within your house. This is due to airborne noise traveling through windows and doors which are a major source of sound leakage.

Structure-Borne Sound

Structure-borne noises are transmitted when sound arises from the actual impact of an object on a building element such as a wall, floor or ceiling. For example, say you live below someone else in an apartment complex or you live in a two-story house. Whenever you hear someone's footsteps above you, you're hearing structure-borne noise.Structure-borne sound occurs because the impact causes both sides of the building element to vibrate, generating sound waves. This can oftentimes be the hardest to isolate.



Sound transmission Into and Within Buildings

Sources of environmental noise are usually located outdoors; for example, road traffic, aircraft or trains. However, people exposed to these noises are often indoors, inside their home or some other building. It is, therefore, important to understand how environmental noises are transmitted into buildings. Most of the same fundamentals discussed earlier apply to airborne sound propagation between homes in multifamily dwellings, via common walls and floors. However, within buildings we can also consider impact sound sources, such as footsteps, as well as airborne sounds.

The amount of incident sound that is transmitted through a building façade is measured in terms of the sound reduction index. The sound reduction index, or transmission loss, is defined as 10 times the logarithm of the ratio of incident-to-transmitted sound power, and it describes in decibels how much the incident sound is reduced on passing through a particular panel. This index of constructions usually increases with the frequency of the incident sound and with the mass of the construction. Thus, heavier or more massive constructions tend to have higher sound reductions. When it is not possible to achieve the desired transmission loss by increasing the mass of a panel, increased sound reduction can be achieved by a double panel construction. The two layers should be isolated with respect to vibrations and there should be sound absorbing material in the cavity. Such double panel constructions can provide much greater sound reduction than a single panel. Because sound reduction is also greater at higher frequencies most problems occur at lower frequencies, where most environmental noise sources produce relatively high sound pressure levels.

The sound reduction of most real building façades is determined by a combination of several different elements. For example, a wall might include windows, doors or some other type of element. If the sound reduction index values of each element are known, the values for the combined construction can be calculated from the area-weighted sums of the sound energy transmitted through each separate element. Although parts of the building façade, such as massive wall constructions, can be very effective barriers to sound, the sound reduction index of the complete façade is often greatly reduced by less effective elements such as windows, doors or ventilation openings. Completely open windows as such would have a sound reduction index of 0 dB.

TRANSMISSION OF SOUND THROUGH STRUCTURES

Basic Definitions

A typical noise control application involves a combination of absorption of sound and transmission of sound energy by a variety of airborne and structure-borne paths.

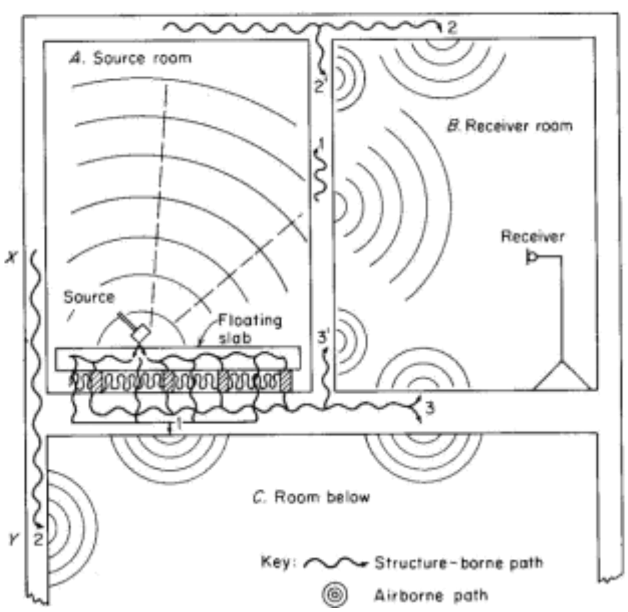
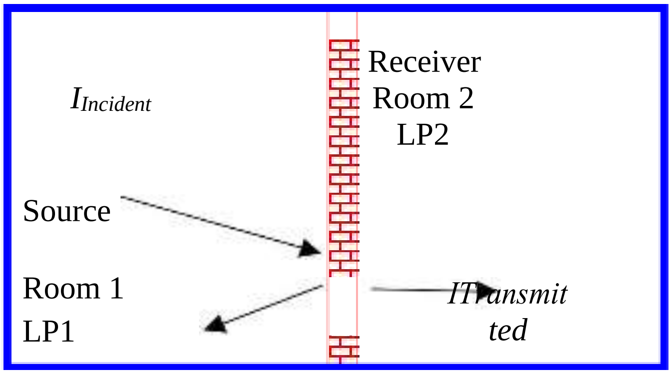


Figure 1. Sound transmission paths between a room containing a noise source and adjacent rooms

IReflected

When sound strikes a partially absorbing partition between two rooms, some is reflected back into room, some transmits into adjacent room

NR = Noise Reduction = LP1-LP2 (easy to measure)



What is the difference between an absorbing material and a barrier material?

The two important noise-related quantities of a material are:

- Ability to absorb acoustic energy – **α**
- Ability to reflect or block sound energy - **STL** or **τ**

Good absorbing materials allow sound pressure fluctuations to enter their surface and dissipate energy by air friction. They are generally porous and lightweight, such as fiberglass, open cell foam, or acoustical ceiling tiles. Good barrier materials reflect sound, and are dense and non-porous (concrete, lead, steel, brick, glass, gypsum board). In general, a single homogeneous material will not be both a good absorber and a barrier. As shown in Table 1, fiberglass insulation makes a terrible barrier, and a sealed concrete wall has virtually no absorption. To get the best of both worlds, it is common to see an absorbing layer laminated to a barrier material, for instance a layer of gypsum board and a layer of fiberglass, or loaded vinyl laminated to open cell foam.

Table 1. Comparison of various material noise properties at 1000 Hz

Material	**Absorption α**	**Transmission τ**
Concrete Cinder Block (painted)	.07 very low	.0001 (STL=40) high
2” Fiberglass	.90 high	~1.0 very low

1.7 VIBRATION

A motion which repeats itself after a regular interval of time is known as Vibration.

Characteristics of Vibration

1. Cycle: The motion which is repeated is called a cycle.

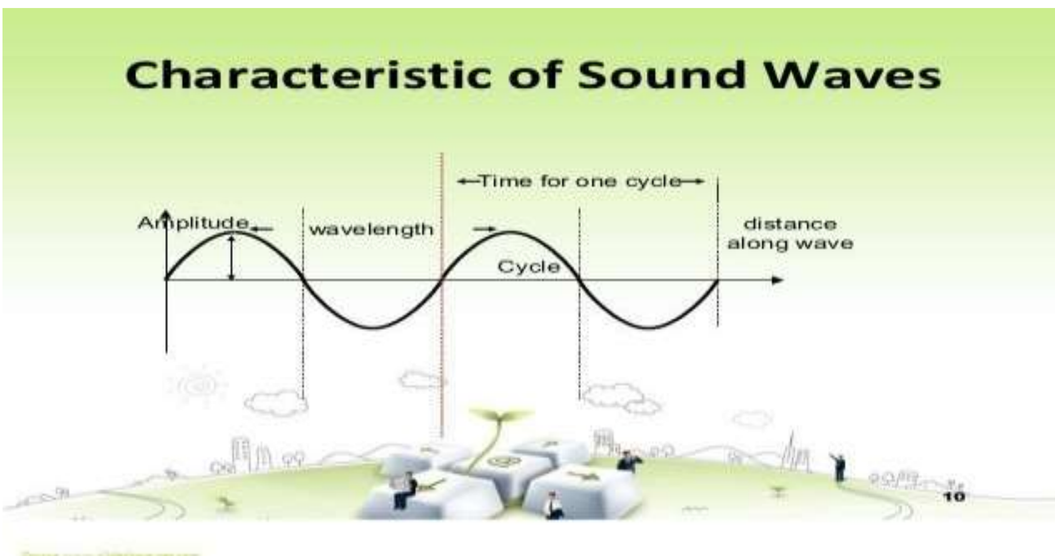
2. Amplitude: The maximum displacement from mean position is known as amplitude.

3. Wave length (λ): The horizontal length of one wave is known as wave length.

4. Time Period (T): It is the time taken to complete one cycle

5. Frequency (f): It is defined as the number of cycles per second.

$$f = 1/T$$



Classification of Vibration

1. Free and Forced Vibration

2. Damped and Undamped Vibration

3. Linear and Non-linear Vibration

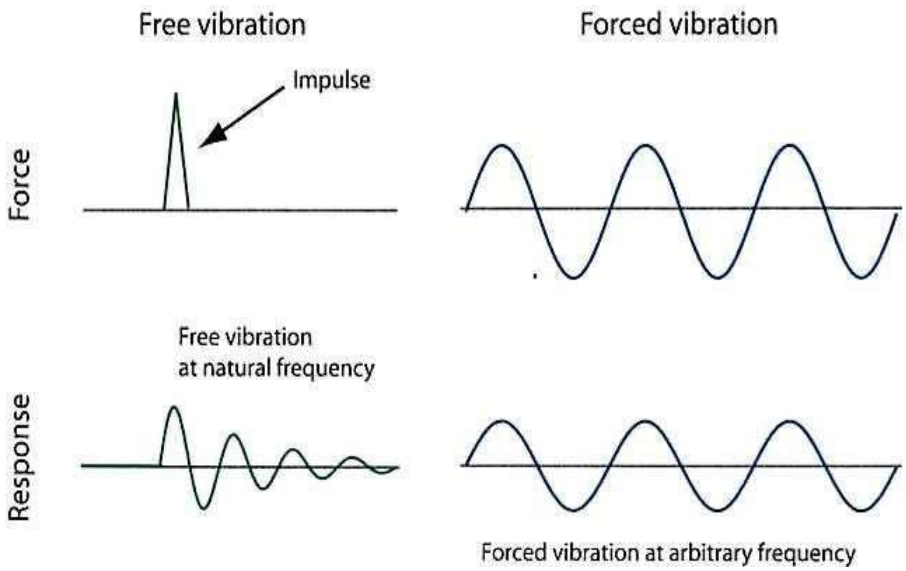
4. Deterministic and Random Vibration

Free Vibration is again classified as Longitudinal, Transverse and Torsional Vibration

CLASSIFICATION OF VIBRATION

Free vibration: If a system, after an initial disturbance is left to vibrate on its own, the ensuing vibration is known as free vibration. No external force acts on the system. The oscillation of a simple pendulum is an example of free vibration.

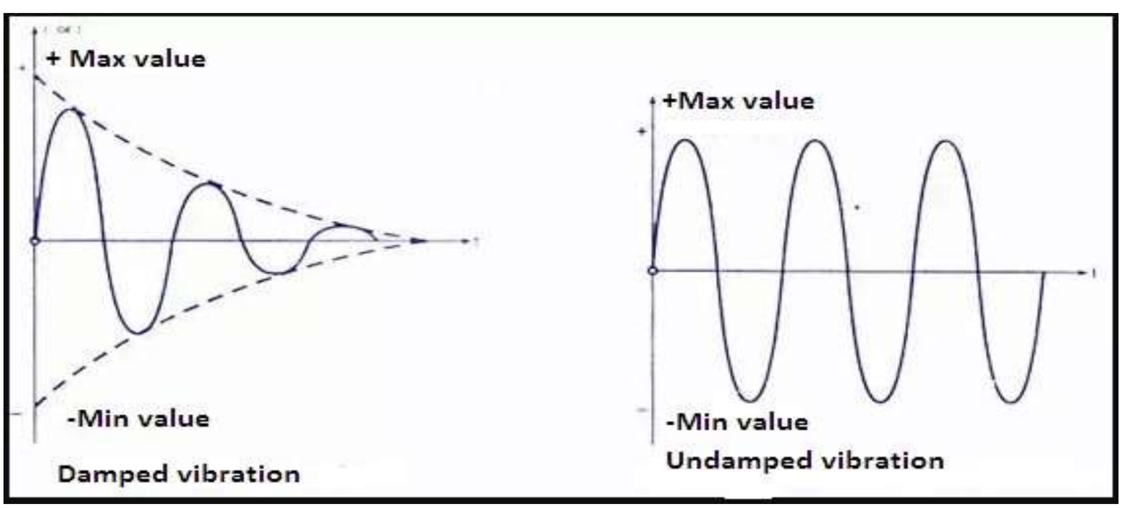
Forced vibration: If a system is subjected to an external force (often a repeating type of force), the resulting vibration is known as forced vibration.



If the frequency of the external force coincides with one of the natural frequencies of the system, a condition known as resonance occurs, and the system undergoes dangerously large oscillations. Failures of such structures as buildings, bridges, turbines, and airplane wings have been assoicated with then occurrence of resonance.

Undamped vibration: If no energy is lost or dissipated in friction or other resistance during oscillation, the vibration is known as undamped vibration.

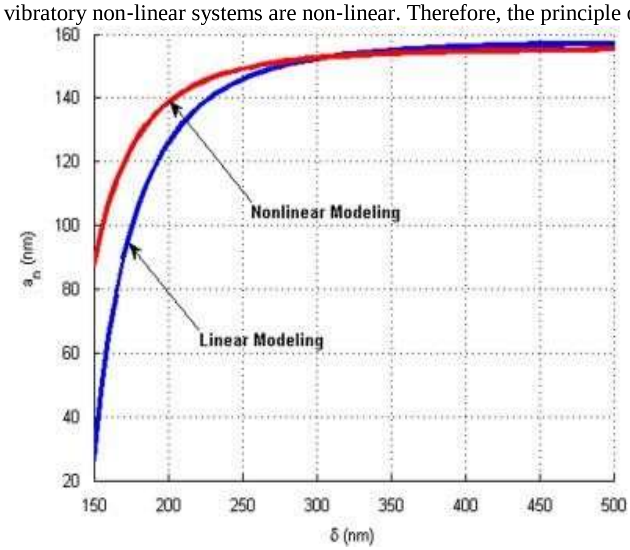
If any energy is lost in this way however, it is called **damped vibration.**



While the spring forms a physical model for storing kinetic energy and hence causing vibration, the dashpot, or damper, forms the physical model for dissipating energy and damping the response of a mechanical system. A dashpot consists of a piston fit into a cylinder filled with oil. This piston is perforated with holes so that motion of the piston in the oil is possible. The laminar flow of the oil through the perforations as the piston moves causes a damping force on the piston.

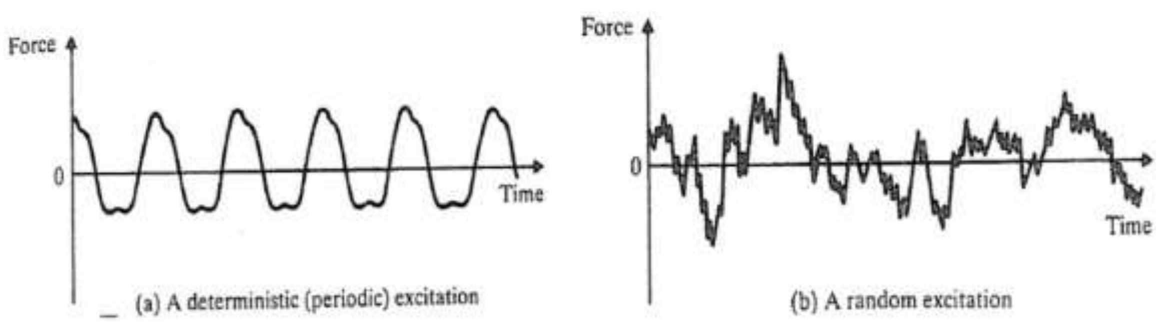
Linear vibration: If all the basic components of a vibratory system-the spring, the mass, and the damper, behave linearly, the resulting vibration is known as linear vibration. The differential equations that govern the behaviour of vibratory linear systems are linear. Therefore, the principle of superposition holds.

Nonlinear vibration: If however, any of the basic components behave nonlinearly, the vibration is called 'nonlinear vibration'. The differential equations that govern the behaviour of vibratory non-linear systems are non-linear. Therefore, the principle of superposition does not hold



Deterministic vibration: If the value or magnitude of the excitation (force or motion) acting on a vibratory system is known at any given time, the excitation is called 'deterministic'. The resulting vibration is known as 'deterministic vibration'.

Nondeterministic vibration: In some cases, the excitation is non-deterministic or random; the value of excitation at a given time cannot be predicted. In these cases, a large collection of records of the excitation may exhibit some statistical regularity. It is possible to estimate averages such as the mean and mean square values of the excitation.



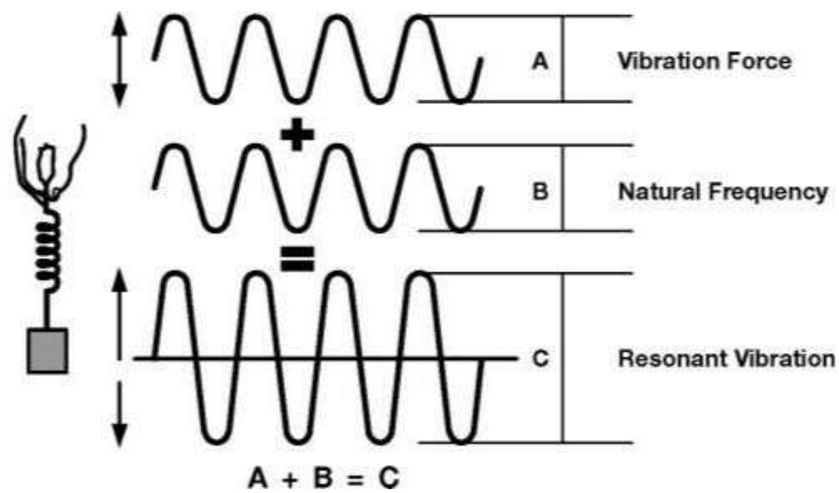
1.8 RESONANCE

Resonance occurs when the vibrating force (external force) on a vibrating system is moving at the same frequency (Hz) as the natural frequency of that vibrating system. Fig. 1-15 shows the wave form of the natural frequency of the system and the wave of the vibrating force at the same frequency. The resulting wave that occurs is at the same frequency but with much greater amplitude.

This is a significant phenomenon in a vehicle because the increased level is sensed by the customer and perceived (aware) to be a problem.

Resonance

Fig. 1-16

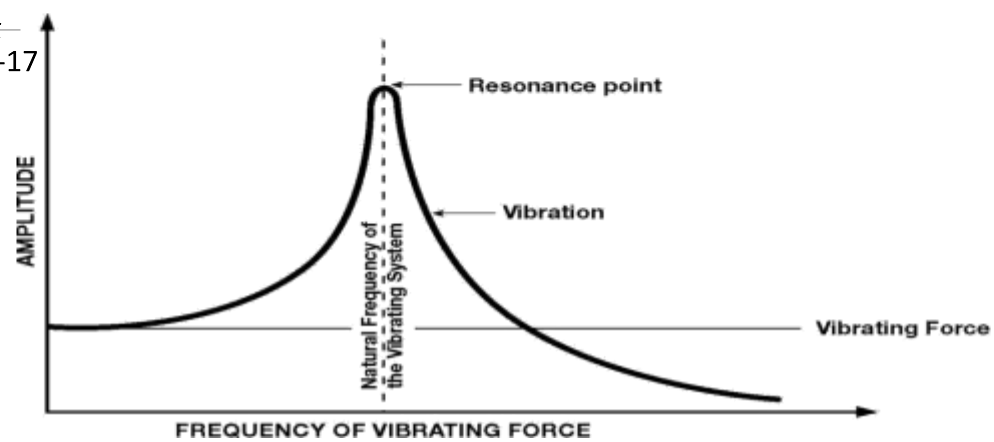


The frequency (Hz) at which this occurs is the •resonance point".

The amplitude (dBg) of the vibrating system increases dramatically when the resonance point is reached.

Resonance Point

Fig. 1-17

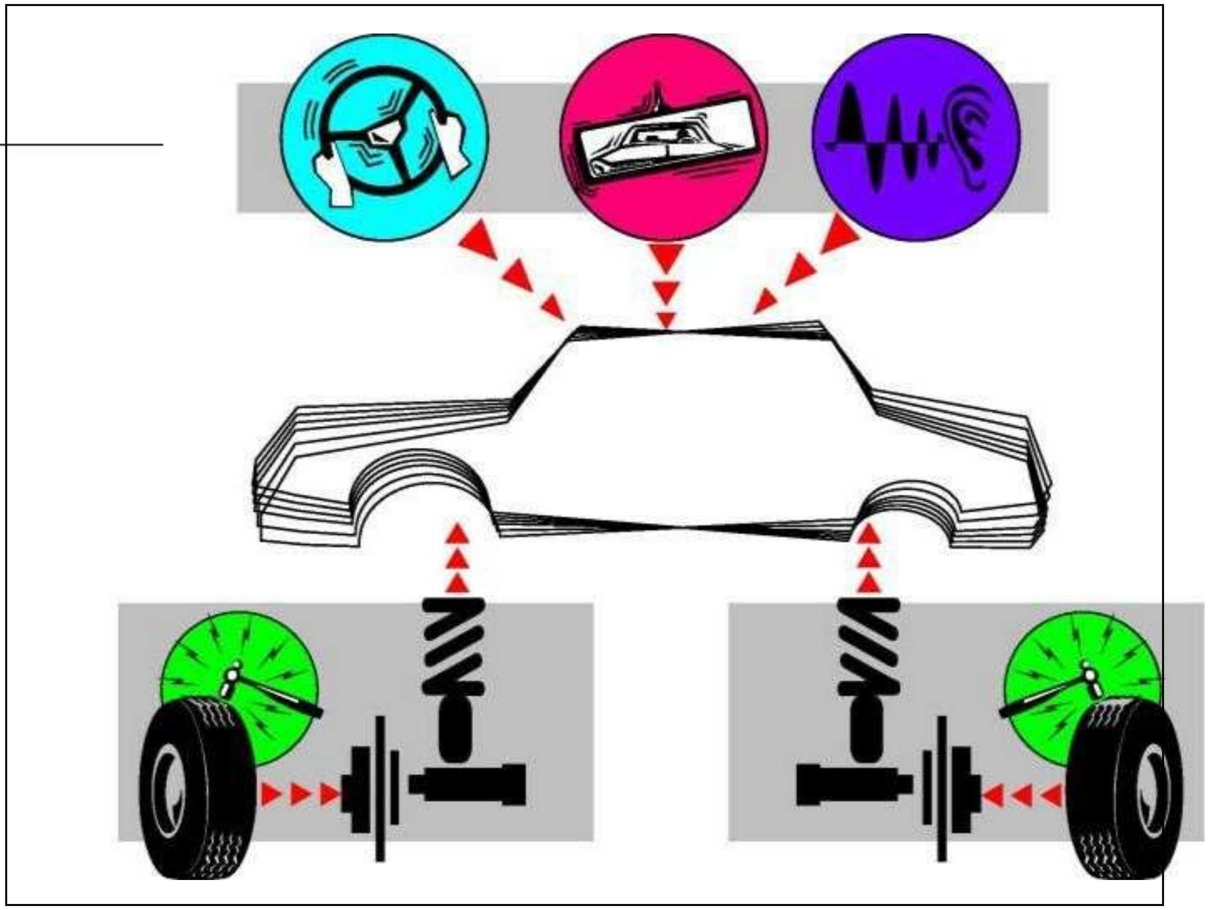


1.9 HARSHNESS

Harshness is the condition a customer senses when a vehicle contacts a single impact such as road irregularities, railroad tracks or speed bumps.

The level of impact that the customer senses depends on the type of suspension used on a vehicle. A sports car suspension system is designed for handling and to give the driver a good •feel of the road". A luxury vehicle is designed to provide the most comfortable ride possible, insulating the driver from unpleasant sensations.

A harshness complaint is relative to the type of vehicle involved and should be compared to other vehicles of the same type.

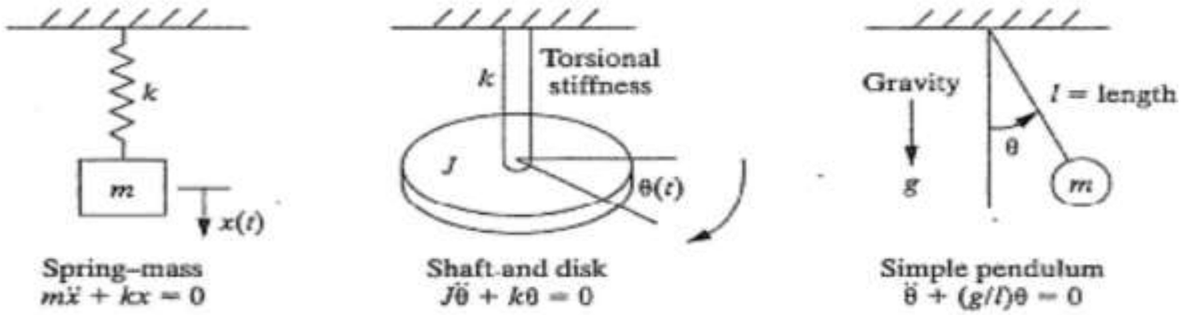


A vibration analyzer will not be the primary tool used to diagnose a harshness complaint because the incident is momentary and difficult to isolate. In addition, the source causing the disturbance is already known and cannot be controlled. What has usually changed, causing the concern, is the transmission system or path.

A good visual inspection starting at the location in the vehicle where the symptom seems to originate will usually identify the component that has changed or deteriorated.

1.10 DEGREES OF FREEDOM

The minimum number of independent coordinates required to determine completely the positions of all parts of a system at any instant of time defines the degree of freedom of the system. A single degree of freedom system requires only one coordinate to describe its position at any instant of time.

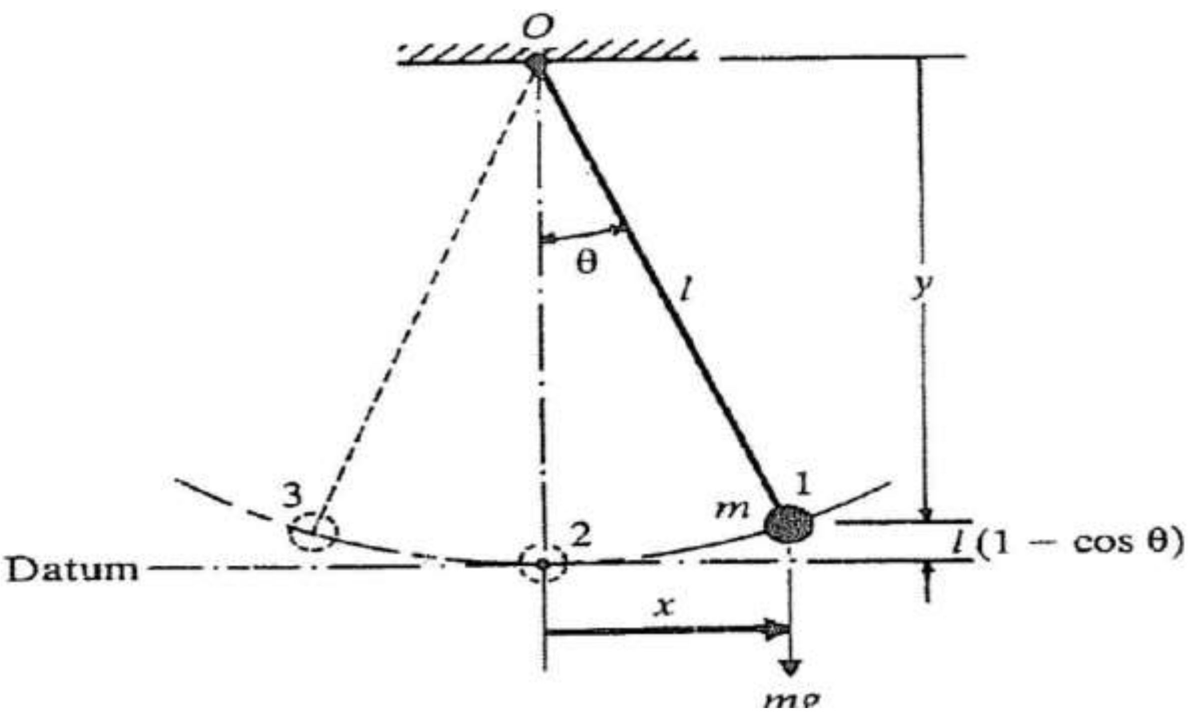


SINGLE DEGREE OF FREEDOM SYSTEM

For the simple pendulum in the figure, the motion can be stated either in terms of θ or x and y. If the coordinates x and y are used to describe the motion, it must be recognized that these coordinates are not independent. They are related to each other through the relation

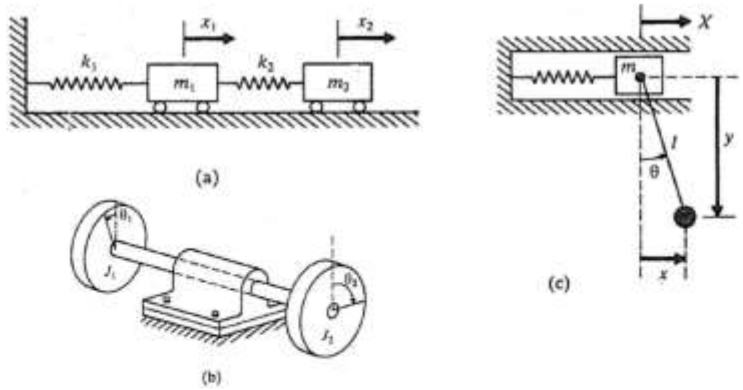
2 + y2 = l 2

Where l is the constant length of the pendulum. Thus any one coordinate can describe the motion of the pendulum. In this example, we find that the choice of θ as the independent coordinate will be more convenient than the choice of x and y.



TWO DEGREE OF FREEDOM SYSTEM

Some examples of two degree of freedom systems are shown in the figure. The first figure shows a two



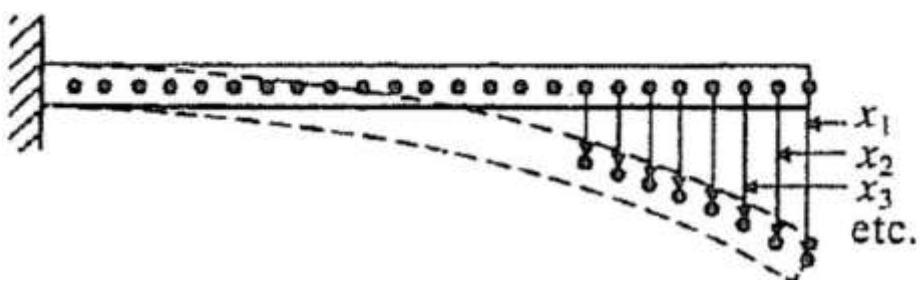
mass – two spring system that is described by two linear coordinates x1 and x2. The second figure

denotes a two rotor system whose motion can be specified in terms of θ1 and θ2. The motion of the system in the third figure can be described completely either by X and θ or by x,y and X.

DISCRETE AND CONTINUOUS SYSTEMS

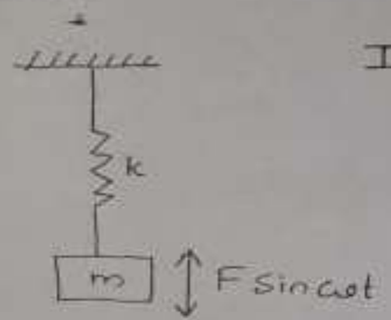
A large number of practical systems can be described using a finite number of degrees of freedom, such as the simple system shown in the previous slides.

Some systems, especially those involving continuous elastic members, have an infinite number of degrees of freedom as shown in the figure. Since the beam in the figure has an infinite number of mass points, we need an infinite number of coordinates to specify its deflected configuration. The infinite number of coordinates defines its elastic deflection curve. Thus, the cantilever beam has infinite number of degrees of freedom.



1.11

Response of Undamped Vibration under Harmonic Force:-



Inertia force + Spring Force = Harmonic Force

$$m\ddot{x} + kx = F\sin\omega t$$

This is the equation of motion of undamped vibration under force.

Let us taken the solution,

$$x = CF + PI$$

CF

Let $m\ddot{x} + kx = 0$

$$\ddot{x} + \frac{k}{m}x = 0$$

$$\frac{d^2x}{dt^2} + \frac{k}{m}x = 0 \qquad D^2 = \frac{d^2}{dt^2}$$

$$D^2x + \frac{k}{m}x = 0 \qquad \frac{k}{m} = \omega_n^2$$

$$\left(D^2 + \frac{k}{m}\right)x = 0$$

$$D^2 + \frac{k}{m} = 0 \Rightarrow D^2 = -\frac{k}{m}$$

$$\Rightarrow D^2 = -\omega_n^2$$

$$D = \pm\sqrt{-\omega_n^2} = \pm i\omega_n$$

$$\therefore CF = e^{0t}\left[C_1\cos\omega_n t + C_2\sin\omega_n t\right]$$

$$CF = C_1\cos\omega_n t + C_2\sin\omega_n t$$

PI

$$PI = \frac{1}{D^2 + \frac{k}{m}} \times RHS$$

Take, $m\ddot{x} + kx = F\sin\omega t$

$$\ddot{x} + \frac{k}{m}x = \underbrace{\frac{F\sin\omega t}{m}}_{RHS}$$

$$\therefore PI = \frac{1}{D^2 + \frac{k}{m}} \times \frac{F\sin\omega t}{m}$$

Put $D^2 = -\omega^2$

$$= \frac{1}{D^2 + \omega_n^2} \times \frac{F}{m}\sin\omega t$$

$$= \frac{F}{m} \times \frac{1}{-\omega^2 + \omega_n^2}\sin\omega t$$

$$= \frac{F}{m} \times \frac{1}{\omega_n^2 - \omega^2} \times \sin\omega t$$

$\frac{\omega}{\omega_n} = r$ where r is frequency ratio

$$= \frac{F}{m\omega_n^2} \times \frac{1}{\left(1 - \frac{\omega^2}{\omega_n^2}\right)}\sin\omega t$$

$$= \frac{F}{m\omega_n^2(1-r^2)}\sin\omega t$$

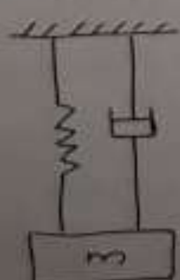
$\therefore$ Total Response,

$$x = CF + PI$$

$$x = \left[C_1\cos\omega_n t + C_2\sin\omega_n t\right] + \frac{F\sin\omega t}{m\omega_n^2(1-r^2)}$$

1.12

Response of Damped Vibration Under Harmonic Force:-



Inertia force + Damping force + Spring Force = Harmonic Force

$$m\ddot{x} + c\dot{x} + kx = F\sin\omega t$$

This is the equation of motion

Let us take, $x = CF + PI$

CF

$$m\ddot{x} + c\dot{x} + kx = 0$$

$$\ddot{x} + \frac{c}{m}\dot{x} + \frac{k}{m}x = 0$$

$$\frac{d^2x}{dt^2} + \frac{c}{m}\frac{dx}{dt} + \frac{k}{m}x = 0$$

$$D^2x + \frac{c}{m}Dx + \frac{k}{m}x = 0$$

$$\left(D^2 + \frac{c}{m}D + \frac{k}{m}\right)x = 0$$

$$D^2 + \frac{c}{m}D + \frac{k}{m} = 0$$

$D = \frac{d}{dt}$

$D^2 = \frac{d^2}{dt^2}$

$$D = \frac{-\frac{c}{m} \pm \sqrt{\left(\frac{c}{m}\right)^2 - 4\times 1\times \frac{k}{m}}}{2\times 1} = -\frac{c}{2m} \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{4k}{4m}}$$

$$= -\frac{c}{m} \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \omega_n^2}$$

$\frac{k}{m} = \omega_n^2$

$$\therefore CF = C_1 e^{\left[-\frac{c}{m} + \sqrt{\left(\frac{c}{2m}\right)^2 - \omega_n^2}\right]t} + C_2 e^{\left[-\frac{c}{m} - \sqrt{\left(\frac{c}{2m}\right)^2 - \omega_n^2}\right]t}$$

PI

$$m\ddot{x} + c\dot{x} + kx = F\sin\omega t$$

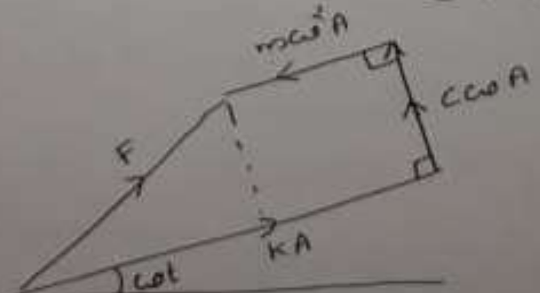
Let $x = A\sin\omega t$

$\dot{x} = A\omega\cos\omega t$

$\ddot{x} = -A\omega^2\sin\omega t$

$$m(-A\omega^2\sin\omega t) + c(A\omega\cos\omega t) + kA\sin\omega t = F\sin\omega t$$

$$\text{ie } mA\omega^2\sin(\omega t - \pi) + cA\omega\left(\sin\omega t + \frac{\pi}{2}\right) + kA\sin\omega t = F\sin\omega t$$



$$\left[kA - m\omega^2 A\right]^2 + \left[c\omega A\right]^2 = F^2$$

$$A^2 \left(k - m\omega^2\right)^2 + A^2 \left[c\omega\right]^2 = F^2$$

$$A^2 \left[\left(k - m\omega^2\right)^2 + \left(c\omega\right)^2\right] = F^2$$

$$A^2 = \frac{F^2}{\left(k - m\omega^2\right)^2 + \left(c\omega\right)^2}$$

Divide ~~and~~ by k^2

$$= \frac{F^2/k^2}{\dfrac{\left(k - m\omega^2\right)^2 + \left(c\omega\right)^2}{k^2}}$$

$$= \frac{F^2/k^2}{\left(1 - \dfrac{m\omega^2}{k^2}\right)^2 + \left(\dfrac{c\omega}{k}\right)^2}$$

Put $\dfrac{c\omega}{k} = 2\varepsilon\dfrac{\omega}{\omega_n} = 2\varepsilon r$

$$\boxed{\frac{m}{k} = \frac{1}{\omega_n^2}}$$

$$= \frac{F^2/k^2}{\left[1 - \left(\dfrac{\omega}{\omega_n}\right)^2\right]^2 + \left(2\varepsilon r\right)^2}$$

$$= \frac{F^2/k^2}{\left(1 - r^2\right)^2 + \left(2\varepsilon r\right)^2}$$

$$\therefore A = \frac{F/k}{\sqrt{\left(1 - r^2\right)^2 + \left(2\varepsilon r\right)^2}}$$

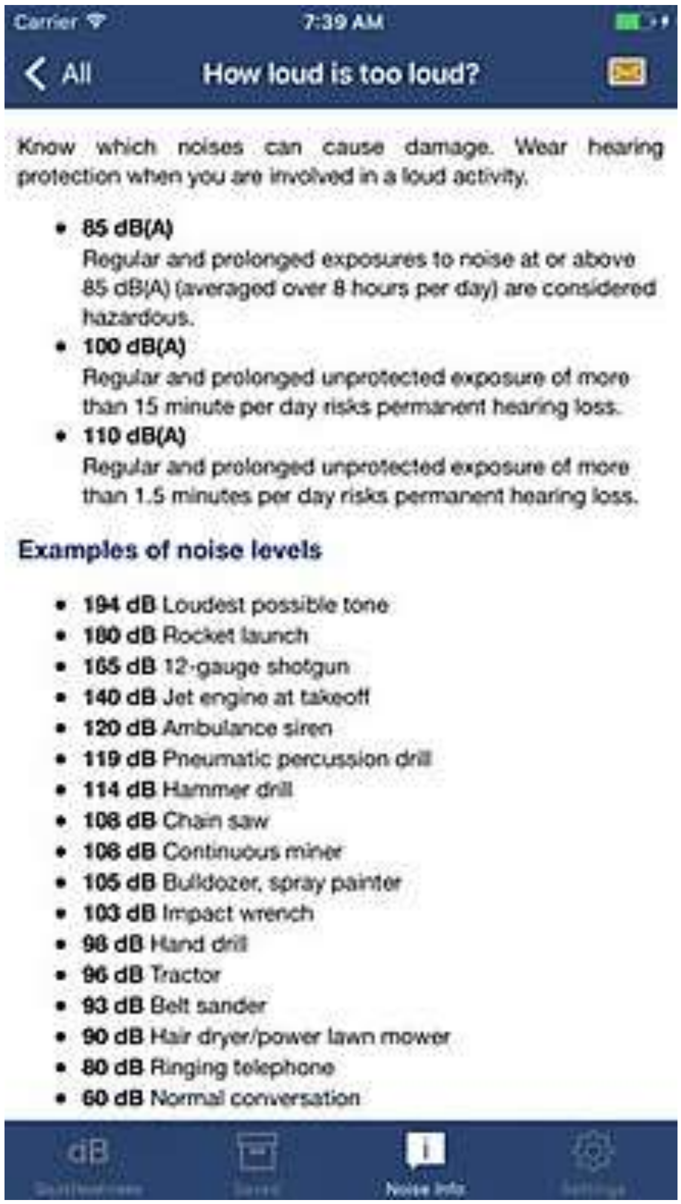
$$\therefore PI = x = A \sin\omega t = \frac{F/k \sin\omega t}{\sqrt{\left(1 - r^2\right)^2 + \left(2\varepsilon r\right)^2}}$$

$\therefore$ So $x = CF + PI$ is the total Response

MODULE 2

Syllabus- Effects of Noise, Blast, Vibration, and Shock on People: General Introduction to Noise and Vibration Effects on People and Hearing Conservation, Noise Exposure, Noise-Induced Annoyance, Effects of Infrasound, Low-Frequency Noise, and Ultrasound on People, Effects of Intense Noise on People and Hearing Loss, Effects of Vibration on People, Effects of Mechanical Shock on People, Rating Measures, Descriptors, Criteria, and Procedures for Determining Human Response to Noise.

2.1 EFFECTS OF NOISE ON PEOPLES



Noise health effects are the physical and psychological health consequences of regular exposure to consistent elevated sound levels. Elevated workplace or environmental noise can cause hearing impairment, tinnitus, hypertension, ischemic heart disease, annoyance, and sleep disturbance. Changes in the immune system and birth defects have been also attributed to noise exposure.

Although age-related health effects (presbycusis) occur naturally with age, in many countries the cumulative impact of noise is sufficient to impair the hearing of a large fraction of the population over the course of a lifetime. Noise exposure has been known to induce noise-induced hearing loss, tinnitus, hypertension, vasoconstriction, and other cardiovascular adverse effects. Chronic noise exposure has been associated with sleep disturbances and increased incidence of diabetes. Adverse cardiovascular effects occur from chronic exposure to noise due to the sympathetic nervous system's inability to habituate. The sympathetic nervous system maintains lighter stages of sleep when the body is exposed to noise, which does not allow blood pressure to follow the normal rise and fall cycle of an undisturbed circadian rhythm.

Stress from time spent around elevated noise levels has been linked with increased workplace accident rates and aggression and other anti-social behaviors. The most significant sources are vehicles, aircraft, prolonged exposure to loud music, and industrial noise.

There are 10,000 deaths per year as a result of noise in the European Union.

Noise Induced Hearing Loss

Noise-induced hearing loss is a permanent shift in pure-tone thresholds, resulting in sensorineural hearing loss. The severity of a threshold shift is dependent on duration and severity of noise exposure. Noise-induced threshold shifts are seen as a notch on an audiogram from 3000–6000 Hz, but most often at 4000 Hz.

Exposure to loud noises, either in a single traumatic experience or over time, can damage the auditory system or result in hearing loss and sometimes tinnitus as well. Traumatic noise exposure can happen at work (e.g. loud machinery), at play (e.g. loud sporting events, concerts, recreational activities), and/or by accident (e.g. a backfiring engine.) Noise induced hearing loss is sometimes unilateral and typically causes patients to lose hearing around the frequency of the triggering sound trauma.

Tinnitus

Tinnitus is an auditory disorder characterized by the perception of a sound (ringing, chirping, buzzing, etc.) in the ear in the absence of an external sound source. There are two types of tinnitus: subjective and objective. Subjective is the most common and can only be heard "in the head" by the person affected. Objective tinnitus can be heard from those around the affected person and the audiologist can hear it using a stethoscope. Tinnitus can also be categorised by the way it sounds in one's ear, pulsatile tinnitus which is caused by the vascular nature of Glomus tumours and non-pulsatile tinnitus which usually sounds like crickets, the sea and bees.

Though the pathophysiology of tinnitus isn't known, noise exposure can be a contributing factor; therefore tinnitus can be associated with hearing loss, generated by the cochlea and central nervous system (CNS). High frequency hearing loss causes a high pitched tinnitus and low frequency hearing loss causes a roaring tinnitus. Noise-induced tinnitus can be temporary or permanent depending on the type and amount of noise a person was exposed to.

Cardiovascular Effects

Noise has been associated with important cardiovascular health problems, particularly hypertension. Noise levels of 50 dB(A) or greater at night may increase the risk of myocardial infarction by chronically elevating cortisol production.

Noise from transportation has been shown to increase blood pressure in individuals within the surrounding residential areas, with railways causing the greatest cardiovascular effects. Roadway noise levels are sufficient to constrict arterial blood flow and lead to elevated blood pressure. Vasoconstriction can result from elevated adrenaline levels or through medical stress reactions. Individuals subject to great than 80 dB(A) in the workplace are at increased risk of having increased blood pressure.

Psychological Impacts of Noise

Causal relationships have been discovered between noise and psychological effects such as annoyance, psychiatric disorders, and effects on psychosocial well-being. Exposure to intense levels of noise can cause personality changes and violent reactions. Noise has also been shown to be a factor that attributed to violent reactions. The psychological impacts of noise also include an addiction to loud music. This was researched in a study where non-professional musicians were found to have loudness addictions more often than non-musician control subjects.

Psychological health effects from noise include depression and anxiety. Individuals, who have hearing loss, including noise induced hearing loss, may have their symptoms alleviated with the use of hearing aids. Individuals who do not seek treatment for their loss are 50% more likely to have depression than their aided peers. These psychological effects can lead to detriments in physical care in the form of reduced self-care, work-tolerance, and increased isolation.

Auditory stimuli can serve as psychological triggers for individuals with post-traumatic stress disorder (PTSD).

Stress

Research commissioned by Rockwool, a multi-national insulation manufacturer headquartered in Denmark, reveals that in the UK one third (33%) of victims of domestic disturbances claim loud parties have left them unable to sleep or made them stressed in the last two years. Around one in eleven (9%) of those affected by domestic disturbances claims it has left them continually disturbed and stressed. More than 1.8 million people claim noisy neighbours have made their life a misery and they cannot enjoy their own homes. The impact of noise on health is potentially a significant problem across the UK given that more than 17.5 million Britons (38%) have been disturbed by the inhabitants of neighbouring properties in the last two year. For almost one in ten (7%) Britons this is a regular occurrence.

Annoyance

Sudden impulse noises are typically perceived as more bothersome than noise from traffic of equal volume. Annoyance effects of noise are minimally affected by demographics, but fear of the noise source and sensitivity to noise both strongly affect the 'annoyance' of a noise. Sound levels as low as 40 dB(A) can generate noise complaints and the lower threshold for noise producing sleep disturbance is 45 dB(A) or lower.

Other factors that affect the 'annoyance level' of sound include beliefs about noise prevention and the importance of the noise source, and annoyance at the cause (i.e. non-noise related factors) of the noise. Many of the interpretations of the level of annoyance and the relationship between noise levels and resulting health symptoms could be influenced by the quality of interpersonal relationships at the workplace, as well as the stress level generated by the work itself. Evidence for impact on annoyance of long-term noise versus recent changes is equivocal.

Approximately 35% to 40% of office workers find noise levels from 55 to 60 dB(A) extremely irritating. The noise standard in Germany for mentally stressful tasks is set at 55 dB(A), however, if the noise source is continuous, the threshold level for tolerability among office workers is lower than 55 dB(A).

Child Physical Development

The U.S. Environmental Protection Agency authored a pamphlet in 1978 that suggested a correlation between low-birthweight (using the World Health Organization definition of less than 2,500 grams (88 oz) and high sound levels, and also high rates of birth defects in places where expectant mothers are exposed to elevated sound levels, such as typical airport environs. Specific birth abnormalities included harelip, cleft palate, and defects in the spine.

According to Lester W. Sontag of the Fels Research Institute (as presented in the same EPA study): “There is ample evidence that environment has a role in shaping the physique, behavior, and function of animals, including man, from conception and not merely from birth. The fetus is capable of perceiving sounds and responding to them by motor activity and cardiac rate change." The effects of noise exposure are highest when it occurs between 15 and 60 days after conception, a period in which major internal organs and the central nervous system are formed.

Later developmental effects occur as vasoconstriction in the mother reduces blood flow and therefore oxygen and nutrition to the fetus. Low birth weights and noise were also associated with lower levels of certain hormones in the mother. These hormones are thought to affect fetal growth and to be good indicators of protein production. The difference between the hormone levels of pregnant mothers in noisy versus quiet areas increased as birth approached.

In a 2000 publication, a review of studies on birthweight and noise exposure note that while some older studies suggest that when women are exposed to >65 dB aircraft noise a small decrease in birthweight occurs, in a more recent study of 200 Taiwanese women including noise dosimetry measurements of individual noise exposure, the authors found no significant association between noise exposure and birth weight after adjusting for relevant confounders, e.g. social class, maternal weight gain during pregnancy, etc.

Cognitive development

When young children are regularly exposed to levels of noise that interfere with speech, they may develop speech or reading difficulties, because auditory processing functions are compromised. Children continue to develop their speech perception abilities until they reach their teens. Evidence has shown that when children learn in noisier classrooms, they have more difficulties understanding speech than those who learn in quieter settings.

In a study conducted by Cornell University in 1993, children exposed to noise in learning environments experienced trouble with word discrimination, as well as various cognitive developmental delays. In particular, the writing learning impairment dysgraphia is commonly associated with environmental stressors in the classroom.

High noise levels have also been known to damage the physical health of small children. Children from noisy residences often have a heart rate that is significantly higher (by 2 beats/min on average) than those of children from quieter homes.

Prevention

A hearing protection device (HPD) is an ear protection device worn in or over the ears while exposed to hazardous noise to help prevent noise-induced hearing loss. HPDs reduce (not eliminate) the level of the noise entering the ear. HPDs can also protect against other effects of noise exposure such as tinnitus and hyperacusis. Proper hygiene and care of HPDs may reduce chances of outer ear infections. There are many different types of HPDs available for use, including earmuffs, earplugs, electronic hearing protection devices, and semi-insert devices. One can measure the personal attenuation rating through a hearing protection fit-testing system.

Earmuff style hearing protection devices are designed to fit over the outer ear, or pinna. Earmuff HPDs typically consist of two ear cups and a head band. Earplug style hearing protection devices are designed to fit in the ear canal. Earplugs come in a variety of different subtypes. Some HPDs reduce the sound reaching the eardrum through a combination of electronic and structural components. Electronic HPDs are available in both earmuff and custom earplug styles. Electronic microphones, circuitry, and receivers perform active noise reduction, also known as noise-cancelling, in which a signal that is 180-degrees out-of-phase of the noise is presented, which in theory cancels the noise. Canal caps are similar to earplugs in that they consist of soft tip that is inserted into the opening of the ear canal.

2.2 EFFECTS OF VIBRATION ON PEOPLE

There are two types of vibration: Whole Body Vibration (WBV) and Hand-Arm Vibration (HAV).

WHOLE BODY VIBRATION (WBV) caused by poorly designed or poorly maintained vehicles, platforms or machinery amy cause or exacerbate other health effects such as:

- Lower back pain (damage to vertebrae and discs, ligaments loosened from shaking)
- Motion sickness
- Bone damage
- Varicose veins/heart conditions (variation in blood pressure from vibration);
- Stomach and digestive conditions;
- Respiratory, endocrine and metabolic changes;
- Impairment of vision, balance or both;
- Reproductive organ damage.

The longer a worker is exposed to WBV, the greater the risk of health effects and muscular disorders.

HAND-ARM VIBRATION (HAV) long term exposure from using hand held tools such as pneumatic tools (eg concrete breakers), chainsaws, grinders etc, causes a range of conditions and diseases, including:

- White finger (also known as "dead finger") - damage to hands causing whiteness and pain in the fingers;
- Carpel tunnel syndrome (and other symptoms similar to occupational overuse syndrome);
- Sensory nerve damage;

- Muscle and joint damage in the hands and arms (eg 'tennis elbow')

These conditions and diseases can have very serious consequences for people. The effects can be permanently disabling even after a few years of uncontrolled exposure.

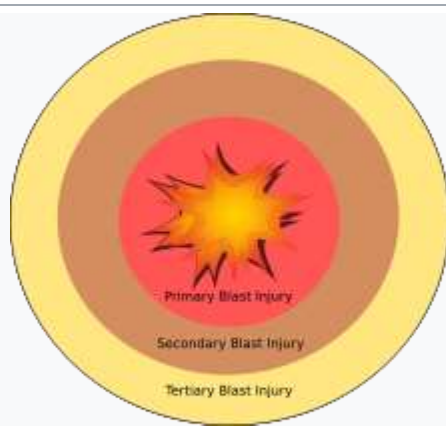
Damage to the body from exposure to vibration depends on:

- Length of exposure time;
- Frequency (rate at which the surface or tool vibrates, measured in vibrations per second or Hertz-Hz);
- Amplitude (the size of the vibration). Amplitude can measure acceleration, speed or distance covered.

2.3 EFFECTS OF BLAST ON PEOPLES

A **blast injury** is a complex type of physical trauma resulting from direct or indirect exposure to an explosion. Blast injuries occur with the detonation of high-order explosives as well as the deflagration of low order explosives. These injuries are compounded when the explosion occurs in a confined space.

Classification



Blast injuries are divided into four classes: primary, secondary, tertiary, and quaternary.

Primary injuries

Primary injuries are caused by blast overpressure waves, or shock waves. These are especially likely when a person is close to an exploding munition, such as a land mine. The ears are most often affected by the overpressure, followed by the lungs and the hollow organs of the gastrointestinal tract. Gastrointestinal injuries may present after a delay of hours or even days. Injury from blast overpressure is a pressure and time dependent function. By increasing the pressure or its duration, the severity of injury will also increase.

Extensive damage can also be inflicted upon the auditory system. The tympanic membrane (also known as the eardrum) may be perforated by the intensity of the pressure waves. Furthermore, the hair cells, the sound receptors found within the cochlea, can be permanently damaged and can result in a hearing loss of a mild to profound degree. Additionally, the intensity of the pressure changes from the blast can cause injury to the blood vessels and neural pathways within the auditory system. Therefore, affected individuals can have auditory processing deficits while having normal hearing thresholds. The combination of these effects can lead to hearing loss, tinnitus, headache, vertigo (dizziness), and difficulty processing sound.

In general, primary blast injuries are characterized by the absence of external injuries; thus internal injuries are frequently unrecognized and their severity underestimated. According to the latest experimental results, the extent and types of primary blast-induced injuries depend not only on the peak of the overpressure, but also other parameters such as number of overpressure peaks, time-lag between overpressure peaks, characteristics of the shear fronts between overpressure peaks, frequency resonance, and electromagnetic pulse, among others. There is general agreement that spalling, implosion, inertia, and pressure differentials are the main mechanisms involved in the pathogenesis of primary blast injuries. Thus, the majority of prior research focused on the mechanisms of blast injuries within gas-containing organs and organ systems such as the lungs, while primary blast-induced traumatic brain injury has remained underestimated. *Blast lung* refers to severe pulmonary contusion, bleeding or swelling with damage to alveoli and blood vessels, or a combination of these. It is the most common cause of death among people who initially survive an explosion.

Secondary injuries

Secondary injuries are caused by fragmentation and other objects propelled by the explosion. These injuries may affect any part of the body and sometimes result in penetrating trauma with visible bleeding. At times the propelled object may become embedded in the body, obstructing the loss of blood to the outside. However, there may be extensive blood loss within the body cavities. Fragmentation wounds may be lethal and therefore many anti-personnel bombs are designed to generate fragments.

Most casualties are caused by secondary injuries as generally a larger geographic area is affected by this form of injury than the primary blast site as debris can easily be propelled for hundreds to thousands of meters. Some explosives, such as nail bombs, are deliberately designed to increase the likelihood of secondary injuries. In other instances, the target provides the raw material for the objects thrown into people, e.g., shattered glass from a blasted-out window or the glass facade of a building.

Tertiary injuries

Displacement of air by the explosion creates a blast wind that can throw victims against solid objects. Injuries resulting from this type of traumatic impact are referred to as tertiary blast injuries. Tertiary injuries may present as some combination of blunt and penetrating trauma, including bone fractures and coup contre-coup injuries. Children are at particularly high risk of tertiary injury due to their relatively smaller body weight.

Quaternary injuries

Quaternary injuries, or other miscellaneous named injuries, are all other injuries not included in the first three classes. These include flash burns, crush injuries, and respiratory injuries.

Traumatic amputations quickly result in death, unless there are available skilled medical personnel or others with adequate training nearby who are able to quickly respond, with the ability for rapid ground or air medical evacuation to an appropriate facility in time, and with tourniquets (for compression of bleeding sites) and other needed equipment (standard, or improvised; sterile, or not) also available, to treat the injuries. Because of this, injuries of this type are generally rare, though not unheard of, in survivors. Whether survivable or not, they are often accompanied by significant other injuries. The rate of eye injury may depend on the type of blast. Psychiatric injury, some of which may be caused by neurological damage incurred during the blast, is the most common quaternary injury, and post-traumatic stress disorder may affect people who are otherwise completely uninjured.

Mechanism

Blast injuries can result from various types of incidents ranging from industrial accidents to deliberate attacks. High-order explosives produce a supersonic overpressure shock wave, while low order explosives deflagrate and do not produce an overpressure wave. A blast wave generated by an explosion starts with a single pulse of increased air pressure, lasting a few milliseconds. The negative pressure (suction) of the blast wave follows immediately after the positive wave. The duration of the blast wave depends on the type of explosive material and the distance from the point of detonation. The blast wave progresses from the source of explosion as a sphere of compressed and rapidly expanding gases, which displaces an equal volume of air at a very high velocity. The velocity of the blast wave in air may be extremely high, depending on the type and amount of the explosive used. An individual in the path of an explosion will be subjected not only to excess barometric pressure, but to pressure from the high-velocity wind traveling directly behind the shock front of the blast wave. The magnitude of damage due to the blast wave is dependent on the peak of the initial positive pressure wave, the duration of the overpressure, the medium in which it explodes, the distance from the incident blast wave, and the degree of focusing due to a confined area or walls. For example, explosions near or within hard solid surfaces become amplified two to nine times due to shock wave reflection. As a result, individuals between the blast and a building generally suffer two to three times the degree of injury compared to those in open spaces.

Neurotrauma

Blast injuries can cause hidden sensory and brain damage, with potential neurological and neurosensory consequences. It is a complex clinical syndrome caused by the combination of all blast effects, i.e., primary, secondary, tertiary and quaternary blast mechanisms. Blast injuries usually manifest in a form of polytrauma, i.e. injury involving multiple organs or organ systems. Bleeding from injured organs such as lungs or bowel causes a lack of oxygen in all vital organs, including the brain. Damage of the lungs reduces the surface for oxygen uptake from the air, reducing the amount of the oxygen delivered to the brain. Tissue destruction initiates the synthesis and release of hormones or mediators into the blood which, when delivered to the brain, change its function. Irritation of the nerve endings in injured peripheral tissue or organs also contributes significantly to blast-induced neurotrauma.

Individuals exposed to blast frequently manifest loss of memory of events before and after explosion, confusion, headache, impaired sense of reality, and reduced decision-making ability. Patients with brain injuries acquired in explosions often develop sudden, unexpected brain swelling and cerebral vasospasm despite continuous monitoring. However, the first symptoms of blast-induced neurotrauma (BINT) may occur months or even years after the initial event, and are therefore categorized as secondary brain injuries. The broad variety of symptoms includes weight loss, hormone imbalance, chronic fatigue, headache, and problems in memory, speech and balance. These changes are often debilitating, interfering with daily activities. Because BINT in blast victims is underestimated, valuable time is often lost for preventive therapy and/or timely rehabilitation.

Blast wave PTSD research

In addition to known posttraumatic stress disorder (PTSD) risk factors experienced by both civilians and military personnel in combat areas; in early 2018, it was reported by *60 Minutes* that neuropathology specialist Dr. Daniel "Dan" Perl had conducted research on brain tissue exposed to traumatic brain injury (TBI), discovering a cause-and-effect relationship between IED blast waves and PTSD. Dr. Perl was recruited to the faculty of the Uniformed Services University of the Health Sciences as a Professor of Pathology and to establish the Center for Neuroscience and Regenerative Medicine mandated by Congress in 2008.

2.4 EFFECTS OF SOUND ON PEOPLES

Sound is a vibration that propagates as an acoustic wave, through a transmission medium such as a gas, liquid or solid. It is an effect produced in human ear by the propagation of waves.

In human physiology and psychology, sound is the reception of such waves and their perception by the brain.[1] Only acoustic waves that have frequencies lying between about 20 Hz and 20 kHz elicit an auditory percept in humans. Sound waves above 20 kHz are known as ultrasound and are not audible to humans. Sound waves below 20 Hz are known as infrasound. Different animal species have varying hearing ranges.

Effects of Ultrasonic sound

The term "ultrasound" applies to all sound waves with a frequency above the audible range of normal human hearing, about 20 kHz. The frequencies used in diagnostic ultrasound are typically between 2 and 18 MHz. Waves of this high frequency can cause some damage to the human body, and perhaps even more to the unborn fetal body.

Fetal effects: The effects of Ultrasound technology have been proven to have many effects on the fetal bodies. In Australia a study conducted on1400 pregnant women showed that women who had 5 monthly ultrasound tests, as compared to women who only had one throughout the entire pregnancy, gave birth lower weight babies over all. Another conclusion from this study showed that the babies that were exposed to ultrasound were mostly left handed. Other research published by the Canadian Medical Association’s Journal showed that in a study of 72 children with delayed speech disorder, more than 70% of the children were exposed to frequent ultrasounds during pregnancy.

Adult effects: Fetuses are not the only ones affected by the possibly damaging effects of ultrasound. One of the most well-known effects of ultrasound is that as Ultrasound waves pass through a tissue they tend to heat it up. The tissue can easily be warmed to 40 degrees Celsius. Although in vivo the heat is usually easily carried away by blood circulation or simply dissipated into surrounding tissues. This regiment can be applied in a technique called Ultrasound therapy where this heat is used to stimulate repair to damaged internal tissues. Another well-known effect of Ultrasound is cavitation. Cavitations are small bubbles of gas that are released upon exposure to extreme negative pressure. These bubbles can cause cells or even tissues to rupture. This effect is used in a form of non-invasive liposuction, in which adipocytes are burst using ultrasound waves. Although Ultrasound cannot be heard by humans, at high decibels it can still cause direct damage to human ears. Ultrasound in excess of 120 decibels may cause Hearing damage. Exposure to 155 decibels causes heat levels that are harmful to the body. 180 decibels may even cause death.

Effects of infrasonic waves on human

Infrasound is generated by natural sources such as earthquakes and wind; means of transportation such as automobiles, trucks, aircraft, watercraft, and rail traffic; certain therapeutic devices (which do not meet the restriction of infrasound to airborne delivery); numerous industrial sources such as heavy machinery and air compressors; air heating and cooling equipment; and household appliances such as washing machines.

There is no agreement about the biological activity of infrasound. Reported effects include those on the inner ear, vertigo, imbalance, etc.; intolerable sensations, incapacitation, disorientation, nausea, vomiting, and bowel spasm; and resonances in inner organs, such as the heart. Workers exposed to simulated industrial infrasound of 5 and 10 Hz and levels of 100 and 135 dB for 15 minutes reported feelings of fatigue, apathy, and depression, pressure in the ears, loss of concentration, drowsiness, and vibration of internal organs. In addition, effects were found in the central nervous, cardiovascular, and respiratory systems.

2.5 EFFECTS OF LOW FREQUENCY NOISE ON PEOPLES

Introduction

In nature, sound frequencies below 200 Hz are signals of thunder, volcano eruptions, earthquakes, or storms –events that are likely to induce arousal or fear. In the urban soundscape, low frequencies may originate from amplified music, transportation, or ventilation/compressor units. Human hearing in the low frequency range is, compared to the higher frequencies, less sensitive and has, for many years, led to the misconception that low frequency sounds are also less annoying. Today, it is known that low frequency noise has a great annoyance potential, and that some people seem to react adversely even to levels just above their hearing threshold. Factors inherent in most low frequency noises such as the throbbing characteristics, the intrusion of low frequencies felt when other frequencies in the sound are attenuated, and the vibration sensations sometimes felt contribute probably to annoyance. The risk for adverse effects is of particular concern because of its general presence due to numerous sources, such as an efficient propagation of the noise from the source and poor attenuation efficiency of building structures.

Definition

Low frequencies lack an internationally established definition but usually indicate the frequency range of 20–200 Hz. Although the upper limit for infrasound is 20 Hz, at sufficiently high sound pressure levels (SPLs), certain noises contain in practice both perceivable infrasound sand low frequency sounds. The division between infra-sound and low frequency sound should therefore be seen as merely conventional. For both infra sounds and low frequency sounds, their relationship to the perception threshold is of relevance as a first estimate of risk assessment. For the low frequency range, comparisons are made to the standardized normal hearing threshold, whereas for infra sounds, there exists no standardized normal hearing threshold, and assessments have to be made to approximations of present studies of hearing and perception. With respect to effects on humans, many studies have shown that adverse reactions appear when the noise consists of perceivable SPLs in low frequencies that are considerably higher relative to the SPLs above approximately 200 Hz. Thus, in terms of effects, a low frequency noise can be defined as a noise with dominant frequencies in the region of 20–200 Hz and is thus used in this article.

Sources of Low Frequency Noise

Low frequency noise is emitted from a multitude of sources such as large ventilation systems, climate systems, diesel motors (heavy vehicles, diesel locomotives, work machines, generators), aircraft (propeller planes, helicopters, jets), compressors (refrigeration compressors, pressurized air drills), and turbines Airborne noise of low frequency may also occur as a result of vibrations in the ground or in building structures. Low frequency noise is also generated when explosives are detonated and in the use of heavy artillery. Compared to high frequencies, low frequencies propagate for long distances. Low frequencies will also pass with little attenuation through walls and windows. At long distances from the source, or indoors, the noise spectrum will be selectively attenuated, resulting in a spectrum dominated by low frequencies. Examples of situations in which the resulting noise can contain a large portion of low frequencies are interior control rooms, steering compartments, and cockpits and when traditional hearing protection equipment is used.

Adverse Effects on Health

1. Subjective Symptoms

In a large number of case studies, the most commonly reported symptoms are headaches or a feeling of pressure in the head, unusual fatigue, concentration difficulties, irritation, vibrations in the body, and a feeling of pressure on the eardrum. Although these reports have been made on the basis of case studies and may thus have a number of sources of error, the agreement between them in terms of symptoms and sound descriptions is good. Some of these symptoms, such as lack of concentration, sleepiness, tiredness, irritation, pressure on the eardrums, and pressure in the head, have been found to be related to noise annoyance in experimental and field experimental studies.

2. Sleep Disturbance

Several case studies report that low frequency noise affects sleep quality, particularly with reference to the time taken to fall asleep and tiredness in the morning. A limited number of cross-sectional epidemiological studies have been carried out, which give some support to the findings in the case studies. In one of the few studies that have tried to relate the low frequency content in heavy vehicle noise to adverse effects, a significant correlation was found between the maximum levels of low frequencies in the noise, measured as LpCmax, and urine cortisol levels sampled in the first half of the night. The increase in cortisol was furthermore significantly related to impaired sleep, memory, and ability to concentrate. The results could indicate that long-term exposure to intermittent low frequency noise resulted in chronic in-creases of subjects' excretion of free cortisol in the first half of the night, and thus disturbance of the circadian rhythm. Similarly, the energy content of 20–160 Hz has been shown to be significantly related to sleep disturbance, concentration difficulties, irritability, anxiety, and tiredness.

The limited number of experimental studies of low frequency noise has been ambiguous with regard to its effects on cortisol, whereas the negative influence of subjectively assessed sleep parameters is clearer.

3. Reduced Wakefulness/Greater Fatigue

An increased risk of drowsiness during exposure to infrasound has been reported in laboratory trials and field studies, with a positive correlation between exposure to infrasound at levels just above the perception threshold and reduced wakefulness. The reduced wakefulness is accompanied with reduced pulse, reduced systolic and diastolic blood pressure. All of these reaction patterns are normal physiological changes produced during falling asleep. Whether this effect also extends to the low frequency range is less well explored, although some data from the field and laboratory studies point in a similar direction. If continuous low frequency noise causes reduced wakefulness and attention, this could have serious consequences for professions where sustained attention is crucial, such as drivers, pilots, and control room workers.

4. Effects on Work Performance

The impact of low frequency noise on work performance can be understood to occur in different ways. Symptoms that have been reported in connection with annoyance due to low frequency noise and that could reduce work performance are fatigue, concentration problems, head-ache, and irritation. Possible mechanisms are suggested by studies where monotonous low frequency noise has been shown to have a sleep-provoking effect.

5. Hearing Loss

Little information is available on permanent hearing impairment due to low frequency noise, and the risk evaluation is complicated by the fact that most occupational settings with low frequency sound also comprise sounds of higher frequencies.

6. Annoyance

Noise-induced annoyance is the most common and most researched adverse effect of noise on people. This is also the case for low frequency noise. Annoyance has been defined as ‘a feeling of displeasure evoked by a noise’ and ‘any feeling of resentment, displeasure, discomfort, and irritation occurring when a noise intrudes into someone’s thoughts and moods or interferes with activity.’ Annoyance is measured using questionnaires or interviews and the rating is usually done on a verbal or numeric scale with endpoints ‘not at all annoying’ to ‘very’ or ‘extremely annoying.’

2.6 EFFECTS OF INTENSE NOISE ON PEOPLES

Noise is most commonly defined as unwanted sound or acoustic energy. However, acoustic descriptions usually characterize noise by its intensity, its frequency spectrum, and its temporal signature. Here we consider the effect of intensity. The effects are explained under auditory and non-auditory effects.

I. AUDITORY AFTEREFFECTS OF NOISE

The figure is a simple model of how the ear reacts to noise. The left-hand portion of the curve is the safe zone of the ear noises in this range cause no measurable damage in normal people. Most people live in this range on a day-to-day basis. Temporary threshold shift (TTS) is a change in absolute hearing threshold due to exposure to a higher level noise that resolves to no measurable threshold shift after some period of time. This recovery time can be from minutes to days. An intense noise exposure results in a combined threshold shift (CTS) that contains both TTS and permanent threshold shift components. Noise of sufficient intensity and appropriate frequency can produce a permanent reduction of sensitivity of the ear to sound, also known as a permanent threshold shift, or PTS. An intermediate level of sound can produce either TTS or PTS the linear, central portion of Fig.

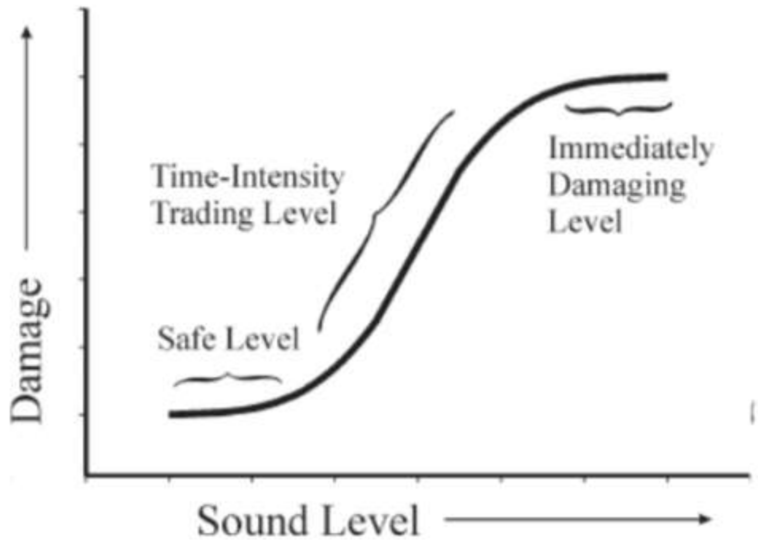


Figure 1 Theoretical noise damage curve. *X* axis is increasing sound level. *Y* axis is increasing damage (may be shift in audiometric threshold or damage to hair cells). Left side of curve shows little or no damage due to noise. The middle section shows damage linearly increasing with noise exposure. The right section of the curve shows effect of extremely high noise exposures that asymptote with higher noise levels.

Noise exposure can also result in tinnitus (a ringing or buzzing in the ears). Tinnitus can be thought of as the ear’s pain response. Tinnitus can be present temporarily or, with continued noise exposure, it can become permanent. Current research places the generator of tinnitus in the central nervous system.

II. NON-AUDITORY EFFECTS NOISE

Extremely loud blasts, usually encountered only in a military setting, can produce enough acoustic energy to damage internal organs. The ear, the gastrointestinal tract, the upper respiratory tract, and the lungs are particularly susceptible to blast damage because they are air filled. Generally, the rank order of susceptibility to damage is the ears, the lungs and the gastrointestinal tract, which is least susceptible of the three systems. Fifty percent of normal human tympanic membranes will rupture in the 57- to 345-kPa peak pressure range (190 to 200 dB SPL peak pressure).Blast overpressure injury of the lungs can result in air emboli that can travel throughout the circulatory system. Even contusions of the lungs by blast can be life threatening. Blast overpressure lung injury may be enhanced by body armor. Foam material may more effectively couple the body to the acoustic event and increase injury. In the civilian sector most non-auditory effects of loud noise are related to psychological stress. Noise is considered stressful if the person cannot control it nor can they habituate to it. At low levels unsignaled noise causes an orienting response. As the level becomes louder, the person startles with increase in blood pressure and muscular contractions. These reactions last a few seconds, with interruption of ongoing activities. At high enough levels sleep can be compromised, impacting quality of life. With chronic exposure a stress reaction results in release of the corticosteroids, which are part of the fight-or-flight system. Researchers have noted statistically significant increases in blood pressure for workers exposed to noise greater than 75 dB(A).

2.7 EFFECTS OF MECHANICAL SHOCK ON PEOPLES

A mechanical or physical shock is a sudden acceleration caused, for example, by impact, drop, kick, earthquake, or explosion. A mechanical shock is a non-periodic disturbance characterized by suddenness and severity with, for the human body, the maximum forces being reached within a few tenths of a second, and a total duration of up to about a second. Shocks are usually measured by vibrometers and accelerometers.

Injury from Shock and Impact

Physiological responses to shocks and objects impacting the body include those discussed for whole-body vibration. For small contact areas, the injuries are often related to the elastic and tensile limits of tissue. The responses are critically dependent on the magnitude, direction, and time history of the acceleration and forces entering the body, the posture, and on the nature of any body supports or restraints (e.g., seat belt or helmet).

Vertical Shocks: Exposure to single shocks applied to a seated person directed from the seat pan toward the head (“headward”) has been studied in connection with the development of aircraft ejection seats, from which the conditions for spinal injury and vertebral fractures have been documented.Exposure to intense repeated vertical shocks is experienced in some off-the-road vehicles and high-performance military aircraft, where spinal injury has also been reported. A headward shock with acceleration in excess of g = 9.81 m/s2 (the acceleration of gravity) is likely to be accompanied by a downward (“tailward”) impact, when the mass of the torso returns to being supported by the seat.

Horizontal shocks: Exposure to rapid decelerations in the horizontal direction has been extensively studied in connection with motor vehicle and aircraft crashes (“spineward” deceleration). Accident statistics indicate that serious injuries to the occupants of motor vehicles involved in frontal.

Protection from Mechanical Shock

Protection against potentially injurious shocks and impacts is obtained by distributing the dynamic forces over as large a surface area of the body as possible and transferring the residual forces preferably to the pelvic region of the skeleton (though not through the vertebral column). Modifying the impact-time history to involve smaller peak forces lasting for a longer time is usually beneficial. Progressive crumpling of the passenger cabin floor and any forward structural members while absorbing horizontal crash forces, as well as extension of a seat's rear legs, are all used for this purpose.

I. Seat Belts and Harnesses.

For seated persons, lap belts, or combined lap and shoulder harnesses, are used to distribute shock loads, and are routinely installed in automobiles and passenger aircraft. In addition, the belts hold the body against the seat, which serves to strengthen the restrained areas. Combined lap and shoulder harnesses are preferable to lap belts alone for forward-facing passengers, as the latter permit the upper body to flail in the event of a spineward deceleration, such as occurs in motor vehicle and many aircraft crashes. Harnesses with broader belt materials can be expected to produce lower pressures on the body and consequently less soft tissue injury. For headward accelerations the static deformation of the seat cushion is important, with the goal being to spread the load uniformly and comfortably over as large an area of the buttocks and thighs as possible. A significant factor in human shock tolerance appears to be the acceleration-time history of the body immediately before the transient event. A dynamic preload imposed immediately before and/or during the shock, and in the same direction as the impending shock forces (e.g., vehicle braking before crash), has been found experimentally to reduce body accelerations.

II. Air Bags

Although originally conceived as an alternative to seat belts and harnesses, air bags are now recognized to provide most benefit when used with passive restraints, which define the position of the body. The device used in automobiles consists, in principle, of one or more crash sensors (accelerometers) that detect rapid decelerations, and a controller that processes the data and initiates a pyrotechnic reaction to generate gas. The gas inflates a porous fabric bag between the decelerating vehicle structure and the occupant within about 25 to 50 ms, to distribute the shock and impact forces over a large surface of the body. An example of the use of the MADYMO model to simulate air bag inflation and occupant response to the frontal collision of an automobile is shown in Fig. 10.13. In this diagram, the response of a person wearing a shoulder and lap seat belt has been calculated at 25-ms time intervals following the initiation of air bag inflation. The forward rotation of the head is clearly visible and is arrested before it impacts the chest. Also, the flailing of the arms can be seen. Air bags can cause injury if they impact someone positioned close to the point of inflation, which may occur in the event of unrestrained, or improperly restrained, vehicle occupants (e.g., small children).

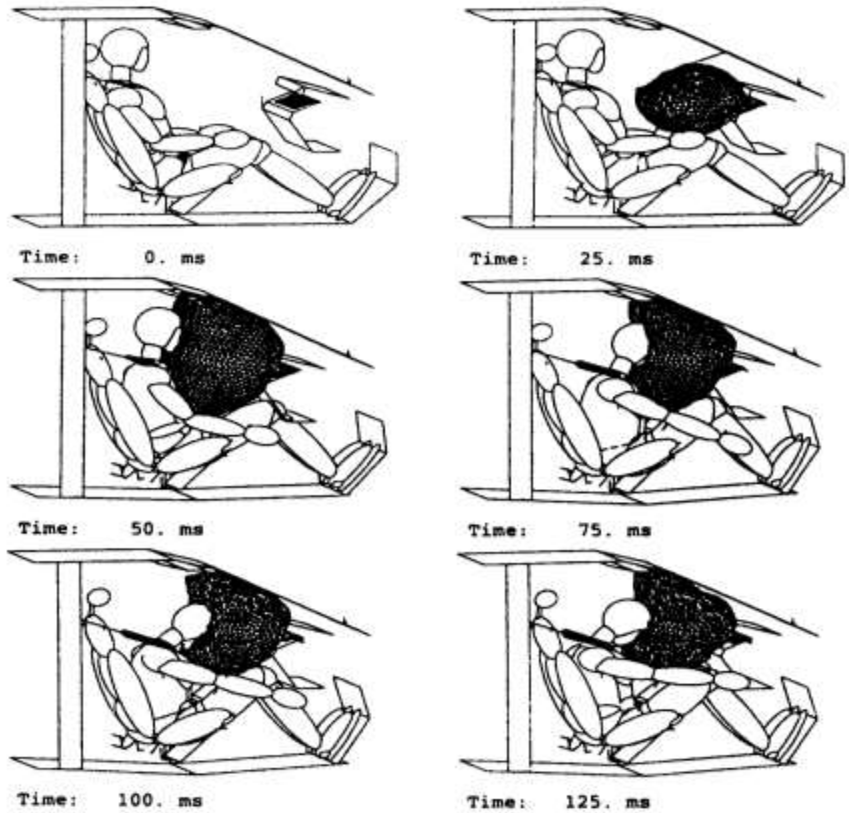


FIGURE 10.13 MADYMO simulation of the response of a person wearing a shoulder and lap seat belt to the inflation of an air bag in a frontal motor vehicle collision. The model predicts the body position every 25 ms after the collision. Note the time for the air bag to inflate (between 25 and 50 ms), the rotation of the head, the flailing of the arms, and the bending of the floor. (*AGARD-AR-330, 1996.*)

III. Helmets.

Impact-reducing helmets surround the head with a rigid shell to distribute the dynamic forces over as large an area of the skull as possible. The shell is supported by energy absorbing material formed to the shape of the head, to reduce transmission of the impact to the skull. The shell of a helmet must be as stiff as possible consistent with weight considerations, and must not deflect sufficiently on impact for it to contact the head. The supporting webbing and energy absorbing foam plastic must maintain the separation between the shell and the skull, and not permit shell rotation on the head, to avoid the edges of the helmet impacting the neck or face. Most practical helmet designs are a compromise between impact protection and other considerations (e.g., bulk and weight, visibility, comfort, ability to communicate). Their efficacy has been demonstrated repeatedly by experiment and accident statistics.

2.8 HUMAN RESPONSE TO NOISE

INTRODUCTION

The ear, seemingly by magic, converts incoming sound energy into eardrum oscillations, then into middle ear bone motions, standing waves on the basilar membrane and ultimately into nerve impulses that are relayed to the brain. The brain processes this information, psychologically interprets it and determines the meaning and value of that sound. The frequency range of human hearing is generally considered as 20 – 20,000 Hz. The upper range varies greatly among individuals and decreases with age and noise exposure. The amplitude of our sensation ranges from the threshold of hearing (~0 dB) to thresholds of discomfort and pain (above 140 dB).

Objectives of this lesson: This lesson introduces the concepts of loudness, annoyance, frequency sensitivity, hearing threshold, masking, binaural hearing and non-auditory effects of noise. After completion, the reader should have a fundamental knowledge of the psychological response of humans to noise.

I. LOUDNESS

Loudness is a subjective response to the amplitude of sound. It is a judgment of the intensity of a sound by a human being. It is not linearly related to either sound pressure (Pa), sound pressure level (dB) or sound power level. Doubling of sound power raises pressure level by 3 dB but only produces a barely noticeable increase in loudness (not a doubling). A 10 dB increase in SPL approximately results in twice the subjective loudness (equivalent to 10 identical sources instead of one).

Our hearing is bounded at low levels by the threshold of hearing. The Minimum Audible Field (MAF) is the threshold of hearing for young adults with normal hearing. MAF is the minimum sound pressure level at which a sound is audible with both ears to a listener in a free field, facing the source. The threshold of hearing shows a pronounced variation of amplitude with frequency, almost 80 dB differences from 20 to 4000 Hz. At higher exposure levels, this variation with frequency diminishes, i.e. the equal loudness contours become flatter. For example, the 90 phon line varies only 40 dB. Above approximately 120 dB, the average listener will begin to experience physical discomfort. At around 130 dB, the large motions of the ear drum and bone chain will cause a sensation of feeling or tickling. Over 140 dB, the sensation is painful, hence the name threshold of pain.

Units of Loudness: The other unit used for loudness is the phon. At 1000 Hz, phons = dB from the equal loudness contours. As previously stated, the subjective judgment of loudness does not directly correspond to SPL or even with loudness (phons). Because most people cannot deal with anything more complicated than a linear relationship, a new unit is thus defined to linearize loudness, - called the sone. 1 sone is defined as equal to the subjective loudness of a 40 phon sound. N sone means N times as loud as a 40 phon sound. There is a simple relation between sones and phons at 1000 Hz:

$$\text{SONES} = 2^{(\text{phone}-40)/10}$$

II. NOISINESS, ANNOYANCE

"Noisiness" and "annoyance" are subjective terms that involve value judgements of the sound in question. Your Harley motorcycle sounds great to you, but to your neighbor, it can be very annoying, especially at 2 am. Annoyance is a reaction to sound based on its physical nature and its emotional effect. Noisiness and annoyance are hard to quantify. The physical aspects of sound which contribute most to perceived noisiness are: 1) spectrum content and level 2) spectrum complexity and existence of pure tones 3) time duration 4) amplitude and frequency of level fluctuations 5) rise time of impulsive sounds Experimental studies have resulted in equal-noisiness contours (similar to equal loudness contours). The unit of noisiness is the noy. 1 noy is defined as the noisiness of a 1000 Hz tone at a SPL of 40 dB

III. PITCH

Pitch is a subjective response to frequency. The presence of a discernible pitch in a complex noise is indicative of one or more pure tone components. Qualitatively, high frequencies correspond to high pitch.

IV. MASKING

Masking occurs when one sound interferes with the perception of another. It is caused when two excited areas overlap on the basilar membrane (due to two or more sounds).

V. BINAURAL HEARING

The ability to localize the direction of noise arrival, i.e. to localize the direction of a source, is dependent primarily on differences in the phase and intensity of the sound received by the two ears. Above about 1500 Hz, the difference in the sound intensity received at the two ears is produced largely by the scattering of sound around the head. The head provides an acoustic shadow which reduces the intensity at the far ear. This intensity difference increases with frequency. Below about 1500 Hz, the primary mechanism of localization is the difference in the time of arrival of the sound at the two ears. This results in a difference in the phase between the sounds at the two ears. The ears combine to form a two element array.

VI. NON-AUDITORY EFFECTS OF NOISE

In addition to hearing loss, noise can induce several non-auditory effects, including stress, tension and adverse health effects. The surprise or “startle” generated by sudden sounds can cause physical stress and tension. Noise that interferes with activities (such as sleep, conversation, music listening, concentration, etc) can also cause stress or tension due to their psychological impact.

2.9 NOISE EXPOSURE

The depth of effect of noise mainly depends on two factors: Intensity of sound and Exposure time. The hazard or damage increases even one factor increase. If high intensity sound continues for long time it will results hearing loss. So there should be a limit for exposure of sound for all intensities. For example if 85 dB sounds continues for more than 8 Hours, it will make damage to ear. So 8 hour is the noise exposure limit corresponding to 85 dB. For an increase of 3 dB, time will reduce around 50%. Some noise exposure limits are given below.

Permissible Noise Exposure (PEL)

Duration Per Day, (Hr)	Permissible Exposure "Slow" Response, (dBA)
16	87
8	90
6	92
4	95
3	97
2	100
1	105
1/2	110
1/4 or less	115

2.10 HEARING CONSERVATION

Since the high level noise are exposed for a long period it will results hearing loss. So it is necessary to take necessary steps to conserve the hearing capacity. There is a hearing conservation program followed in European countries under OSHA (Occupational Safety and Health Administration).

What is occupational noise exposure?

Noise, or unwanted sound, is one of the most pervasive occupational health problems. It is a by-product of many industrial processes. Sound consists of pressure changes in a medium (usually air), caused by vibration or turbulence. These pressure changes produce waves emanating away from the turbulent or vibrating source. Exposure to high levels of noise causes hearing loss and may cause other harmful health effects as well. The extent of damage depends primarily on the intensity of the noise and the duration of the exposure. Noise-induced hearing loss can be temporary or permanent. Temporary hearing loss results from short-term exposures to noise, with normal hearing returning after period of rest. Generally, prolonged exposure to high noise levels over a period of time gradually causes permanent damage. OSHA's hearing conservation program is designed to protect workers with significant occupational noise exposures from hearing impairment even if they are subject to such noise exposures over their entire working lifetimes.

What monitoring is required?

The hearing conservation program requires employers to monitor noise exposure levels in a way that accurately identifies employees exposed to noise at or above 85 decibels (dB) averaged over 8 working hours, or an 8-hour time-weighted average (TWA). Employers must monitor all employees whose noise exposure is equivalent to or greater than a noise exposure received in 8 hours where the noise level is constantly 85 dB. The exposure measurement must include all continuous, intermittent, and impulsive noise within an 80 dB to 130 dB range and must be taken during a typical work situation. This requirement is performance-oriented because it allows employers to choose the monitoring method that best suits each individual situation.

What is audiometric testing?

Audiometric testing monitors an employee's hearing over time. It also provides an opportunity for employers to educate employees about their hearing and the need to protect it. The employer must establish and maintain an audiometric testing program. The important elements of the program include baseline audiograms, annual audiograms, training, and follow up procedures. Employers must make audiometric testing available at no cost to all employees who are exposed to an action level of 85 dB or above, measured as an 8-hour TWA. The audiometric testing program follow up should indicate whether the employer's hearing conservation program is preventing hearing loss. A licensed or certified audiologist, otolaryngologist, or other physician must be responsible for the program. Both professionals and trained technicians may conduct audiometric testing. The professional in charge of the program does not have to be present when a qualified technician conducts tests. The professional's responsibilities include overseeing the program and the work of the technicians, reviewing problem audiograms, and determining whether referral is necessary. The employee needs a referral for further testing when test results are questionable or when related medical problems are suspected. There are two types of audiograms required in the hearing conservation program: baseline and annual audiograms.

What is a baseline audiogram?

The baseline audiogram is the reference audiogram against which future audiograms are compared. Employers must provide baseline audiograms within 6 months of an employee's first exposure at or above an 8-hour TWA of 85 dB. An exception is allowed when the employer uses a mobile test van for audiograms. In these instances, baseline audiograms must be completed within 1 year after an employee's first exposure to workplace noise at or above a TWA of 85 dB. Employees, however, must be fitted with, issued, and required to wear hearing protectors whenever they are exposed to noise levels above a TWA of 85 dB for any period exceeding 6 months after their first exposure until the baseline audiogram is conducted.

What are annual audiograms?

Employers must provide annual audiograms within 1 year of the baseline. It is important to test workers' hearing annually to identify deterioration in their hearing ability as early as possible. This enables employers to initiate protective followup measures before hearing loss progresses. Employers must compare annual audiograms to baseline audiograms to determine whether the audiogram is valid and whether the employee has lost hearing ability or experienced a standard threshold shift (STS). An STS is an average shift in either ear of 10 dB or more at 2,000, 3,000, and 4,000 hertz.

What is an employer required to do following an audiogram evaluation?

The employer must fit or refit any employee showing an STS with adequate hearing protectors, show the employee how to use them, and require the employee to wear them. Employers must notify employees within 21 days after the determination that their audiometric test results show an STS. Some employees with an STS may need further testing if the professional determines that their test results are questionable or if they have an ear problem thought to be caused or aggravated by wearing hearing protectors. If the suspected medical problem is not thought to be related to wearing hearing protection, the employer must advise the employee to see a physician. If subsequent audiometric tests show that the STS identified on a previous audiogram is not persistent, employees whose exposure to noise is less than a TWA of 90 dB may stop wearing hearing protectors.

When is an employer required to provide hearing protectors?

Employers must provide hearing protectors to all workers exposed to 8-hour TWA noise levels of 85 dB or above. This requirement ensures that employees have access to protectors before they experience any hearing loss.

What training is required?

Employee training is very important. Workers who understand the reasons for the hearing conservation programs and the need to protect their hearing will be more motivated to wear their protectors and take audiometric tests. Employers must train employees exposed to TWAs of 85 dB and above at least annually in the effects of noise; the purpose, advantages, and disadvantages of various types of hearing protectors; the selection, fit, and care of protectors; and the purpose and procedures of audiometric testing.

What exposure and testing records must employers keep?

Employers must keep noise exposure measurement records for 2 years and maintain records of audiometric test results for the duration of the affected employee's employment. Audiometric test records must include the employee's name and job classification, date, examiner's name, date of the last acoustic or exhaustive calibration, measurements of the background sound pressure levels in audiometric test rooms, and the employee's most recent noise exposure measurement.

2.11 NOISE INDUCED ANOOYANCE

Noise Induced Annoyance is "a feeling of displeasure associated with sound, that is believed to affect adversely an individual or a group". Traffic noise (road noise, railway noise, aircraft noise, noise of parking cars), is the most dominant source of annoyance in the living environment of many European countries. This is followed by neighbourhood noise (neighbouring apartments, staircase and noise within the apartment). The subjective experience of noise stress can, through central nervous processes, lead to an inadequate neuro-endocrine reaction and finally lead to regulatory diseases. Within the context of the LARES-survey (Large Analysis and Review of European housing and health Status), noise annoyance in the housing environment was collected and evaluated in connection with medically diagnosed illnesses.

Results for Annoyance Caused by Traffic Noise and Neighbourhood Noise

In the following figures the relative risk of illness (OR), including a 95% confidence interval, is represented for people who have felt annoyed by traffic noise in the last 12 months. This is compared with people in the same age group who did not indicate any annoyance from the analysed noise source (comparison group). A recorded relative risk (OR) is statistically significant if the associated confidence interval does not include the value 1. Furthermore, the values of the OR are specified in the diagrams beneath the confidence intervals. The numbers of observed diseases (N) are recorded above the confidence intervals and the level of significance for a linear trend (1 d.f.) within the annoyance categories is specified in the middle of the diagrams.

Adults

The LARES study confirm that chronic annoyance from traffic noise can be associated with an increased risk to the cardio-vascular system in adults (18 to 59 years). A significantly higher risk of "cardiovascular symptoms" (CV-symptoms) as well as of "high blood pressure" (hypertension) was shown in subjects severely and chronically annoyed by traffic noise.

The trend within the annoyance categories (from "not at all" to "severely") was significant and supports a dose-effect relationship between hypertension and chronic annoyance induced by traffic noise. No increased risk was found for medically diagnosed heart attacks.

The effect of severe and chronic annoyance by traffic noise was not only seen in the cardiovascular system, but also, for example, in the respiratory system. Significantly increased risks were recorded for "respiratory symptoms" as well as for "bronchitis" in conjunction with severe and chronic annoyance by traffic noise. A significant, positive trend within the annoyance categories (from "not at all" to "severely) also appeared. In contrast, no significant trend within the annoyance categories could be seen for asthmatic diseases.

The effects of a chronic annoyance by traffic noise were also revealed in the stress-sensitive locomotor system. Significantly increased risks were registered for "arthritic symptoms" as well as for "arthritis" when severe and chronic annoyance by traffic noise is reported. The trend within the annoyance categories (from "not at all" to "severely") was significant in each case. A significantly increased risk towards allergies was also shown with severe and chronic annoyance by traffic noise. Here too the trend over the annoyance categories reached a statistical significance.

The effects of severe and chronic annoyance by traffic noise were very pronounced in the neuro-psychic system. The trend towards depression (based on sleep disturbance, anhedonia, low self-esteem and appetite change measured with the SALSA screening tool) as well as medically diagnosed depressions appeared frequently in conjunction with severe and chronic noise annoyance. The trend within the annoyance categories was highly significant. Furthermore, an increased risk of migraine was seen with severe and chronic noise annoyance. Here too the trend within the annoyance categories was highly significant.

Elderly

Stress research shows that the ability to cope with stress decreases with age. In this context, elderly people are often considered a potential risk group. The results of the LARES Study cannot confirm an increased illness risk for the elderly (people aged 60 years and older). No statistical association could be shown between chronic annoyance by traffic noise and an increased risk for the cardiovascular system of elderly adults is applies also to respiratory and neuro-psychicsystems.

In elderly people, the effect of chronic annoyance by traffic noise was only apparent in the locomotor system. For elderly people who indicate severe and chronic annoyance by traffic noise a significant increased risk for arthritic symptoms and arthritis were recorded. The trend within the annoyance categories was highly significant.

The results of the LARES-study do not verify that older people represent a risk group with regard to health impairment by traffic noise-induced annoyance.

Children

Many functional systems in small children (e.g., the nervous and the cognitive systems) are subject to rapid growth and intensive development phases during which neural structures develop and abilities are acquired. The development of the child is not designed to compensate for high environmental noise exposure. In such cases there stands a high risk for lasting dysfunctions. Beyond that, with early exposure to environmental influences, children have significantly more time to develop chronic illness. As a result, children can be regarded as an independent risk group. The results of the LARES study reveal a close relationship between severe and chronic annoyance by traffic noise and disorders of the respiratory system in children. When severe and chronic annoyance by traffic noise is reported, significantly high risks were noted for respiratory symptoms as well as for bronchitis. The trend within the annoyance categories was significant. The trend within the annoyance categories was significant. The risks were higher for children who indicate severe annoyance by traffic noise than the corresponding risks for adults. A higher risk for asthma for children was not identified.

The highly increased risks for illness in the respiratory system support the assumption that children are a risk group regarding traffic noise-induced annoyance.

2.12 VIBRATION OR SHOCK MEASURING INSTRUMENTS

The instruments which are used to measure the displacement, velocity or acceleration of a vibrating body are called vibration measuring instruments. Vibration measuring devices having mass, spring, dashpot, etc. are known as seismic instruments. The quantities to be measured are displayed on a screen in the form of electric signal which can be readily amplified and recorded. The output of electric signal of the instrument will be proportional to the quantity which is to be measured. The input is reproduced as output very precisely. Two types of seismic transducers known as vibrometer and accelerometer are widely used. A vibrometer or a seismometer is a device to measure the displacement of a vibrating body. Similarly, other device known as an accelerometer is an instrument to measure the acceleration of a vibrating body. Vibrometer is designed with low natural frequency and accelerometer with high natural frequency. So vibrometer is known as low frequency transducer and accelerometer as high frequency transducer.

2.12.1 Vibrometer

Let us consider Eqn. (4.5.2.3) again, *i.e.*,

$$\frac{Z}{B} = \frac{(\omega/\omega_n)^2}{\sqrt{[1-(\omega/\omega_n)^2]^2 + [2\varepsilon\,\omega/\omega_n]^2}}$$

Let us assume $\omega/\omega_n = r$ in the above equation

$$\frac{Z}{B} = \frac{r^2}{\sqrt{[1-r^2]^2 + [2\varepsilon r]^2}} \qquad \text{...(4.11.1.1)}$$

We have plotted the characteristics of this equation in Fig. 4.7. It is repeated here for convenience in Fig. 4.15.

When the value of r is very high (more than 3), the above equation can be written as

$$\frac{Z}{B} = \frac{r^2}{\sqrt{[(1-r^2)]^2}} \simeq 1$$

$$Z = B \qquad \text{...(4.11.1.2)}$$

(as $2\varepsilon r$ is very small term, so it is neglected for a wide range of damping factors)

So the relative amplitude Z is shown equal to the amplitude of vibrating body B on the screen. Though Z and B are not in the same phase but B being in single harmonic, will result in the output signal as true reproduction of input quantity. From Fig. 4.15 it can be seen that for large

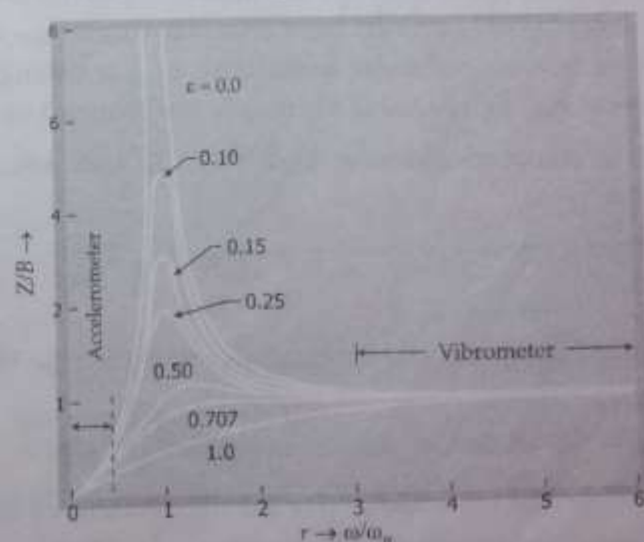


Fig. 4.15 Vibration measuring instrument.

values of ω/ω_n (r), the ratio $\frac{Z}{B}$ approaches unity for every value of damping. The instrument shown in Fig. 4.16 works as a vibrometer for very large value of r.

Vibrometer known as low frequency transducer is used to measure the high frequency ω of a vibrating body. Since the ratio r is very high so the natural frequency of the instrument is low. Low natural frequency means heavy mass of the body of the instrument which makes its rare application in practice specially in systems which require much sophistication. The instrument is used to record building vibrations or vibrations of huge structures like railway bridges. The frequency range of a vibrometer depends upon several factors such as damping, its natural frequency, etc. It may have natural frequency 1 Hz to 5 Hz.

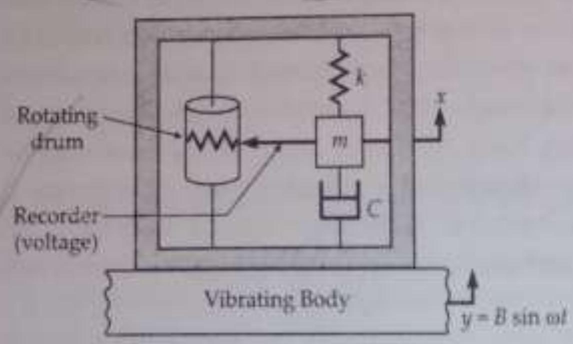


Fig. 4.16 Vibrometer.

The relative motion ($\dot{z}$) between the mass and vibrating body is converted into proportional voltage by assuming the mass as permanent magnet (refer Fig. 4.16).

2.12.2 Accelerometer

An accelerometer is used to measure the acceleration of a vibrating body. If the natural frequency ω_n of the instrument is very high compared to the frequency ω which is to be measured, the ratio ω/ω_n (r) is very small *i.e.*, $\omega/\omega_n << 1$. The range of frequency measurement is shown in Fig. 4.14. Since the natural frequency of the instrument is high so it is very light in construction. With the help of electronics integration devices it displays velocity and displacement both. Because of its small size and usefulness for determining velocity and displacement besides acceleration, it is very widely used as a vibration measuring device and is termed as high frequency transducer. The voltage signals obtained from an accelerometer are usually very small which can be preamplified to see them bigger in size on oscilloscope. For getting velocity and displacement double integration device may be used and the results are obtained on screen.

Again considering Eqn. (4.5.2.3) and assuming $\omega/\omega_n << 1$, we can also assume that $(\omega/\omega_n) \to 0$

$$\frac{Z}{B} = \left(\frac{\omega}{\omega_n}\right)^2 \cdot f \quad \text{or} \quad Z = \frac{\omega^2 B}{\omega_n^2} f \qquad ...(4.11.2.1)$$

where f is a factor which remains constant for the useful range of accelerometer.

where
$$f = \frac{1}{\sqrt{(1-r^2)^2 + (2\varepsilon r)^2}} \qquad ...(4.11.2.2)$$

In this equation $\omega^2 B$ is the acceleration of the vibrating body. It is clearly seen that the acceleration is multiplied by a factor $\frac{1}{(\omega_n)^2}$. To keep the value of factor f equal to 1 for very high range of ω/ω_n ratio, ε should be high in value. The amplitude Z becomes proportional to the acceleration provided the natural frequency remains constant. Thus Z is treated proportional to the amplitude of acceleration to be measured, so it can be written as $Z \alpha$ acceleration. The instrument gives accurate results for very high value of its natural frequency. With the help of Eqn. (4.11.2.2), a Fig. 4.17 is drawn to show the linear response of the accelerometer. It is seen that for $\varepsilon = 0.70$ there is complete linearity for accelerometer for $\omega/\omega_n \leq .25$. The above equation can be written as

$$f = \frac{1}{\sqrt{1 + r^4}} = 1 \quad \text{for } r << 1.0$$

Thus the instrument with 100 Hz natural frequency will have a useful frequency range from 0 to 25 Hz at $\varepsilon = 0.70$ and will provide very accurate results. For this purpose electromagnetic type accelerometers are widely used nowadays.

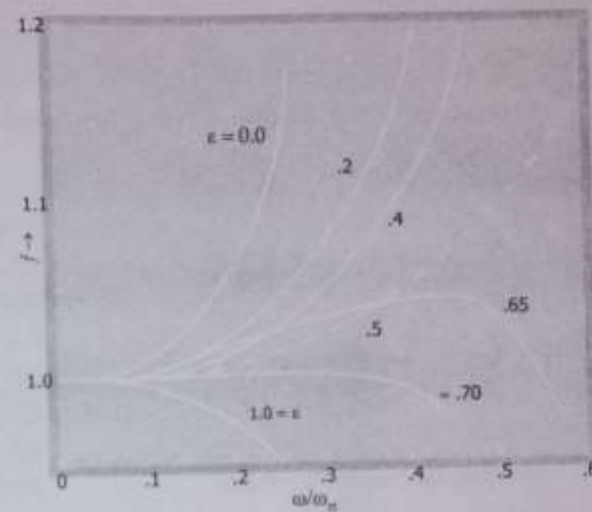


Fig. 4.17 Linearity response of an accelerometer.

MODULE 3

Syllabus- Introduction to Transportation Noise and Vibration Sources, Noise Characteristics of engines, engine overall noise levels, assessment of combustion noise, assessment of mechanical noise, engine radiated noise, intake and exhaust noise, engine accessory contributed noise, transmission noise, aerodynamic noise, tyre noise, brake noise

3.1 INTRODUCTION TO TRANSPORTATION NOISE

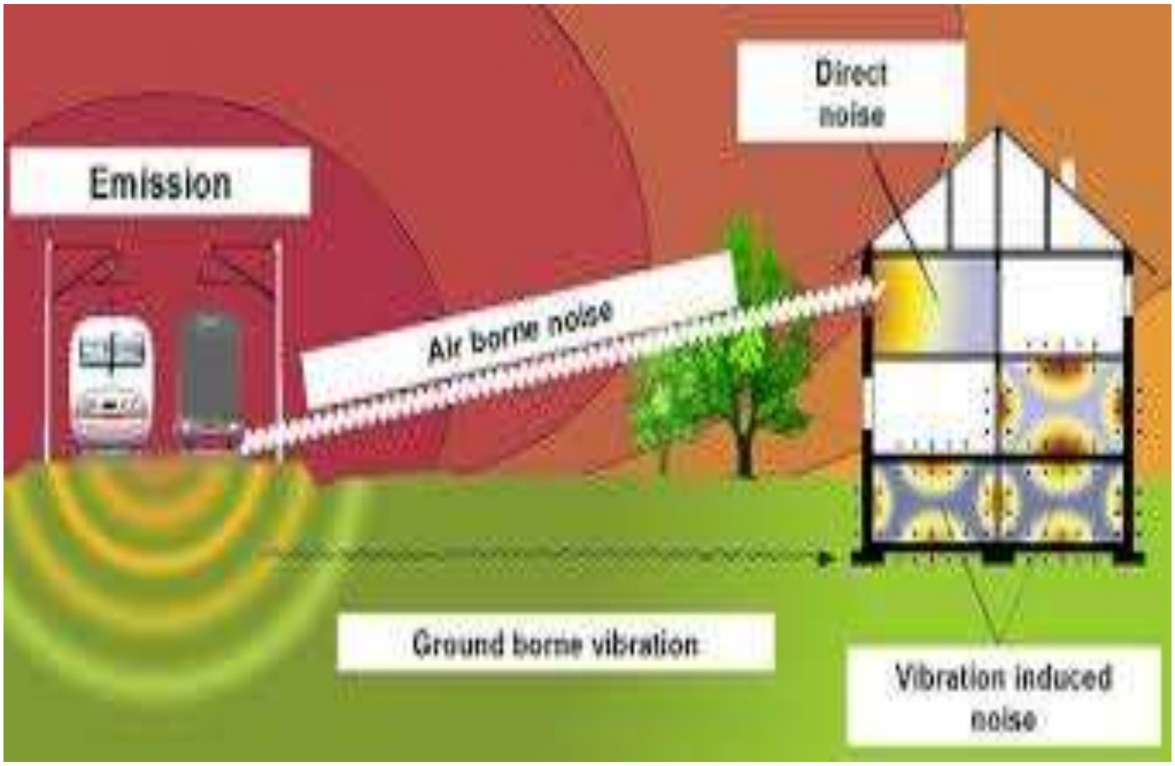
Transportation noise is the main source of environmental noise pollution, including road traffic, rail traffic and air traffic. As a general rule, larger and heavier vehicles emit more noise than smaller and lighter vehicles. Exceptions would include: helicopters and 2- and 3-wheeled road vehicles.

1. Road Traffic

The noise of road vehicles is mainly generated from the engine and from frictional contact between the vehicle and the ground and air. In general, road-contact noise exceeds engine noise at speeds higher than 60 km/h. The physical principle responsible for generating noise from tire-road contact is less well understood. The sound pressure level from traffic can be predicted from the traffic flow rate, the speed of the vehicles, the proportion of heavy vehicles, and the nature of the road surface. Special problems can arise in areas where the traffic movements involve a change in engine speed and power, such as at traffic lights, hills, and intersecting roads; or where topography, meteorological conditions and low background levels are unfavorable (for example, mountain areas).

2. Rail Traffic

Railway noise depends primarily on the speed of the train, but variations are present depending upon the type of engine, wagons, and rails and their foundations, as well as the roughness of wheels and rails. Small radius curves in the track, such as may occur for urban trains, can lead to very high levels of high-frequency sound referred to as wheel squeal. Noise can be generated in stations because of running engines, whistles and loudspeakers, and in marshaling yards because of shunting operations. The introduction of high-speed trains has created special noise problems with sudden, but not impulsive, rises in noise. At speeds greater than 250 km/h, the proportion of high-frequency sound energy increases and the sound can be perceived as similar to that of overflying jet aircraft. Special problems can arise in areas close to tunnels, in valleys or in areas where the ground conditions help generate vibrations. The long-distance propagation of noise from high-speed trains will constitute a problem in the future if otherwise environment-friendly railway systems are expanded.



3. Air Traffic

Aircraft operations generate substantial noise in the vicinity of both commercial and military airports. Aircraft takeoffs are known to produce intense noise, including vibration and rattle. The landings produce substantial noise in long low-altitude flight corridors. The noise is produced by the landing gear and automatic power regulation, and also when reverse thrust is applied, all for safety reasons. In general, larger and heavier aircraft produce more noise than lighter aircraft. The main mechanism of noise generation in the early turbojet-powered aircraft was the turbulence created by the jet exhaust mixing with the surrounding air. This noise source has been significantly reduced in modern high by-pass ratio turbo-fan engines that surround the high-velocity jet exhaust with lower velocity airflow generated by the fan. The fan itself can be a significant noise source, particularly during landing and taxiing operations. Multi-bladed turbo-prop engines can produce relatively high levels of tonal noise. The sound pressure level from aircraft is, typically, predicted from the number of aircraft, the types of airplanes, their flight paths, the proportions of takeoffs and landings and the atmospheric conditions. Severe noise problems may arise at airports hosting many helicopters or smaller aircraft used for private business, flying training and leisure purposes. Special noise problems may also arise inside airplanes because of vibration. The noise emission from future super jets is unknown.

A sonic boom consists of a shock wave in the air, generated by an aircraft when it flies at a speed slightly greater than the local speed of sound. An aircraft in supersonic flight trails a sonic boom that can be heard up to 50 km on either side of its ground track, depending upon the flight altitude and the size of the aircraft (Warren 1972). A sonic boom can be heard as a loud double boom sound. At high intensity it can damage property.

Noise from military airfields may present particular problems compared to civil airports (von Gierke & Harris 1987). For example, when used for night-time flying, for training interrupted landings and takeoffs (so-called touch-and-go), or for low-altitude flying. In certain instances, including wars, specific military activities introduce other intense noise pollution from heavy vehicles (tanks), helicopters, and small and large fire-arms.

3.2 SOURCES OF VIBRATION

There are two types of Sources, natural sources and manmade sources.

1. Natural Sources:-

- Earthquake
- Thunder
- Volcano
- Tornado

2. Manmade Sources:-

- Engines
- Motors
- Compressors
- Generators
- Machines in industries, workshops, etc.
- Home Appliances, Example: Mixer, Grinder
- Mobile Phones
- Automobiles

- Explosions

3.3 NOISE CHARACTERISTICS OF ENGINES

There are four characteristics for noise.

- Loudness
- Frequency
- Duration
- Subjectivity

1. Loudness of Sound

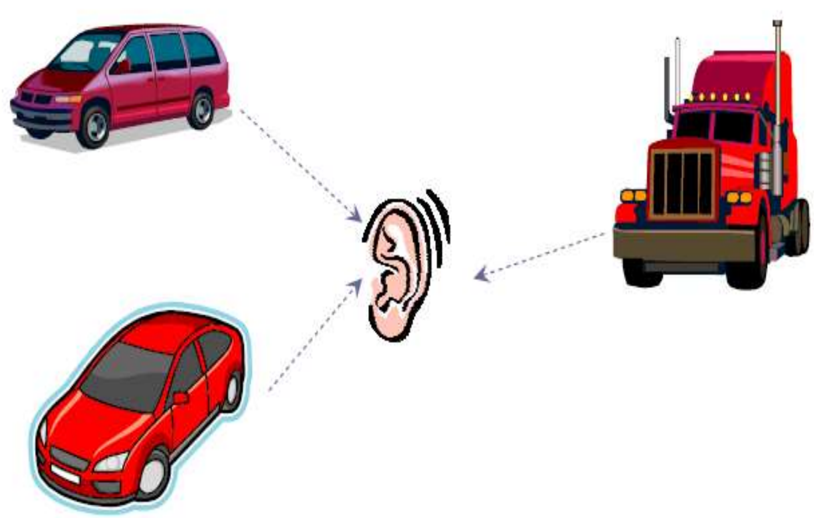
- Loudness also called “intensity”

- Mechanism of sound transmission:-
    - Noise is emitted
    - Results in pressure fluctuations in the air
    - Pressure fluctuations cause contracting of the ear drum and generate the sensation of sound to the receiver

- Hearing extremes:-
    - Lowest pressure fluctuation that your ear can sense: $2x10^{-5}$ N/m^2
    - Highest: 63 N/m^2 (causes hearing pain in your ear)

- Measuring Loudness: What units?
    - Sound pressure (N/mm^{2}or psi)
    - Sound pressure levels (or decibels)

Loudness of Sound: How does it all add up?



$$SPL_{(total)} = 10 \log_{10}\left(10^{(SPL_{AUTO})/10} + 10^{(SPL_{VAN})/10} + 10^{(SPL_{TRUCK})/10}\right)$$

Addition of Sound Loudness - Example

- A typical jet flying overhead has a SPL of 105 dB. Find the total SPL of two of such jets flying overhead at that height at the same time.

- **Solution:**

$$SPL_{(total)} = 10\log_{10}\left(10^{SPL_1/10} + 10^{SPL_2/10}\right)$$

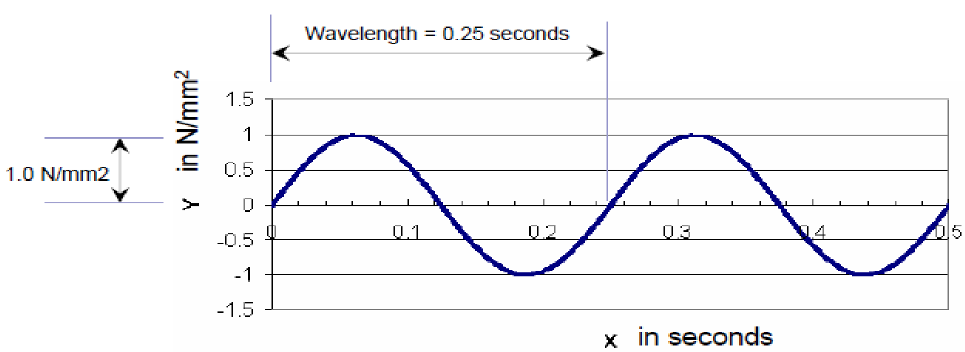
$$= 10\log_{10}\left(10^{105/10} + 10^{105/10}\right)$$

$$= 108 \text{ dB}$$

2. Frequency of Sound

- Definition: change in the rate of pressure fluctuations in the air.
- Units: Number of oscillations (pressure changes) per second or hertz (Hz)
- Frequencies that can be heard by human ear: 20 Hz to 20,000 Hz.
- Ear identifies a sound by its frequency and not its loudness. (example, braking sound vs. horn sound)
- Human ear does not hear well sounds at following frequencies
- Less than 500 Hz or
- Higher than 10,000 Hz
- Therefore, loudness not sufficient to describe a sound. Frequency also needed.

Difference between sound loudness and sound frequency



Loudness = maximum amplitude = 1.0 N/mm^2

Frequency = 1 cycle per 0.25 seconds = 4 cycles per second

3. Noise Duration

- Together with loudness and frequency, duration helps us to describe a noise more completely.
- Consider these extremes:-
    - Collision between two vehicles: very loud, but very short duration.
    - Noise from a nearby freeway: not very loud, but is continual.
- Variation of traffic noise with time is considered important for noise assessment.
- L_{max}: The maximum noise level occurring during a definite time period.

4. Subjectivity of Noise

- Individuals have different responses to various sounds.
- A sound type that is pleasing to an individual may be a nuisance (noise) to another.
- Degree of noise unpleasantness may be influenced by the time or place at which it occurs.
    - For example, flow of truck traffic through a residential area may be more offensive at night than on a weekday afternoon.

3.4 ENGINE OVERALL NOISE LEVELS

The engine produces different types of noises. Each noise has different noise levels. Some may be low noise levels. Some may be high level noise. The total effect of all engine related noises is termed as engine overall noise level.

The different types of engine noises are

1. Engine intake noise

2. Engine combustion noise

3. Engine mechanical noise

4. Engine radiated noise

5. Engine exhaust noise

All these noises are measured in dB.

Engine overall noise level = $10 \log [10^{I.N/10} + 10^{C.N/10} + 10^{M.N/10} + 10^{R.N/10} + 10^{E.N/10}]$

3.5 ENGINE INTAKE NOISE

The engine intake noise produced mainly due to the movement of air inside the intake system.

The engine intake system consist of

1. Air Filter

2. Air Compressor

3. Throttle Valve

4. Intake Manifold

5. Inlet Valve

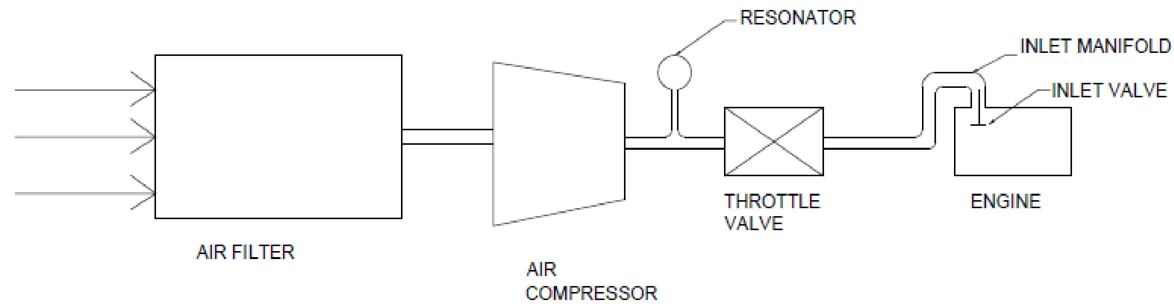


FIG: ENGINE INTAKE SYSTEM

The dust particle from the atmosphere is removed by air filter. Then the filtered air is compressed and given to engine through inlet valve. The valve is protected by intake manifold. The throttle valve regulates the flow of air. The air produces noise due to its pulsating and turbulence movement inside the system. Intake noise among the noises occurring in a vehicle is primarily Airborne Noise produced in the engine. This noise is low in temperature, and is propagated in the opposite direction to that of intake flow. The intake noise is a noise produced as the air column within the intake tube is vibrated according to pressure change as a result of opening/closing of the intake valve. Main causes for occurrence of the intake system include noise due to surface vibration of intake system tube or air filter box, etc., and abnormal flow of fluids due to intake valve and turbulent flow around the throttle.

High-frequency noise above about 1,000Hz of broad band relatively easy to be attenuated is produced by this turbulent flow. When the fluid enters in the cylinder as the intake valve is opened the minimum pressure occurs, and a large pulsation is produced as kinetic energy of the fluid is converted to pressure energy when the intake valve is closed.

Reduction Methods for Intake Noise

Methods for reduction of noise are largely divided into 3 types, which include the method of installing a resonator, the method of using a sound-absorbing material, and application of a particular groove shape at compressor inlet.

1. Noise reduction by using sound-absorbing material:-

Intake noise at particular frequencies is reduced by using the porous duct for the plastic duct part after air cleaner. The principle for noise reduction by porous duct with diversified porosities is that the porous duct wall plays a role of a sort of sound-absorbing material since the sound is leaked out through the duct wall.

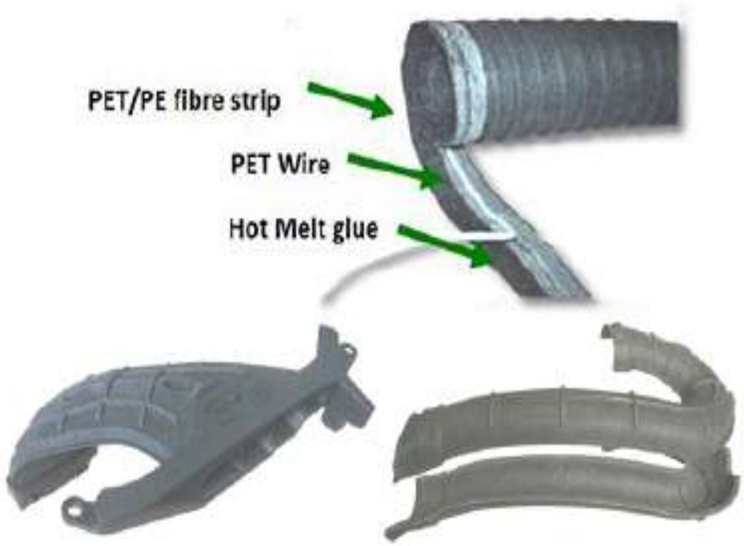


Figure 1: Porous type duct of intake system

2. Reverse flow-type silencer with attachment of resonator:-

Reverse flow-type silencer is used mainly in a form of air cleaner rather than being used as an acoustic element due to spatial problems. Since it changes the direction of fluid flow and sound wave propagation to the opposite one, a large transmission loss occurs in comparison with a simple expansion-type silencer, and such form causes degradation in engine performance by inducing a high negative pressure although noise attenuation in low-frequency regions is particularly outstanding.

The resonance frequency is calculated by the relation

$f = rpm \times (n/2) \times (1/60)$

The resonator is working with the relation,

$$f = \frac{c}{2\pi}\sqrt{\frac{S_b}{LV}} \qquad (1)$$

Where S_b is neck cross section area, L is neck length, V is cavity volume and c is speed of sound.

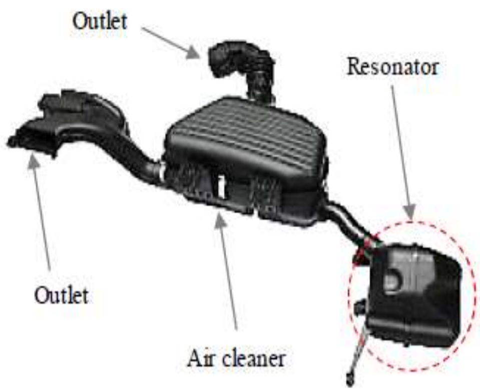


Figure 2: Resonator of air intake system

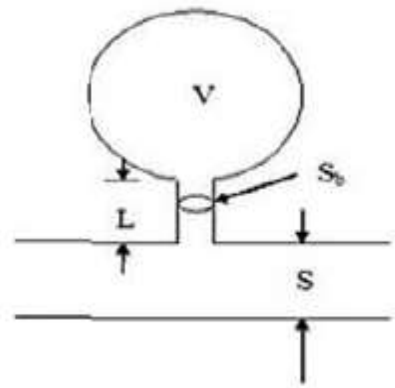
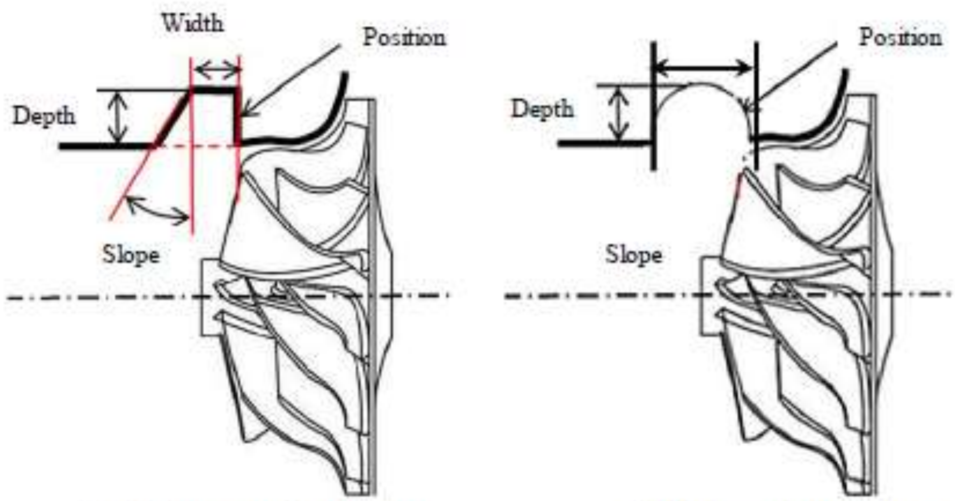


Figure 1: The simplified typical resonator

3. Application of optimum groove shape at compressor inlet:-

When a groove with diversified shapes was applied to the compressor inlet, the shape with relatively excellent noise reduction effects was a square groove rather than a circular groove, and not only the flow noise of narrowband but also that of a broad region with high frequency was affirmed to be applicable for the reduced noise.



(a) Rectangular grooves (b) Round grooves

Figure 3: Grooves of automotive turbocharger

3.6 ENGINE EXHAUST NOISE

The engine exhaust noise produced mainly due to the movement of air inside the exhaust system.

The engine exhaust system consist of

1. Exhaust Valve

2. Exhaust Manifold

3. Turbocharger turbine

4. Muffler

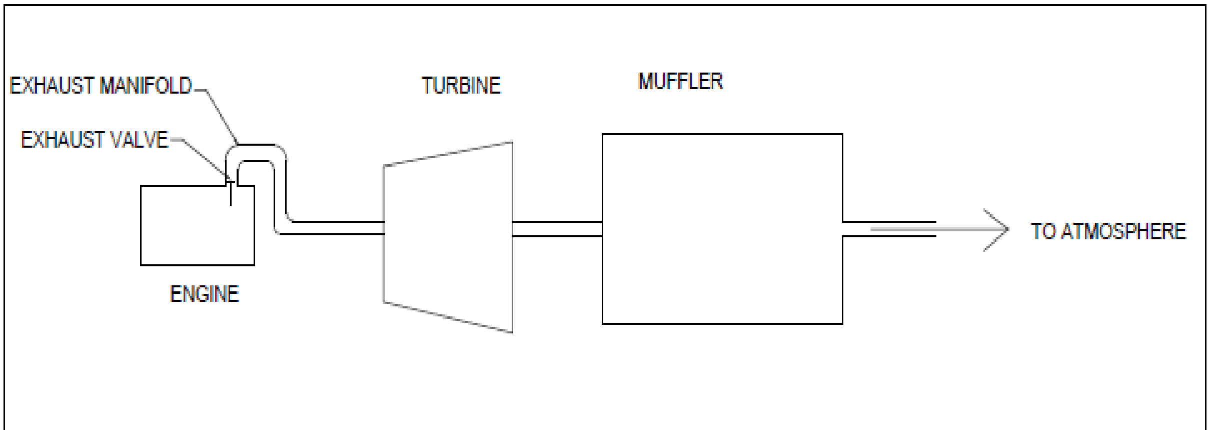
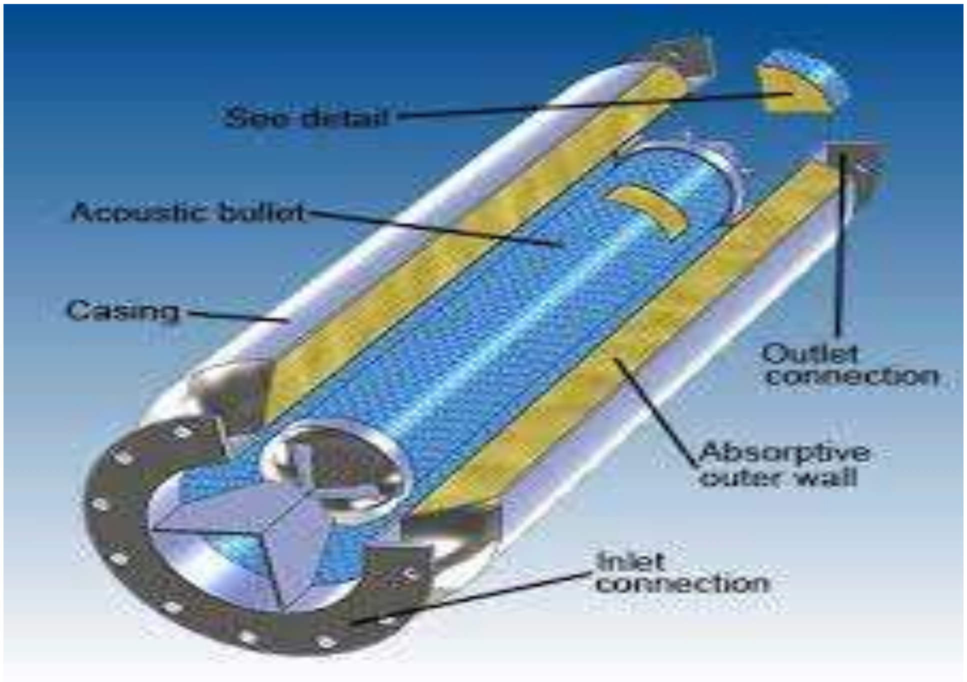


FIG: ENGINE EXHAUST SYSTEM

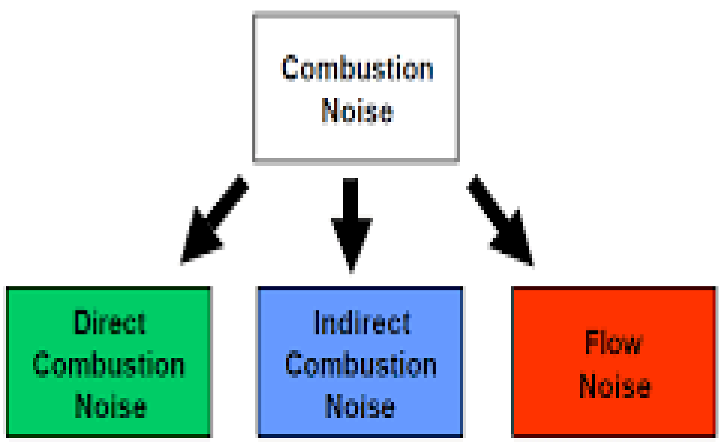
Exhaust noise produced by release of gases as exhaust valves open and close.



The turbocharger and muffler are used to reduce the noise. Turbo charging reduces engine and exhaust noise (because of better combustion). Muffler reduces the speed of exhaust air and reduces noise at outlet. So the muffler is also known as silencer.

3.7 ENGINE COMBUSTION NOISE

The combustion noise occurs inside the engine due to the combustion of fuel. Shock pressure waves produced inside the engine at the time of combustion and it propagates outwards. If the condition of engine is bad, it produce more noise. Ubnormal noise inicates engine complaints.

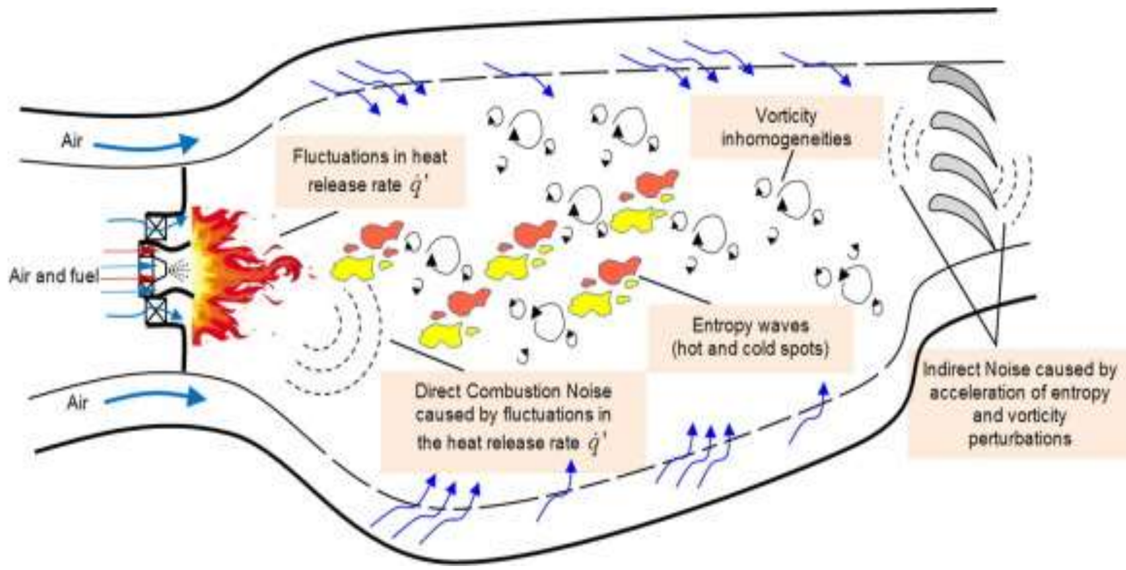


The combustion noise is classified into three: - Direct combustion noise, Indirect Combustion Noise and Flow Noise.

1. Direct Combustion Noise: - It is the noise due to direct combustion, caused by fluctuations in the heat releasing rate at the time of combustion.

2. Indirect Combustion Noise: - It is the noise caused by acceleration of entropy and vorticity inhomogeneities.

3. Flow noise: - It is the noise caused by the flow of combustion products due to concentration difference to the surroundings.

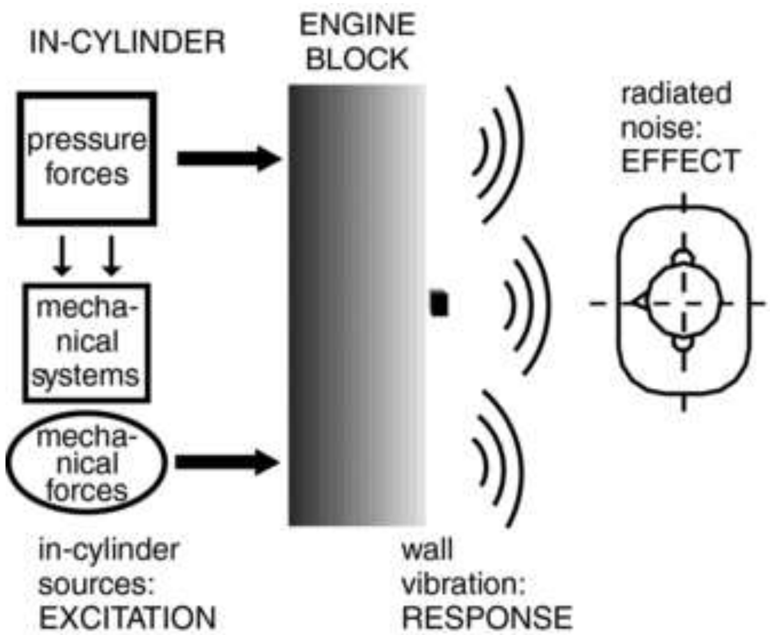


3.8 ENGINE RADIATED NOISE

ENGINE SURFACE NOISE: Engine surface noise refers to sound emitted from vibrating surfaces of engine components and accessories and other than items included in the engine exhaust, in take and cooling systems.

- Engine surface noise is generally much higher for diesel engine than for gasoline engine

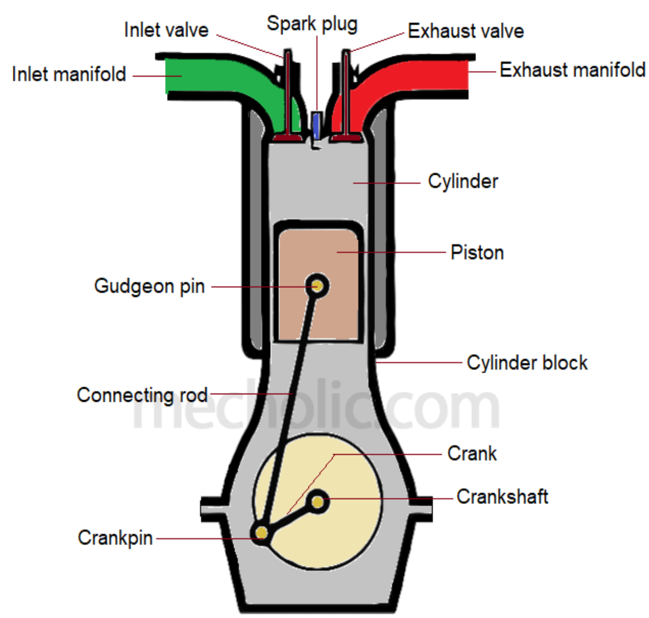
- Turbo charging of a diesel engine can result in some reduction of engine surface-radiated noise at high engine loads.



The noise emitted by the engine surface is known as engine radiated noise. It is in the form of electromagnetic waves. Due to combustion inside the chamber, the engine surface temperature increases. The temperature outside engine is the atmospheric temperature. This difference in temperature creates a temperature gradient and the surface of engine emits radiations to the atmosphere. This produces noise termed as engine radiated noise.

3.9 MECHANICAL NOISE

The engine mechanical noise is the noise produced by the moving parts of an engine. Due to the relative movement of different parts friction is developed and noise is the result of friction. The movement of parts are either rotating or reciprocating.



The moving parts are,

1. Inlet and Exhaust valves (Pulsating movement)

2. Piston and Piston rod (Piston slap – Reciprocating movement)

3. Connecting Rod (Combined motion of rotation and Reciprocating Motion)

4. Crank (Rotation)

5. Crankshaft (Rotation)

6. Camshaft (Rotation)

7. Flywheel (Rotation)

Due to the movement of above parts noise produced. The abnormal noise is the sign of any failure of these parts. If it is ignored it will results engine failure.

3.10 ENGINE ACCESSORY NOISE

These noises are produced from the engine accessories. The important accessories are

1. Fuel Pump: - Used to pump the fuel into engine.

2. Fuel injection Pump: - Used to inject the fuel to engine chamber.

3. Oil Pump: - Used to pump the oil.

4. Radiator and Cooling fan: - To cool the Engine.

5. Electric Motor: - To start the engine.

6. Alternator: - To generate current from engine movement and it is stored in battery.

7. Oil: - Used for lubrication. Absence of oil creates metal to metal contact between the moving parts and develops friction and hence noise.

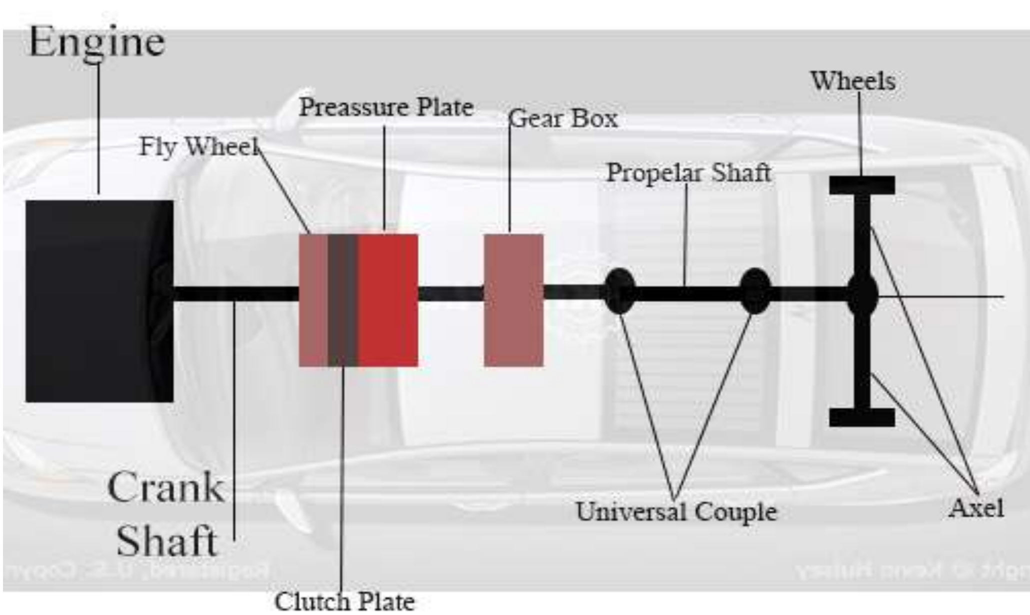
8. Turbocharger: - Used to make use of exhaust gas and it rotates compressor in the intake system.

3.11 ENGINE TRANSMISSION NOISE

The transmission is an essential component of a vehicle because it sustains its drivability. Basically, the transmission works to redirect the engine power to the driveshaft so that the driver can successfully turn the wheels of the car.

When your car starts making strange noises or vibrations, it's never a good thing – especially if it's coming from the transmission. Noise – whether it's banging, grinding or scraping – means that two parts are coming into contact that isn't supposed to. Those sounds are your warning that trouble's coming, and you need to take action right away.

If the fluid level in your transmission is too low, you will notice a gurgling noise. This noise is caused by the excess air in your transmission line.



Below Are The Top 3 Causes Of Transmission Noise.

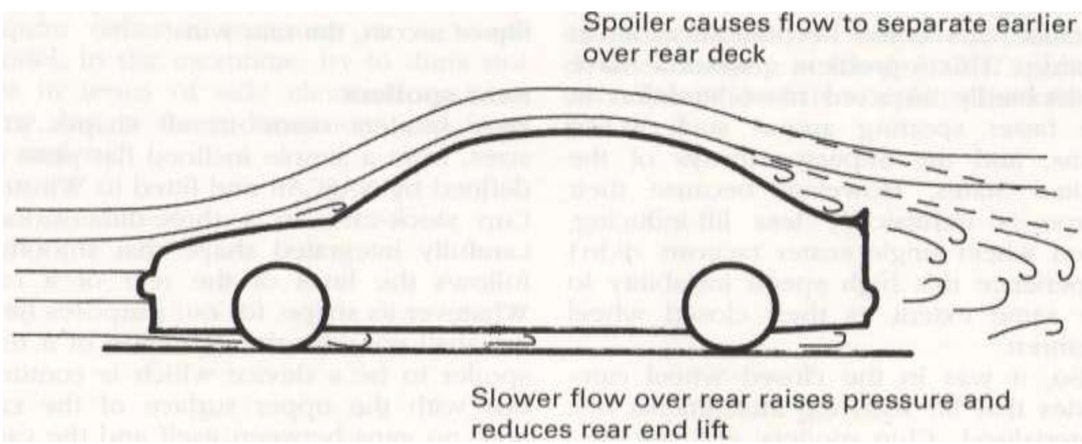
Old Transmission Fluid- If your transmission fluid has not been changed after your car has traveled this many miles, then it means your fluid is too old and must be replaced.

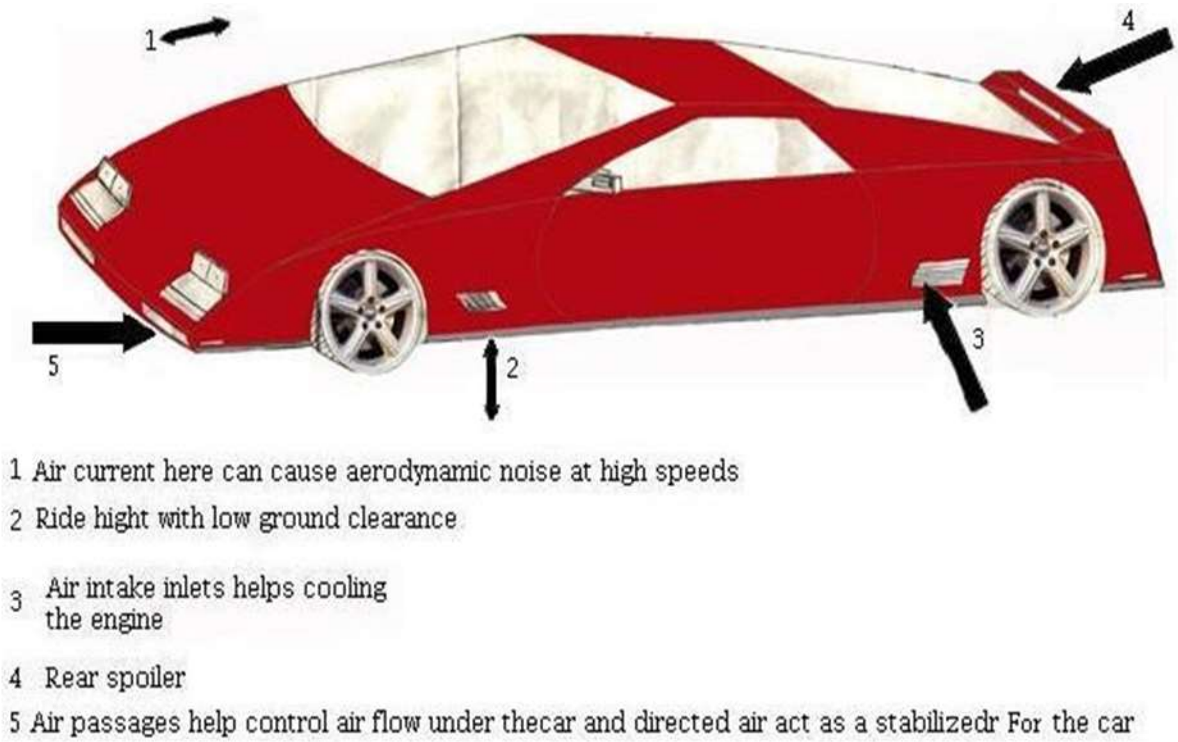
Petroleum-based Transmission Fluid - petroleum-based transmission fluid which would cause varnish deposits to form quickly. It would only take a couple of years for the filters to get clogged and prevent the normal flow of the transmission fluid. It will cause more heat and friction from the moving components of your transmission. Just replace the petroleum-based fluid with the synthetic fluid and then all that nasty debris will be washed away.

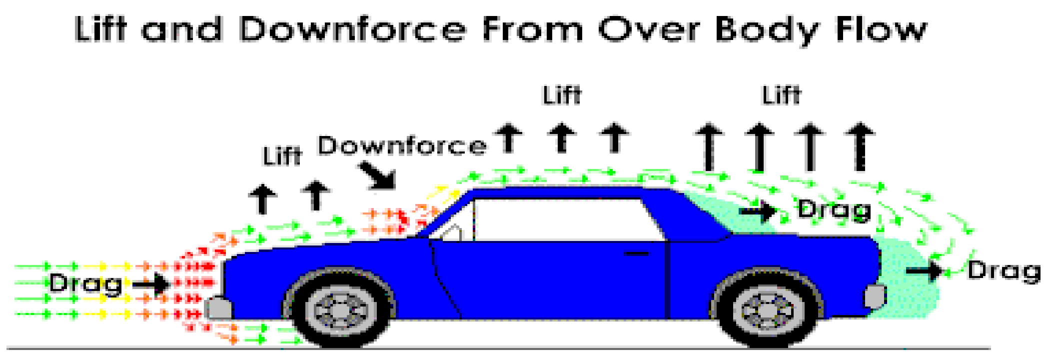
Bad Torque Converter – The transmission depends on the torque converter to allow it to shift gears properly. There are needle bearings in the torque converter which may get damaged or worn out after a while. If this were to happen, your transmission will make unusual sounds whenever your driving gear is set. These are often grinding noises which will be annoying to hear. If you set it to the neutral gear, then the sounds will stop. This is a clear indication that you need to replace your torque converter.

3.12 AERODYNAMIC NOISE

This noise could come from an aircraft's engine—propellers, fans, combustion chamber, jets—or the vehicle itself—external surfaces—or from sonic booms. The majority of the sound produced is due to the motion of air and its interaction with solid boundaries. Aerodynamic Noise is ideal for mechanical and aerospace engineering. It may also be useful for designers of cars, trains, and wind turbines.







In motor vehicles there are two primary sources of aerodynamic sound: the engine-cooling fan and the interaction of either the entire vehicle or some of its components with the airstream created by vehicle movement.

Aerodynamically generated noise (commonly known as wind noise) is the major source of noise at high speed in a modern car. They often dominate at cruise speeds above 60 mph.

Aircraft noise is noise pollution produced by aircraft during the various phases of a flight. Aerodynamic noise arises from the airflow around the aircraft fuselage (the main body of an aircraft) and control surfaces. This type of noise increases with aircraft speed and also at low altitudes due to the density of the air. Jet-powered aircraft create intense noise from aerodynamics. Low-flying, high-speed military aircraft produce especially loud aerodynamic noise.

3.13 TYRE NOISE

Several factors can lead to tire noises when driving. Oftentimes, the noise is just air being compressed in the tire treads. Different tread designs will produce different volumes of noise. For example, tires designed for heavy towing or off-roading will be louder than others because their treads are deeper.

Here are a few problems that can cause tire noises.

• **Uneven wear** is a leading cause of tire noises because contact between the road and uneven tires isn't uniform. The unbalanced tread depths cause tires to emit loud noises while driving. Usually, you'll hear sounds caused by uneven wear coming from one tire.

• **Alignment issues** can also cause tire noises. As you travel, the air chamber produces a low humming or drumming sound. If your car is overdue for a wheel alignment, then you'll start to experience a bumpier ride. This will cause irregular tire movement and make the sounds coming from the air chamber louder.

• **A bad wheel bearing** is one of the more serious issues that cause tire noise. When the wheel bearing in your tires is damaged or deteriorating, it produces a soft humming sound or grinding noise when you change lanes. It's best to have the wheel bearings replaced as soon as possible to prevent excessive

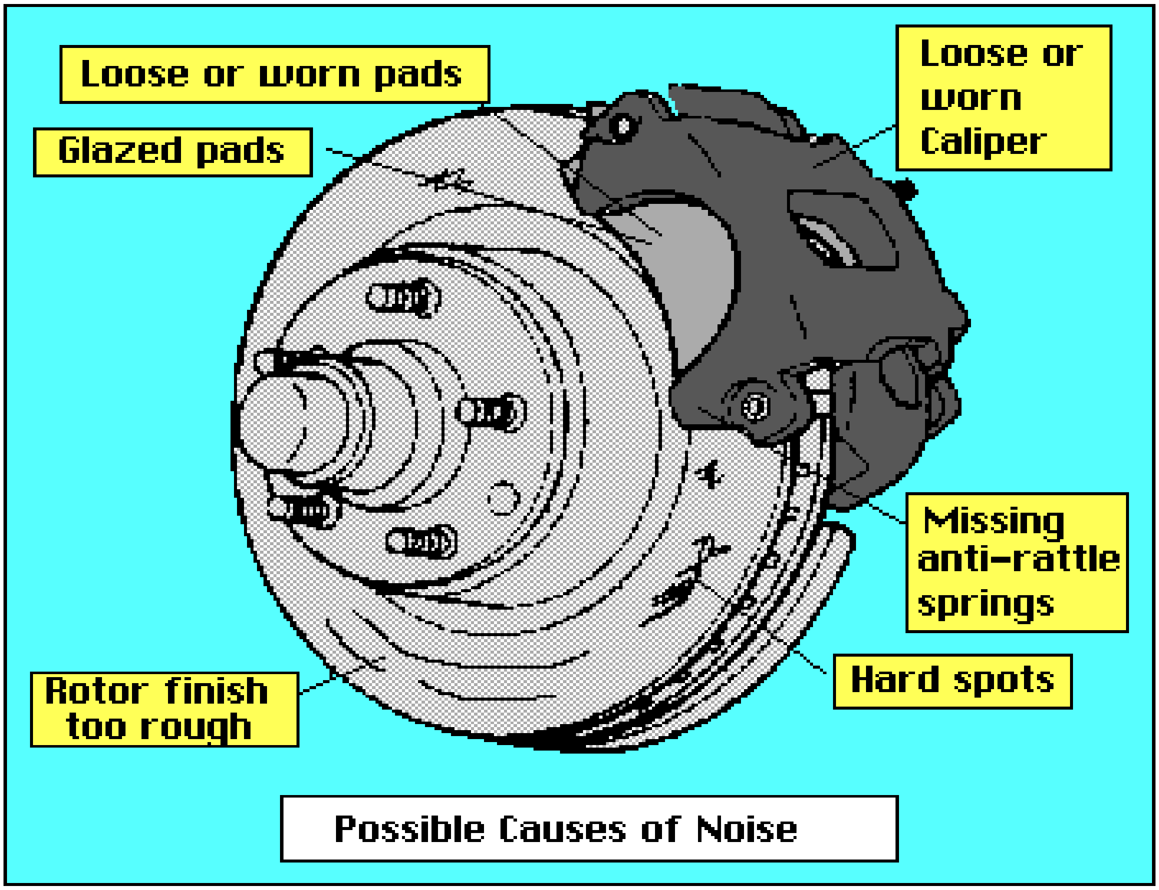
damage and collisions.

To reduce the tire noise ensure that the tires have the right amount of air pressure and routine wheel alignments will help to prevent uneven tire wear.

3.14 BRAKE NOISE

Brake noise typically originates from vibration on a part within the wheel end section of the vehicle – between the tire and the connection to the chassis. Noise is often blamed on the brake pad itself but can come from any part, from the wheel bearing to the ball joint. Within the brake system, it's normal to have some vibration, but it is not usually intense enough to be audible.

Hearing a grinding noise when you apply your brakes is really like hitting a rumble strip on the edge of the highway; if you hear this, you need to wake up and stop driving. A grinding noise on braking is usually caused by a lack of brake pad material; the pads and rotors are now metal to metal, with no braking material left.



Most brake noise complaints are squeak-related or metal-on-metal is related to the brake pad. The grinding noise is the result of worn pads contacting the rotor and is a common problem. The least common noise is a knocking sound. Brake pads are like bars of soap. Eventually they get used up, and you have to replace it.

The knocking noise mentioned earlier is caused by the brake pads rattling in the brackets. This diagnosis is easy and can be performed on the initial road test. Lightly apply pressure to the brakes while going over a potholed road. If the noise is gone, the pads are moving. To fix the rattling pads, buy a hardware kit with the parts needed.

Common Brake Noises and Their Causes

Noise	Possible Cause
Grinding	Stop driving! Usually caused by the brake pad being worn down to nothing.
Thumping from rear	Hard to diagnose, but usually the rear drums.
Squeaking	Either cheap brake pads, or the brake wear indicator is hitting the rotor.
Thumping or squealing	If car is parked outdoors, probably caused by rusted rotors.
Scraping	You may have picked up a rock.

Another solution to the brake-pad vibration problem is a good coating of anti-squeal compound, either in spray or liquid application form. Another option for reducing the vibration is to use a thin coating of a high-temperature anti-seize compound applied to the same area indicated for the anti-squeal compound.

MODULE 4

Syllabus- Reduction of noise and vibrations I: Vibration isolation, tuned absorbers, untuned viscous dampers, damping treatments, application dynamic forces generated by IC engines, engine isolation, crank shaft damping, modal analysis of the mass elastic model shock absorbers.

REDUCTION OF NOISE AND VIBRATIONS

Damping is one of the most effective methods of controlling noise and vibration. It is a process that converts vibrational energy into heat, eliminating the vibrational energy through friction and other processes. Increasing damping or stiffness can both reduce resonant vibration and the resulting noise by preventing the vibration from travelling through the structure. Appliances, heavy equipment, generators, and other mechanical structures are capable of producing a great amount of noise and vibration. Vibrational energy is problematic for a variety of reasons; it can make appliances such as washing machines, blenders, vacuums noisy and disruptive for users. Medical equipment can be uncomfortable, and in larger mechanisms, like engines, noise and vibration control may be needed in the engine compartments, enclosures, cab walls, and floor and ceiling systems. This is because vibrations cause instability and fatigue in mechanical structures in addition to creating excessive noise.

4.1 VIBRATION ISOLATION

Vibration isolation is the process of isolating an object, such as a piece of equipment, from the source of vibrations.

Vibration is undesirable in many domains, primarily engineered systems and habitable spaces, and methods have been developed to prevent the transfer of vibration to such systems. Vibrations propagate via mechanical waves and certain mechanical linkages conduct vibrations more efficiently than others. Passive vibration isolation makes use of materials and mechanical linkages that absorb and damp these mechanical waves. Active vibration isolation involves sensors and actuators that produce disruptive interference that cancels-out incoming vibration.

VIBRATION ISOLATION

- Vibration isolation is the process of isolating an object, such as a piece of equipment, from the source of vibration
- The effectiveness of isolation is expressed in terms of force or motion
- Lesser the amount of force or motion transmitted to the foundation greater is said to be the isolation

TYPES

➢ PASSIVE VIBRATION ISOLATION

- Refers to vibration isolation or mitigation of vibrations by passive techniques such as rubber pads or mechanical springs

➢ ACTIVE VIBRATION ISOLATION

- Also known as electronic force cancellation
- Employs electric power, sensors, actuators, and control systems for vibration isolation

Type 1. Passive Vibration Isolation

"Passive vibration isolation" refers to vibration isolation or mitigation of vibrations by passive techniques such as rubber pads or mechanical springs, as opposed to "active vibration isolation" or "electronic force cancellation" employing electric power, sensors, actuators, and control systems. Passive vibration isolation is a vast subject, since there are many types of passive vibration isolators used for many different applications. A few of these applications are for industrial equipment such as pumps, motors, HVAC systems, or washing machines; isolation of civil engineering structures from earthquakes (base isolation), sensitive laboratory equipment, valuable statuary, and high-end audio.

A basic understanding of how passive isolation works, the more common types of passive isolators, and the main factors that influence the selection of passive isolators.

Common passive isolation systems

a) Pneumatic or air isolators:-

These are bladders or canisters of compressed air. A source of compressed air is required to maintain them. Air springs are rubber bladders which provide damping as well as isolation and are used in large trucks. Some pneumatic isolators can attain low resonant frequencies and are used for isolating large industrial equipment. Air tables consist of a working surface or optical surface mounted on air legs. These tables provide enough isolation for laboratory instrument under some conditions. Air systems may leak under vacuum conditions. The air container can interfere with isolation of low-amplitude vibration.

b) Mechanical springs and spring-dampers:-

These are heavy-duty isolators used for building systems and industry. Sometimes they serve as mounts for a concrete block, which provides further isolation.

c) Pads or sheets of flexible materials such as elastomers, rubber, cork, dense foam and laminate materials:-

Elastomer pads, dense closed cell foams and laminate materials are often used under heavy machinery, under common household items, in vehicles and even under higher performing audio systems

d) Molded and bonded rubber and elastomeric isolators and mounts:-

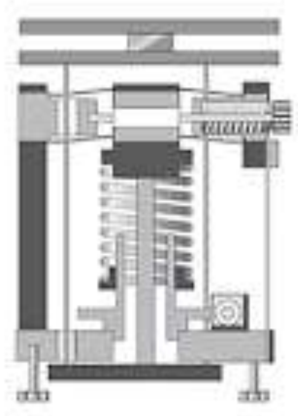
These are often used as machinery mounts or in vehicles. They absorb shock and attenuate some vibration.

e) Negative-stiffness isolators:-

Negative-stiffness isolators are less common than other types and have generally been developed for high-level research applications such as gravity wave detection. Lee, Goverdovskiy, and Temnikov (2007) proposed a negative-stiffness system for isolating vehicle seats.

The focus on negative-stiffness isolators has been on developing systems with very low resonant frequencies (below 1 Hz), so that low frequencies can be adequately isolated, which is critical for sensitive instrumentation. All higher frequencies are also isolated. Negative-stiffness systems can be made with low stiction, so that they are effective in isolating low-amplitude vibrations.

Negative-stiffness mechanisms are purely mechanical and typically involve the configuration and loading of components such as beams or inverted pendulums. Greater loading of the negative-stiffness mechanism, within the range of its operability, decreases the natural frequency.



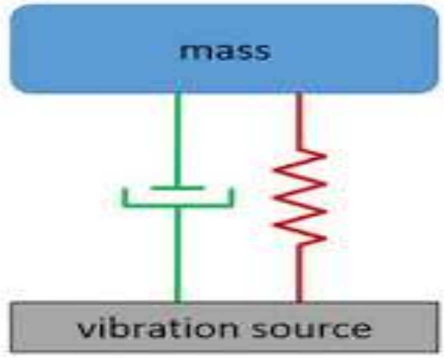
f) Wire rope isolators:-

These isolators are durable and can withstand extreme environments. They are often used in military applications.

How passive isolation works

A passive isolation system, such as a shock mount, in general contains mass, spring, and damping elements and moves as a harmonic oscillator. The mass and spring stiffness dictate a natural frequency of the system. Damping causes energy dissipation and has a secondary effect on natural frequency.

Vibration Isolation



Factors influencing the selection of passive vibration isolators

1. Characteristics of item to be isolated
    - Size: The dimensions of the item to be isolated help determine the type of isolation which is available and appropriate. Small objects may use only one isolator, while larger items might use a multiple-isolator system.
    - Weight: The weight of the object to be isolated is an important factor in choosing the correct passive isolation product. Individual passive isolators are designed to be used with a specific range of loading.
    - Movement: Machines or instruments with moving parts may affect isolation systems. It is important to know the mass, speed, and distance traveled of the moving parts.
2. Operating Environment
    - Industrial: This generally entails strong vibrations over a wide band of frequencies and some amount of dust.
    - Laboratory: Labs are sometimes troubled by specific building vibrations from adjacent machinery, foot traffic, or HVAC airflow.
    - Indoor or outdoor: Isolators are generally designed for one environment or the other.
    - Corrosive/non-corrosive: Some indoor environments may present a corrosive danger to isolator components due to the presence of corrosive chemicals. Outdoors, water and salt environments need to be considered.
    - Clean room: Some isolators can be made appropriate for clean room.
    - Temperature: In general, isolators are designed to be used in the range of temperatures normal for human environments. If a larger range of temperatures is required, the isolator design may need to be modified.
    - Vacuum: Some isolators can be used in a vacuum environment. Air isolators may have leakage problems. Vacuum requirements typically include some level of clean room requirement and may also have a large temperature range.
    - Magnetism: Some experimentation which requires vibration isolation also requires a low-magnetism environment. Some isolators can be designed with low-magnetism components.
    - Acoustic noise: Some instruments are sensitive to acoustic vibration. In addition, some isolation systems can be excited by acoustic noise. It may be necessary to use an acoustic shield. Air compressors can create problematic acoustic noise, heat, and airflow.

- Static or dynamic loads: This distinction is quite important as isolators are designed for a certain type and level of loading.

  Static loading is basically the weight of the isolated object with low-amplitude vibration input. This is the environment of apparently stationary objects such as buildings (under normal conditions) or laboratory instruments. **Dynamic loading** involves accelerations and larger amplitude shock and vibration. This environment is present in vehicles, heavy machinery, and structures with significant movement.

3. Cost:
   - Cost of providing isolation: Costs include the isolation system itself, whether it is a standard or custom product; a compressed air source if required; shipping from manufacturer to destination; installation; maintenance; and an initial vibration site survey to determine the need for isolation.
   - Relative costs of different isolation systems: Inexpensive shock mounts may need to be replaced due to dynamic loading cycles. A higher level of isolation which is effective at lower vibration frequencies and magnitudes generally costs more. Prices can range from a few dollars for bungee cords to millions of dollars for some space applications.
4. Adjustment: Some isolation systems require manual adjustment to compensate for changes in weight load, weight distribution, temperature, and air pressure, whereas other systems are designed to automatically compensate for some or all of these factors.
5. Maintenance: Some isolation systems are quite durable and require little or no maintenance. Others may require periodic replacement due to mechanical fatigue of parts or aging of materials.
6. Size Constraints: The isolation system may have to fit in a restricted space in a laboratory or vacuum chamber, or within machine housing.
7. Nature of vibrations to be isolated or mitigated
   - Frequencies: If possible, it is important to know the frequencies of ambient vibrations. This can be determined with a site survey or accelerometer data processed through FFT analysis.
   - Amplitudes: The amplitudes of the vibration frequencies present can be compared with required levels to determine whether isolation is needed. In addition, isolators are designed for ranges of vibration amplitudes. Some isolators are not effective for very small amplitudes.
   - Direction: Knowing whether vibrations are horizontal or vertical can help to target isolation where it is needed and save money.
8. Vibration specifications of item to be isolated: Many instruments or machines have manufacturer-specified levels of vibration for the operating environment. The manufacturer may not guarantee the proper operation of the instrument if vibration exceeds the spec.

Type 2. Active Vibration Isolation

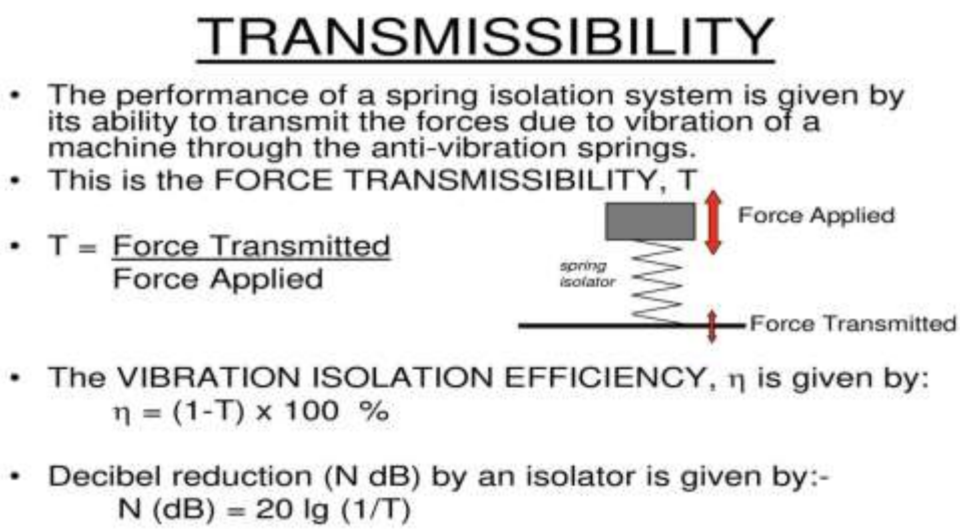
Active vibration isolation systems contain, along with the spring, a feedback circuit which consists of a sensor (for example a piezoelectric accelerometer or a geophone), a controller, and an actuator. The acceleration (vibration) signal is processed by a control circuit and amplifier. Then it feeds the electromagnetic actuator, which amplifies the signal. As a result of such a feedback system, a considerably stronger suppression of vibrations is achieved compared to ordinary damping. Active isolation today is used for applications where structures smaller than a micrometer have to be produced or measured. A couple of companies produce active isolation products as OEM for research, metrology, lithography and medical systems. Another important application is the semiconductor industry. In the microchip production, the smallest structures today are below 20 nm, so the machines which produce and check them have to oscillate much less.

Sensors for active isolation

- Piezoelectric accelerometers and force sensors
- MEM accelerometers
- Geophones
- Proximity sensors
- Interferometers

Actuators for active isolation

- Linear motors
- Pneumatic actuators
- Piezoelectric motors



4.2 TUNED VIBRATION ABSORBERS

Tuned dynamic absorbers and tuned mass dampers are reactive devices used in structural and acoustic systems to either absorb oscillation at a certain forcing frequency or damp oscillation at a particular resonant frequency. The make-up of tuned absorber and tuned damper are for the most part the same, i.e., they are both made up of an inertia element (mass), a resilient element (spring), and an energy dissipating element (damper, mainly of viscous type). What distinguishes one from the other is the extent of energy dissipation in their dissipative element. Tuned absorbers have negligible but tuned dampers have sizeable amount of damping (energy dissipation).

What is Tuned Mass Damper (TMD)?

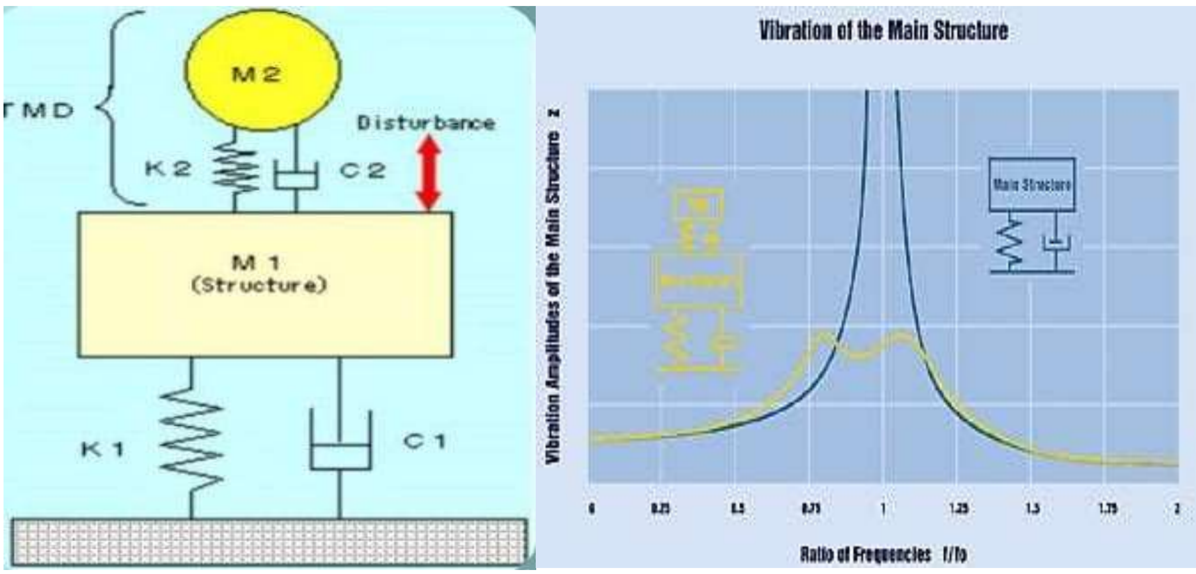
Tuned mass damper (also called vibration absorbers or vibration dampers) is a device mounted to a specific location in a structure, so as to reduce the amplitude of vibration to an acceptable level whenever a strong lateral force such as an earthquake or high winds hit.

Components of Tuned Mass Damper

Components of tuned mass damper include:

1. Spring (K2)
2. Oscillating Mass (M2)
3. Viscodamper (C2)

The value of K2 and M2 are specified so that the moving part of damper system can be tuned to the frequency of the structure. Figure shows curves for the two structures with and without the use of tuned mass damper.



Types of Tuned Mass Damper (TMD)

1. Horizontal Tuned Mass Damper (TMD)

It is normally found in slender buildings, communication towers, spires and the like. Horizontal tuned mass damper (TMD) as shown in Figure 1 composed of viscodampers and leaf springs or pendulum suspensions. It eats horizontal and torsional excitations.

2. Vertical Tuned Mass Damper (TMD)

It is usually applied in long span horizontal structures such as bridges, floors and walkways. Vertical tuned mass damper (TMD) as shown in Figure 2 is a combination of coil springs and Viscodampers and it declines vertical vibrations.

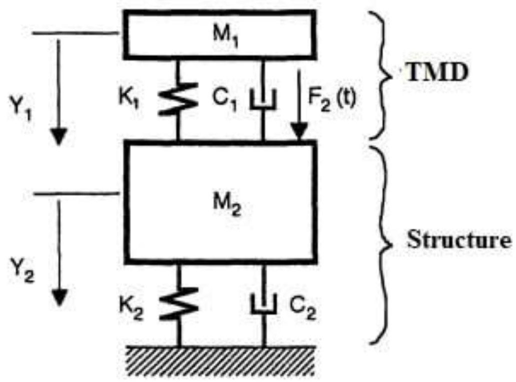
Both types have similar functions, though there might be slight differences in terms of mechanism.

How Tuned Mass Dampers Work?

A tuned mass damper (TMD) consists of a mass (m), a spring (k), and a damping device (c), which dissipates the energy created by the motion of the mass (usually in a form of heat). In this figure, M is the structure to which the damper would be attached.

From the laws of physics, we know that F = ma and a = F/m. This means that when an external force is applied to a system, such as wind pushing on a skyscraper, there has to be acceleration.

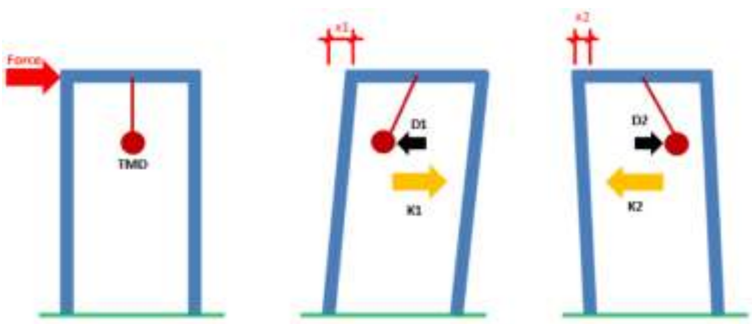
Consequently, the people in the skyscraper would feel this acceleration. In order to make the occupants of the building feel more comfortable, tuned mass dampers are placed in structures where the horizontal deflections from the wind's force are felt the greatest, effectively making the building stand relatively still.



When the building begins to oscillate or sway, it sets the TMD into motion by means of the spring and, when the building is forced right, the TMD simultaneously forces it to the left.

Ideally, the frequencies and amplitudes of the TMD and the structure should nearly match so that EVERY time the wind pushes the building, the TMD creates an equal and opposite push on the building, keeping its horizontal displacement at or near zero.

If their frequencies were significantly different, the TMD would create pushes that were out of sync with the pushes from the wind, and the building's motion would still be uncomfortable for the occupants. If their amplitudes were significantly different, the TMD would, for example, create pushes that were in sync with the pushes from the wind but not quite the same size and the building would still experience too much motion.



Schematic B - Building With TMD

The effectiveness of a TMD is dependent on the mass ratio (of the TMD to the structure itself), the ratio of the frequency of the TMD to the frequency of the structure (which is ideally equal to one), and the damping ratio of the TMD (how well the damping device dissipates energy). Wide span structures (bridges, spectator stands, large stairs, stadium roofs) as well as slender tall structures (chimneys, high rises) tend to be easily excited to high vibration amplitudes in one of their basic mode shapes, for example by wind or marching and jumping people.

Low natural frequencies are typical for this type of structures, due to their dimensions, as is their low damping. With GERB Tuned Mass Dampers (TMD), these vibrations can be reduced very effectively.

Applications of Tuned Mass Dampers

Tuned mass dampers are mainly used in the following applications:

1. Tall and slender free-standing structures (bridges, pylons of bridges, chimneys, TV towers) which tend to be excited dangerously in one of their mode shapes by wind,
2. Stairs, spectator stands, pedestrian bridges excited by marching or jumping people. These vibrations are usually not dangerous for the structure itself, but may become very unpleasant for the people,
3. Steel structures like factory floors excited in one of their natural frequencies by machines , such as screens, centrifuges, fans etc.,
4. Ships exited in one of their natural frequencies by the main engines or even by ship motion.

Tuned Mass Dampers may be already part of the structure's original design or may be designed and installed later.

Example of Tuned Mass Damper Application

Taipei structure has TMD of weight 730 tonnes and has the largest diameter in the world. Remaining figures show Tuned Mass Damper of Burj Al Arab and Emirate Tower respectively.

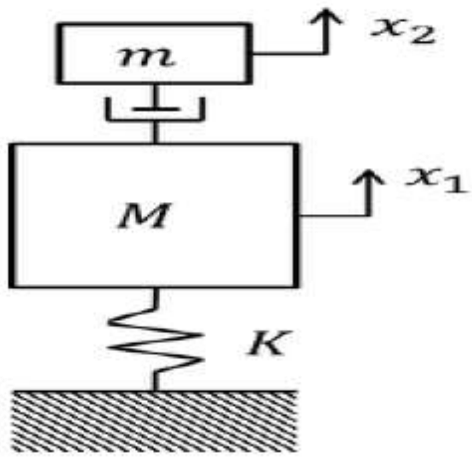
Tuned mass damper of Taipei structure

Tuned mass damper of Burj Al Arab

Tuned mass damper of Emirate tower

4.3 UNTUNED VIBRATION ABSORBERS

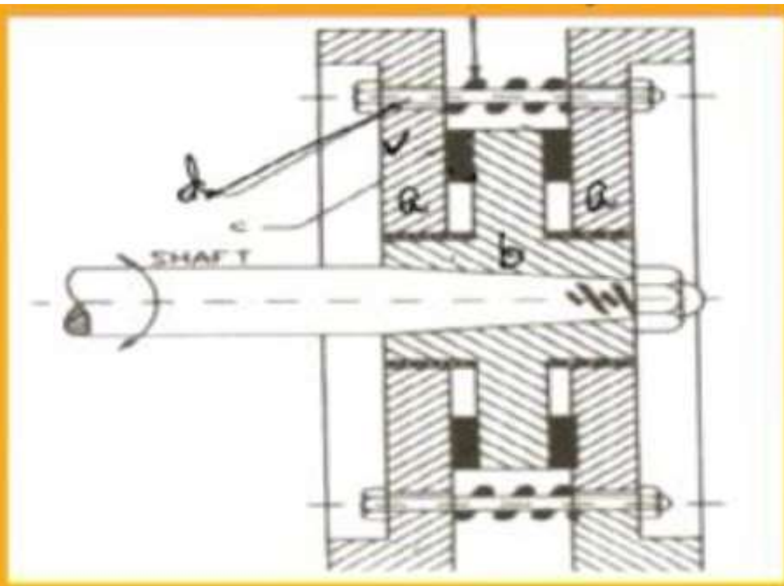
It is a reaction mass damper with robust performance because it is insensitive to tuning and and provides good performance over a wide frequency range whereas a traditional tuned-mass damper is quite sensitive to tuning and only provides damping to the primary system over a relatively narrow frequency range.



1. **Lanchester damper**

This damper consists of 2 fly wheels. These 2 fly wheels are loosely connected or loosely mounted on the wave which is mounted on the shaft. This is mounted on this wave b you may note that this is loosely connected to this wave b which is rigidly connected to this shaft. So, this hub is rotating with same speed as that of the shaft and this fly wheel is loosely mounted on this hub. So, there is a friction, so there is a friction plate attached to this or this fly wheel is driven by this friction plate which is mounted on this wave hub. So, it is mounted on this hub and you may note that we can apply this force by this clamping or spring mounted bolt. So, this is a spring mounted bolt. So, this d is the spring mounted bolt. So, you can apply any pressure on this fly wheel by tightening this bolt and you can drive this fly wheel. So, when it is loosely connected or when this friction, we are assuming this friction to be zero. So, when the shaft is rotating. So, no energy will be transferred to this fly wheel.

Also, when the friction is very high then there will be a rigid bond between this hub and this fly wheel, and it will act as a single degree of freedom system or single system, and it will increase the inertia of the system. So, the natural frequency of the system will be changed. But we can control the vibration or we can damp out the vibration by suitably choosing the damping which we can make by suitably adjusting this pressure on this fly wheel. So, when the shaft is rotating with a lower speed at the time this due to the inertia very huge inertia of the fly wheel it will not follow the speed of the shaft. So, there will be some relative motion between this fly wheel and this hub and due to the presence of a friction plate between these two, there will be relative probing of the surface which will damp out some of the energy and there by this disturbing forcing which cause this vibration of the system will be reduced.



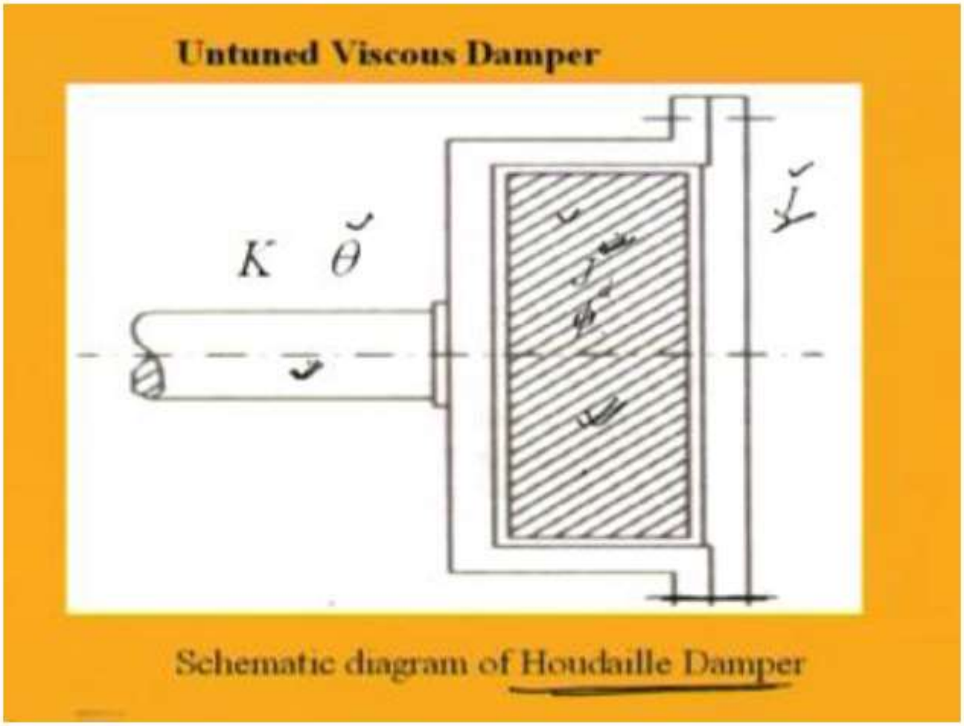
Torsional Vibration Damper

So, in this way by using this dry friction one may damp out the vibration of the system. So, I may repeat this process or in this case on the shaft. So, on the shaft this hub is mounted and the fly wheel is loosely mounted on this hub and between this fly wheel and this hub there is a friction plate, and the fly wheel is driven by this friction plate by applying the pressure by this bolt which is. So, there is a spring also the spring mounted bolt. So, by applying suitably the pressure by this bolt the pressure on this friction plate can be adjusted. So, when it is rotating at a lower speed, when it is rotating at a lower speed at that time there will be relative motion between this hub and the fly wheel. As, the fly wheel has a very huge inertia it will not follow this hub. So, there will be relative motion between this fly wheel and this hub.

Due to this relative motion there will be rubbing of this surface on this friction plate. So, due to this rubbing, so some energy will be transferred. So, the disturbing energy of the shaft will be will be dissipated by this friction damper. So, in this way some part of the disturbing energy will be dissipated and the system will be the system vibration will be damped out.

2. **Houdaille Damper**

In this case, so this is the shaft and you can put this viscous liquid viscous liquid in a cylindrical container and it is kept in between or loosely mounted in between a cylindrical cavity. So, this is the cylindrical cavity. So, this side of this is mounted or attached to the shaft which has which is vibrating. So, this is the vibrating shaft.



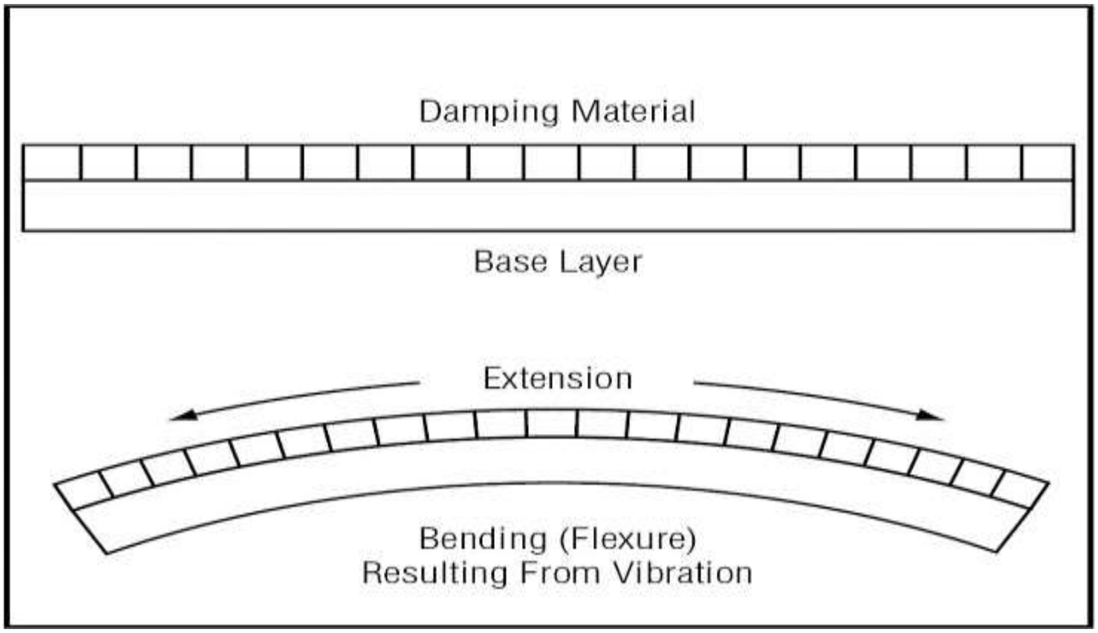
Let the stiffness of the vibrating shaft is K, let it is rotating with theta. So, if this rotating with theta and. So, let it is mounted on this on a mass, so this is a cavity in which you are putting this liquid. So, in this case, so we can write the inertia of this mass equal to J and the inertia of this equal to J. So, this is a pulley inside which there is a cavity cylindrical cavity. So, in that cylindrical cavity there is a mass hollow mass in which you are putting the viscous fluid. So, this is the system and this system is known as this schematic diagram of a Houdaille damper. So, when it is rotating, so this mass will be subjected to a torque. So, due to free rotation of this, so as it is loosely mounted on this. So, there will be free rotation of this mass with inertia J with respect to this primary system which has inertia J.

1.3 DAMPING TREATMENTS

Constrained-layer damping is a mechanical engineering technique for suppression of vibration. Typically a viscoelastic or other damping material is sandwiched between two sheets of stiff materials that lack sufficient damping by themselves. The ending result is, any vibration made on either side of the constraining materials (the two stiffer materials on the sides) are trapped and evidently dissipated in the viscoelastic or middle layer.

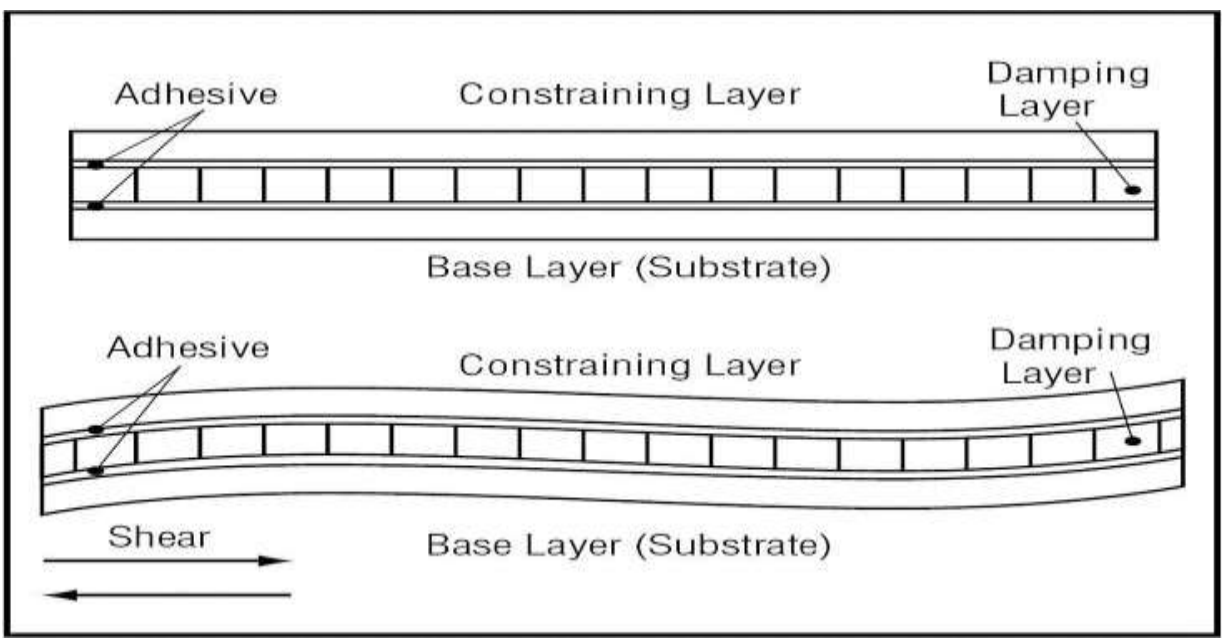
Free layer or extensional damping

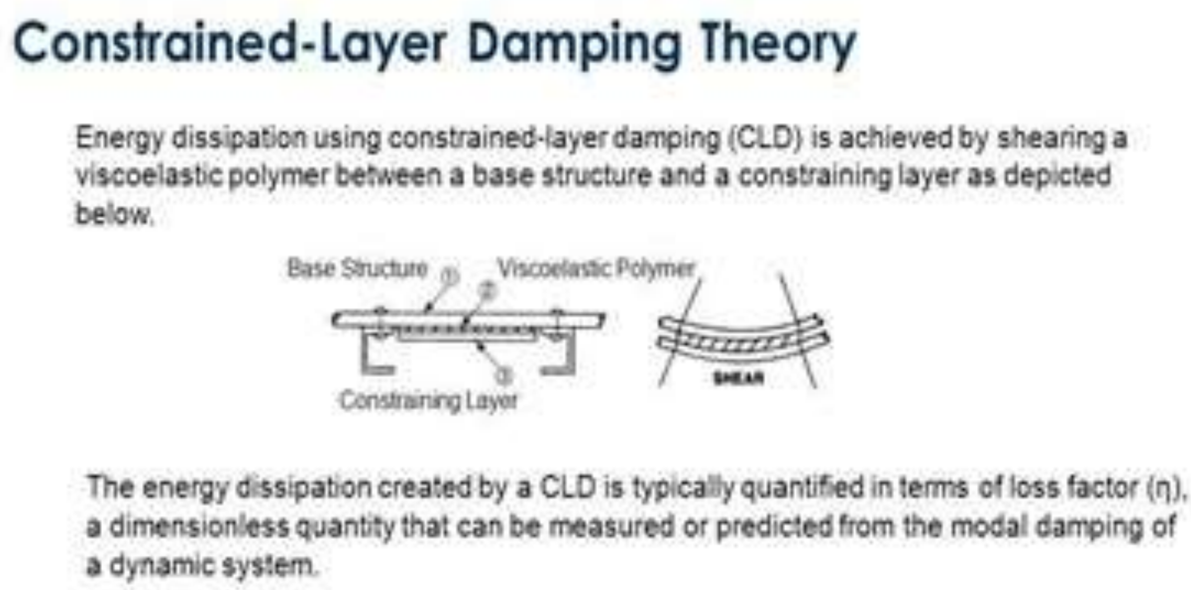
Free layer damping is the easiest type of damping to implement. Also known as extensional damping, it is commonly seen in automotive applications. It involves a viscoelastic material, typically a polymer. When sound hits the material, the damping product stretches or extends (hence, extensional damping) and then compresses, converting the noise and vibrational energy into heat

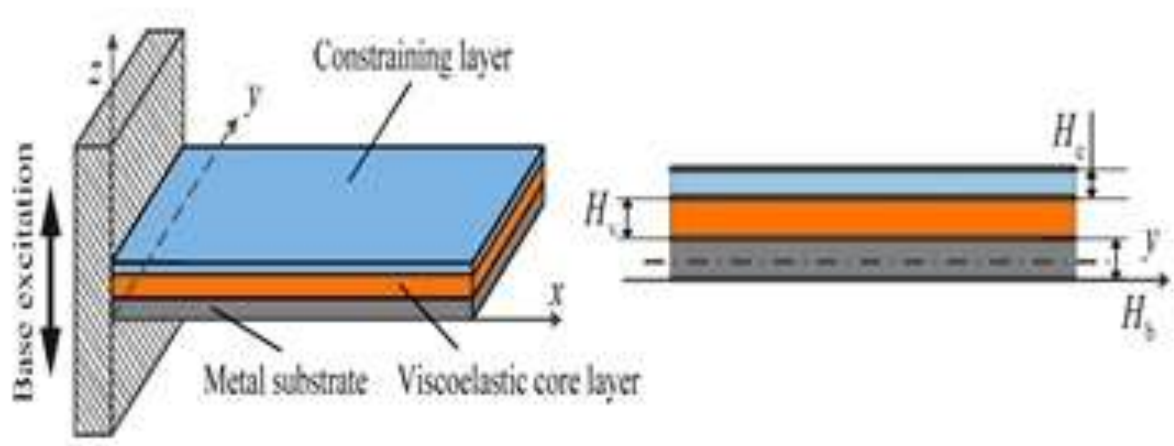


Constrained layer damping (CLD)

When a structure thicker than ¼ of an inch requires damping, the situation calls for constrained layer damping (CLD). Like extensional damping, CLD converts vibration to heat, but this type of damping utilizes a layered construction with a viscoelastic polymer sandwiched between two sheets of a stiff material such as a metal. Because the stiff materials keep the damping material constrained in the face of vibrational energy, CLD reduces impact noise.







4.4 DYNAMIC FORCES GENERATED BY IC ENGINES

Here is a brief overview of what is going on in the internal combustion engine.

1. The pressure of the gases (air + fuel, or by products of combustion) exerts a force on the piston.

2. All the parts of the internal combustion engine have a finite mass (inertia). Thus a fraction of the input forces are “spent” on accelerating or decelerating the masses.

3. Some of the input is used to overcome the friction on the piston walls and the friction at the bearings.

4. The crank is coupled to the crankshaft which in turn is coupled via a power train to the wheels of the automobile. Since the crank has a rotary motion, the fraction of the input force used to drive

Force Analysis in IC Engine Mechanism

- The study of forces in IC engine mechanism are classified into two types as follows :

1. **Steady force analysis,**
2. **Dynamic force analysis.**

- In **static force analysis**, we do not consider the effect of inertia forces arising due to the mass of the connecting rod.
- In **dynamic force analysis**, we also consider the effect of inertia forces caused due to the mass of connecting rod.
- The force analysis can be done both by analytical and graphical methods.

the crank is effectively a moment, and is called the turning moment.

Applications of dynamic force analysis

- ♦ Dynamic Analysis of Reciprocating engines.
- ♦ Inertia force and torque analysis by neglecting weight of connecting rod.
- ♦ Velocity and acceleration of piston.
- ♦ Angular velocity and Angular acceleration of connecting rod.
- ♦ Force and Torque Analysis in reciprocating engine neglecting the weight of connecting rod.
- ♦ Equivalent Dynamical System
- ♦ Determination of two masses of equivalent dynamical system

4.6 ENGINE ISOLATION

Engine isolation is an important design consideration because of the problems that may arise if proper steps aren't taken to control and manage vibration. Vibration is produced as a result of the transfer of energy when rotating machinery is mounted to a support structure. This vibration may affect the overall performance of the equipment and potentially damage its longevity.

A good vibration isolation system works in two directions.

- It can keep vibration produced by a source such as an engine from being transmitted to the frame; and
- It can keep vibration in a system from being transmitted to a sensitive piece of electronics or even a human.

A properly designed engine isolation system can improve a vehicle's NVH (noise, vibration, and harshness), which is a subjective rating expressed by the driver on the quality of the driving experience in those three areas.

Choosing the wrong vibration isolator or vibration damper may actually make the problem worse by amplifying, which can worsen NVH, shorten the life and performance of the equipment, and result in serious malfunctions.

Vibration isolation is the process of isolating an object, such as a piece of equipment, from the source of vibrations. Vibration is undesirable in many domains, primarily engineered systems and habitable spaces, and methods have been developed to prevent the transfer of vibration to such systems.

BENEFITS OF ENGINE ISOLATORS

- Offer optimum distribution of engine casing and airframe loads by design of isolator stiffness and snubbing.
- Thermal expansion of the engine can be taken by deflection of isolator
- Offer broad-band vibration isolation for high frequency vibration.

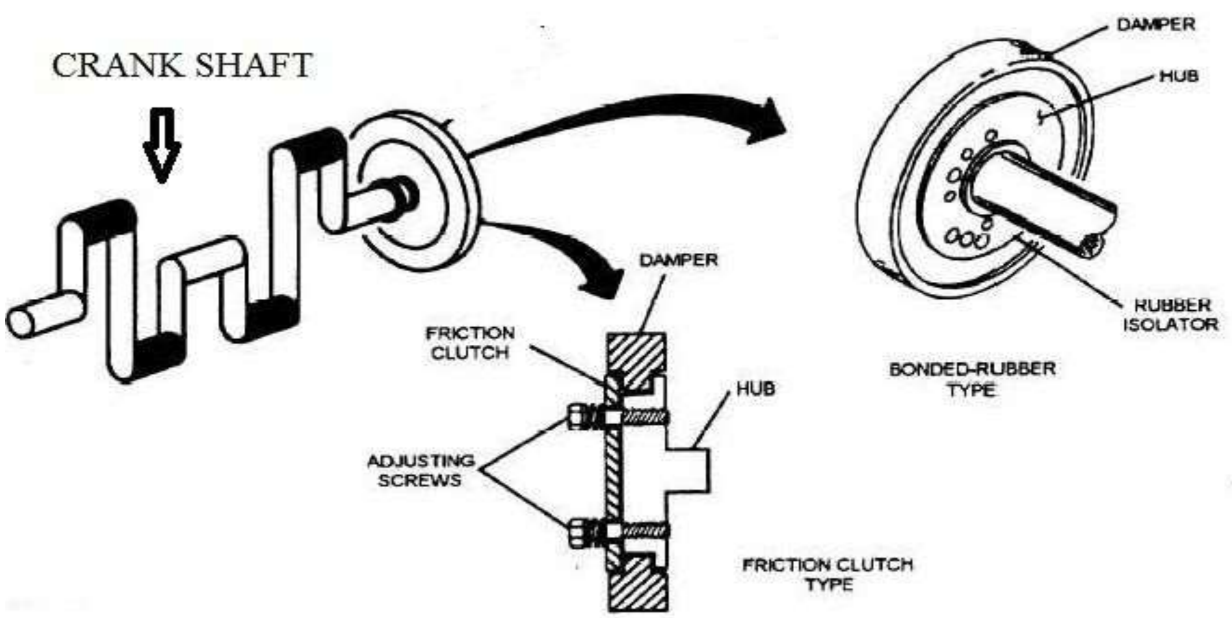
- Improves engine blade-out loading and flutter conditions.
- Facilitates engine installation and removal.
- Allows for increased airframe and engine tolerances using the allowance gained from isolator flexibility.
- Reduces possibility of damage to engine and airframe.

4.7 CRANK SHAFT DAMPING

Each and every time if the cylinders fire torque is taken to the crankshaft. The crankshaft deflects under this torque which causes the vibrations when torque is released. At certain value of engine speeds the torque imparted to cylinder is in sync with the vibrations in crankshaft, which in turn results in phenomenon called resonance. This resonance causes stress beyond what the crankshaft can accommodate resulting in crankshaft failure.

Torsional vibration is one of most prominent complex problem in the crack shaft design. The damping caused during torsional vibration is occurred by the damping from externally caused piston friction. Other means of the damping are the combined friction of the crankshaft material and the viscous friction into the crankshaft bearings.

Torsional vibration dampers (TVD) or rotation vibration dampers must damp these rotational irregularities and vibrations of the crankshaft so that they are not passed on to the belt drive system. TVD pulley has a built-in harmonic damper, in the form of a split design, with a thick rubber pad sandwiched between two steel sheets. The damper is designed to absorb torsional and vertical vibrations from the crank, as a result of the engine combustion process.



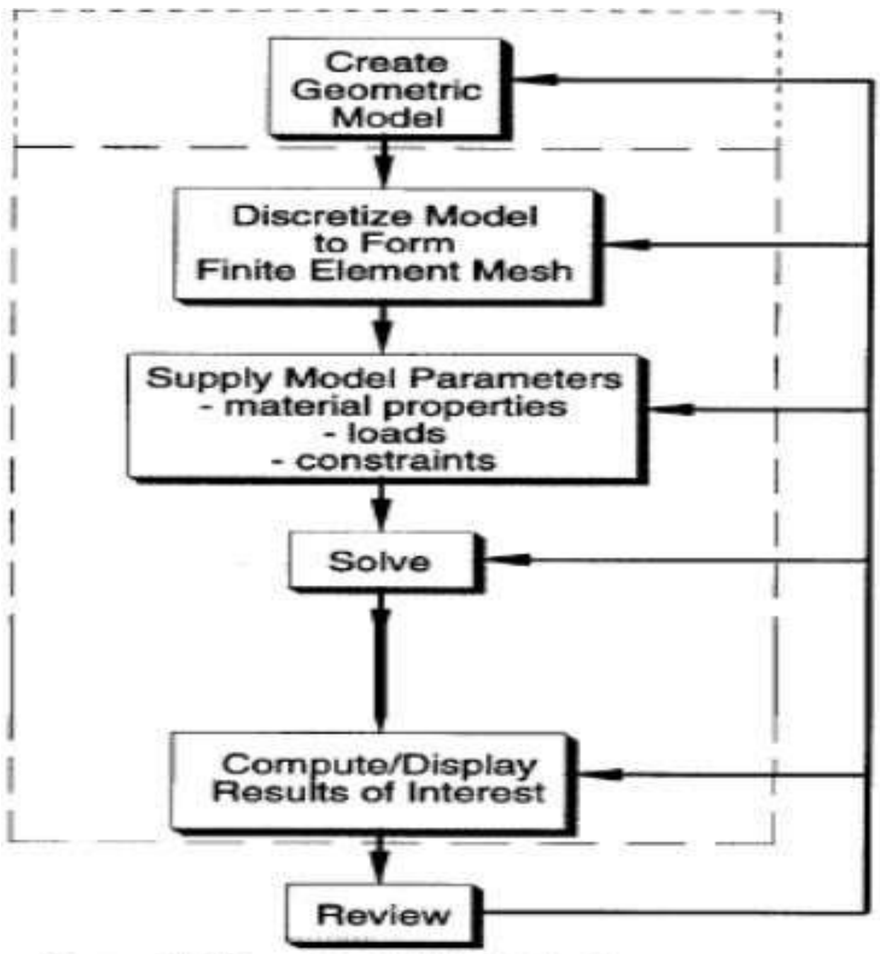
Torsional vibration dampers, or rotation vibration dampers, they are screw-mounted directly on the crankshaft and fitted with a special damping device (inertia ring, plain bearing, rubber bearing).

4.8 MODAL ANALYSIS OF THE MASS ELASTIC MODEL SHOCK ABSORBERS.

A modal analysis is typically used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a harmonic response or full transient dynamic analysis.

Shock absorbers are a critical part of a suspension system, connecting the vehicle to its wheels. Depending on the type of physical problem being analysed, the related variables may include physical displacement, temperature, heat flux, and fluid velocity. These related variables are called as field variables which relates to the working atmosphere of the shock absorber.

A General Procedure for Finite Element Analysis (FEA) or modal analysis



Overall Steps in FEA Solution

Steps in modal analysis

1. **Pre-processing**

The pre-processing step is, quite generally, described as defining the model and includes

- Define the geometric domain of the problem.
- Define the element type(s) to be used.
- Define the material properties of the elements.
- Define the geometric properties of the elements (length, area)
- Define the element connectivity's (mesh the model).
- Define the physical constraints (boundary conditions).
- Define the loadings.

2. **Solution**

During the solution phase, finite element software assembles the governing algebraic equations in matrix form and computes the unknown values of the primary field variable(s). The computed values are then used by back substitution to compute additional, derived variables, such as reaction forces, element stresses, and heat flow.

3. **Post processing**

Analysis and evaluation of the solution results is referred to as post processing. Examples

of operations that can be accomplished include:

- Sort element stresses in order of magnitude.
- Check equilibrium. Calculate factors of safety.
- Plot deformed structural shape.
- Animate dynamic model behaviour.
- Produce colour-coded temperature plots.

4. **Structural Analysis**

It is used to determine displacements stresses, etc. under static loading conditions. ANSYS can compute both linear and nonlinear static analyses.

By observing the analysis results, the analyzed stress values must be less than the respective yield stress values of given material. So our design is safe.

MODULE 5

Syllabus- Reduction of noise and vibrations: noise dose level, legislation, measurement and analysis of noise, measurement environment, equipment, frequency analysis, tracking analysis, sound quality analysis. Methods for control of engine noise, combustion noise, mechanical noise, predictive analysis, palliative treatments and enclosures, automotive noise control principles, sound in enclosures, sound energy absorption, sound transmission through barriers

REDUCTION OF NOISE AND VIBRATION

Noise Reduction Rating (NRR) is a unit of measurement used to determine the effectiveness of hearing protection devices to decrease sound exposure within a given working environment. Noise protectors are classified by their potential to reduce noise in decibels (dB). The higher the NRR number associated with a hearing protector, the greater the potential for noise reduction.

Exposing yourself to high decibel environments can result in permanent damage to your hearing. In the event you find yourself in one of these environments, protect yourself with the proper hearing protection. Earplugs and ear muffs are used as noise protection equipment with various noise reduction rating. For a better grasp of industry standards,

Here are a few of the most common producers of noise levels.

- Painful:

150 dB = Rock Concerts at Peak
140 dB = Firearms, Air-Raid Siren, Jet Engine 130
dB = Jackhammer
120 dB = Jet Plane Take-off, Amplified Music at 4-6 ft., Car Stereo, Band Practice

- Extremely loud:

110 dB = Machinery, Model Airplanes
100 dB = Snowmobile, Chain saw, Pneumatic Drill
90 dB = Lawnmower, Shop Tools, Truck Traffic, Subway

- Very loud:

80 dB = Alarm Clock, Busy Street 70
dB = Vacuum Cleaner
60 dB = Conversation, Dishwasher

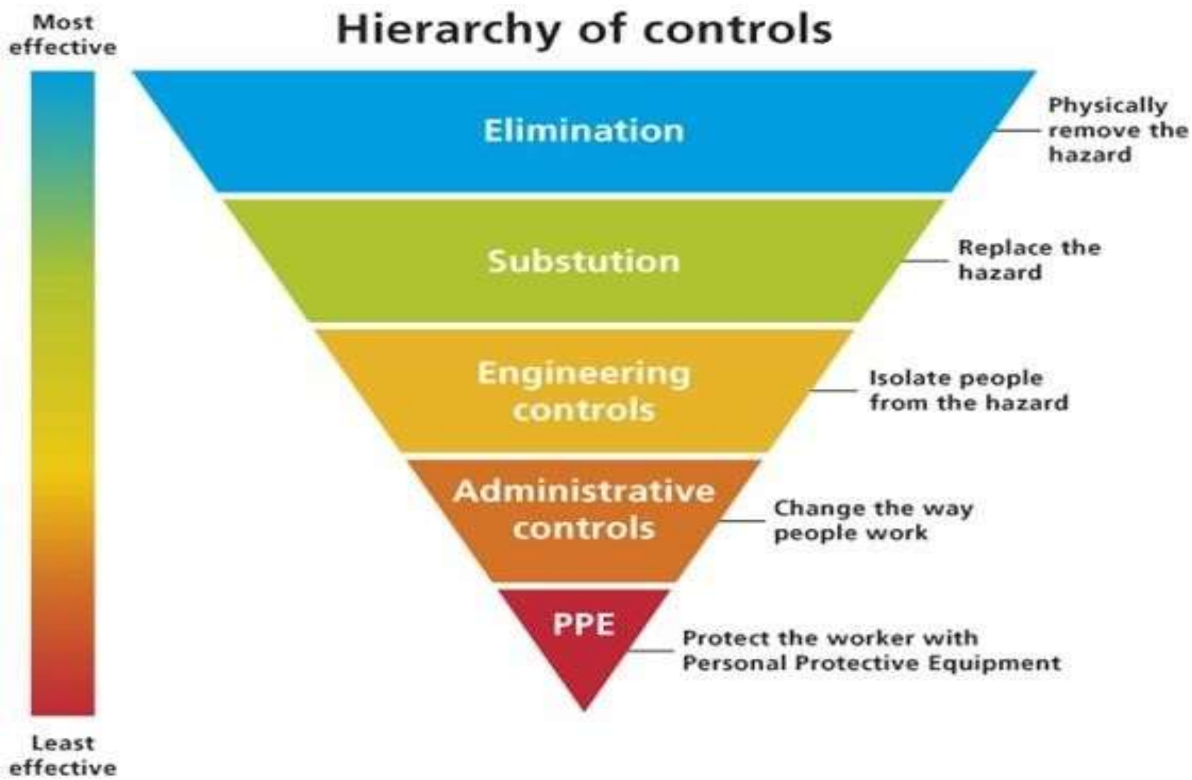
- Moderate:

50 dB = Moderate Rainfall 40
dB = Quiet room

- Faint:

30 dB = Whisper, Quiet Library

Occupational safety and health OSH professionals use the hierarchy of control to determine how to implement practical and effective risk management programmes to tackle noise- related issues in the workplace.



Some engineering measures that may be considered to reduce noise include:

- Separating the noisy area from other workspaces by a sound-reducing partition
- Enclosure of noisy machinery with sound-absorbing
- Avoiding metal-to-metal contact by using plastic bumpers
- Using absorbent lining on surfaces to cushion the fall or impact of objects
- Fitting sound-absorbing materials to hard reflective surfaces
- Using conveyor belts rather than rollers
- Using acoustical silencers in intake and exhaust systems
- Using rubber mounts to isolate vibrating noise source to separate it from the surface it's mounted to
- Maintaining optimum speed of machinery or its particular components
- Repairing and replacing loose rotating parts, worn bearings and gears
- Using sound-absorbing material on walls, ceiling and floors to reduce the noise level due to reverberation
- Undertaking regular maintenance on equipment (very effective in reducing noise emission if carried out regularly)

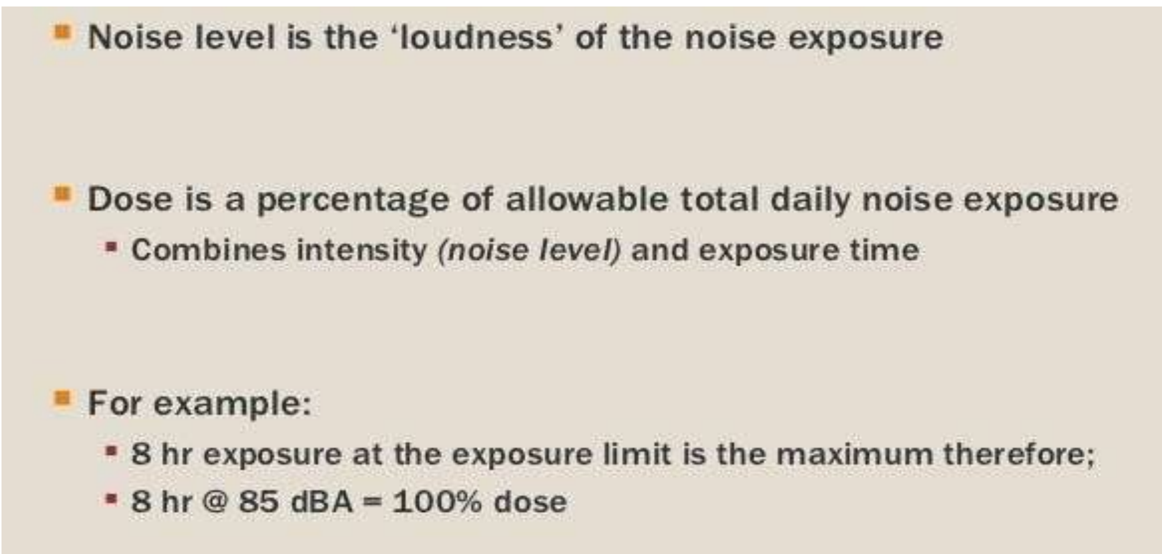
5.1 NOISE DOSE LEVEL

Noise Dose is the total sound exposure normalized to an 8-hour working day.

A noise dosimeter or noise dose meter is a specialized sound level meter intended specifically to measure the noise exposure of a person integrated over a period of time; usually to comply with Health and Safety regulations such as the Occupational Safety and Health (OSHA). Noise dosimeters measure and store sound pressure levels (SPL) and, by integrating these measurements over time, provide a cumulative noise-exposure reading for a given period of time.

A sound level meter is used for acoustic (sound that travels through air) measurements. It is commonly a hand-held instrument with a microphone. The diaphragm of the microphone responds to changes in air pressure caused by sound waves. That is why the instrument is sometimes referred to as a Sound Pressure Level (SPL) Meter. This movement of the diaphragm, i.e. the sound pressure deviation (Pascal Pa), is converted into an electrical signal (volts V).

NOISE LEVEL VS DOSE



Noise Dose Criteria

The Noise Dose Criteria, in the UK is currently 85dBA and if anyone is exposed to a time weighted average noise level of 85 dBA during an 8-hour period their noise dose is 100%.

Employers must assess and identify measures to eliminate or reduce risks from exposure to noise, in order to protect the hearing of their employees.

The British and ISO Standards are based on the 3 dB exchange rate, which means noise levels of 88 dBA have twice as much energy as levels of 85 dBA. It follows that if 85 dBA = 100% noise dose, then 88 dBA = 200% noise dose and therefore the maximum exposure time is restricted to 4 hours per shift - ergo twice the level means half the time.

Example - Daily Noise Dose Level

- During a working day a person is exposed to 100 dB in 5 minutes and 94 dB in 30 minutes.
- The maximum noise exposure time for 100 dB is 15 minutes and for 94 dB 60 minutes.

The daily dose can be calculated as

D = ((5 min) / (15 min) + (30 min) / (60 min)) 100%

= 83 %

The Time-Weighted Average -TWA can be calculated as

TWA = 10 log (83 / 100) + 85

= 84 dB

Table 2: Permissible noise exposures according to OSHA

Sound level (dBA)	Permissible time (hour)
80	32
85	16
90	8
95	4
100	2
105	1
110	0.5
115	0.25
120*	0.125*
125*	0.063*
130*	0.031*

* Exposure above 115 dBA are not permitted regardless of duration; but should they exist, they to be included in computations of the noise dose. (Source OSHA, 1983).

5.2 NOISE LEGISLATION OR NOISE REGULATIONS

The aim of the Noise Regulations is to ensure that workers' hearing is protected from excessive noise at their place of work, which could cause them to lose their hearing and/or to suffer from tinnitus (permanent ringing in the ears).

- Most common form of state-enacted noise legislation applies to motor vehicles. Historically, trucks have been the first vehicles regulated, with regulations for automobiles, buses and motor cycles following. Motor vehicle regulations generally established a quantitative sound limit at a specified distance from the vehicle.

Legislation On Noise In India

In India the government had included " Noise hearing loss" as a notifiable disease under the Factories Act. 1948.

Under section 89 of the Act. Any Medical practioner who detects noise included hearing losses in worker has to report the case to the chief inspector of the factories.

LAW FOR CONTROLLING NOISE POLLUTION

Constitution of India

Article 21	Right to decent and wholesome environment
Article 39 (e)	State to Protect health and strength of workers, men and women, tender age of children and of citizens from entering into avocation unsuited to health
Article 48-A	Duty of state to protect natural environment
Article 51-A (g)	Fundamental duty of citizen to protect and preserve environment

5.3 MEASUREMENT AND ANALYSIS OF NOISE

The Decibel Meter shows examples of things that make noise and measurements in decibels. Amplitude measures how forceful the wave is. It is measured in decibels or dBA of sound pressure. 0 dBA is the softest level that a person can hear.

A sound unit is any acoustic unit of sound measurement.

- dB, decibel - noise of sound measurement is called decibels (dB). Ratio of the sound pressure to reference pressure to something.
- Sone - a unit of perceived loudness equal to the loudness of a 1000-hertz tone at 40 dB above threshold, starting with 1 sone.
- Phon - a unit of subjective loudness.
- Hz, hertz = unit of sound frequency is called hertz (Hz)

The Noise Level Analyzer is a portable instrument designed for the measurement and analysis of environmental noise, airport noise, traffic noise and any other noise where statistical analysis is useful. The instrument is also capable of measuring Equivalent Continuous Level ($L_{Aeq,T}$), Sound Exposure Level (*SEL*), Noise Pollution Level (*NPL*), Traffic Noise Index (*TNI*), Day-Night Average Sound Level (*DNL*) and Community Noise Equivalent Level (*CNEL*) over required intervals and produce print-outs containing all results and plots of statistical data.

Glossary of terms

The following terms are used for describing environmental noise.

A-weighted Sound Pressure Level, L_{pA}: A measure of noise levels, in dB(A), using the A-(frequency) weighted network. A-weighted sound pressure levels correlate well with subjective loudness.

Equivalent Continuous A-Weighted Sound Pressure Level, $L_{Aeq,T}$: That constant level in dB(A) which, lasting for as long as a given A-weighted noise event, i.e. for a period of time *T*, has the same amount of acoustic energy as the given event.

Sound Exposure Level (*SEL*), L_{AE}: That constant level in dB(A) which, lasting for one second, has the same amount of acoustic energy as a given A-weighted noise event.

Day-Night Average Sound Level (*DNL*), L_{dn}: A 24-hour equivalent continuous level in dB(A) where 10 dB is added to nighttime noise levels from 2200 hours to 0700 hours.

Community Noise Equivalent Level (*CNEL*), L_{den}: A 24-hour equivalent continuous level in dB(A) where 5 dB is added to evening noise levels from 1900 hours to 2200 hours and 10 dB is added to nighttime noise levels from 2200 hours to 0700 hours.

Percentile Level, $L_{AN,T}$: That noise level in dB(A) exceeded for *N*% of the measurement time *T*.

Noise Pollution Level (*NPL*), L_{NP}: A variation on $L_{Aeq,T}$ which accounts for short term variability in noise level. L_{NP} is defined as;

$$L_{NP} = L_{Aeq,T} + 2{,}56\,\sigma$$

Where σ is the standard deviation of the dB(A) levels. For a gaussian distribution of dB(A) levels the term $2{,}56\,\sigma$ can be replaced by $(L_{A10,T} - L_{A90,T})$

Traffic Noise Index, *TNI*: Introduced as a descriptor of road traffic noise, it is defined as follows:

$$TNI = 4\,(L_{A10,T} - L_{A90,T}) + L_{A90,T} - 30$$

Perceived Noise Level, L_{PN}: A complex rating based on one-third octave band data used to certify aircraft types for flyover noise. An approximation is given by adding $13(\pm 3)$ dB to the measured A-weighted noise level.

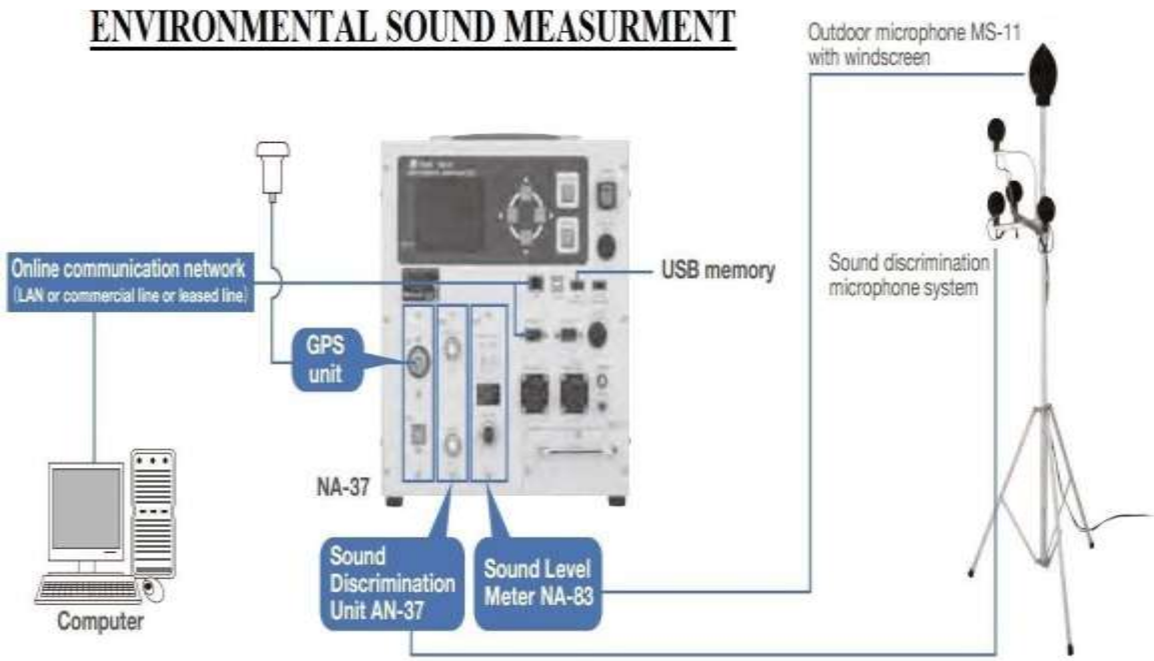
Effective Perceived Noise Level, L_{EPN}: This is the result of applying tone and duration corections to the Perceived Noise Level based on one-third octave band data.

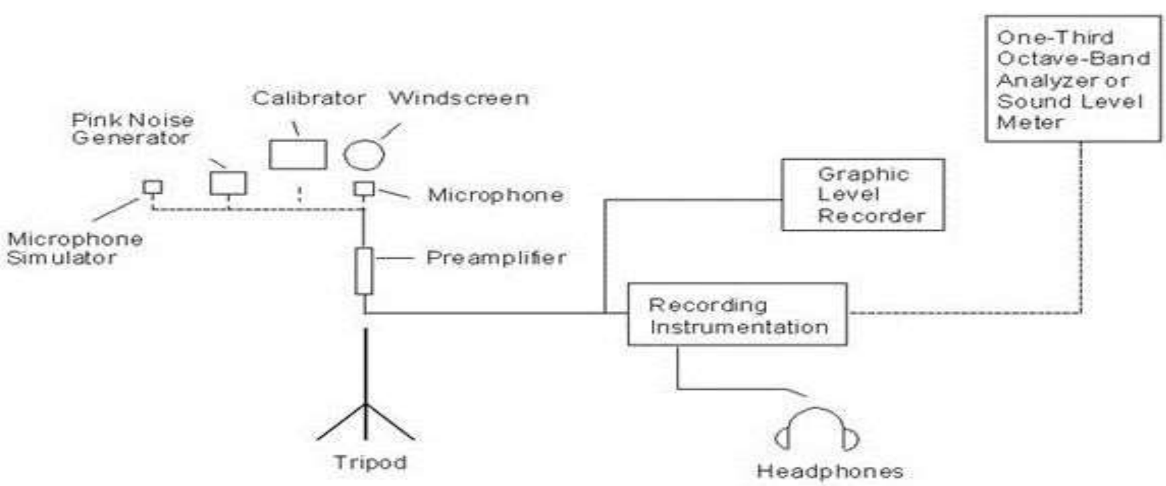
Noise Exposure Forecast, *NEF*: A complex criteria for predicting future noise impact of airports. The computation considers the effective perceived noise level of each type of aircraft, flight profiie, number of flights, time of day, etc. Generally used in plots of equal NEF contours around airports for zoning control.

5.4 MEASUREMENT OF ENVIRONMENTAL NOISE

Noise measurement in acoustics, noise measurement can be for the purpose of measuring environmental noise with the help of sensors. Applications include monitoring of construction sites, aircraft noise, road traffic noise, entertainment venues and neighborhood noise.

The sensor is based on an inexpensive credit-card-sized single-board computer with a microphone and associated electronics and wireless connectivity. The measurement results and the noise source information are transferred from the sensors scattered around the measurement site to a cloud service and a noise portal is used to visualize the measurements to users.





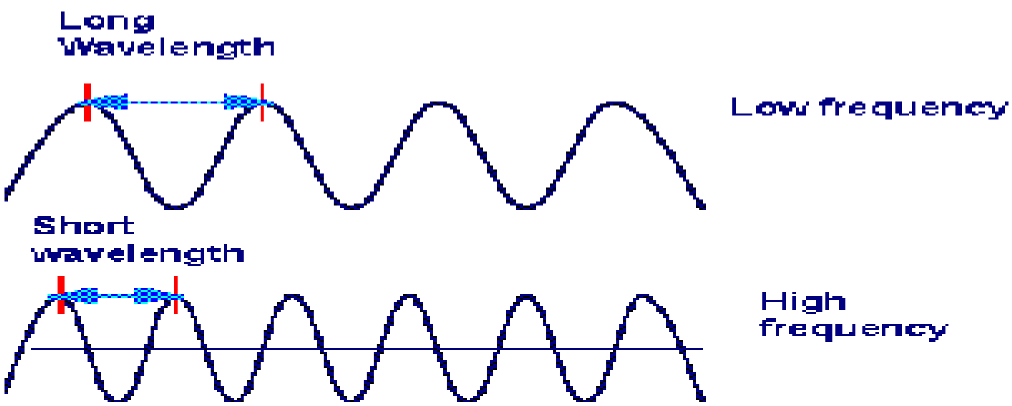
5.5 FREQUENCY ANALYSIS OF SOUND WAVES

Sound waves can be analyzed in terms of their amplitude and frequency. The loudness of a sound corresponds to the amplitude of the wave, and is measured in decibels. The frequency of a sound wave affects the pitch of the sound we hear.

- Most musical sounds are composed of a superposition of many frequencies called **partial tones, or simply partials**.
- The lowest frequency for a given sound is called the **fundamental frequency.** For a vibrating object like a tuning fork, this is also the natural resonant frequency of the sound source.
- Partial tones that are whole multiples of the fundamental frequency are called **harmonics**.
- A tone that has twice the frequency of the fundamental is called the **second harmonic.**

Frequency

Frequency is the speed of the vibration, and this determines the pitch of the sound. It is only useful or meaningful for musical sounds, where there is a strongly regular waveform. Frequency is measured as the number of wave cycles that occur in one second. The unit of frequency measurement is Hertz (Hz).



Frequency means oscillations (cycles) per second in Hz = hertz = 1/s

The formula for frequency is: f (frequency) = 1 / T (period).

$f = c / \lambda$ = wave speed (c) (m/s) / wavelength(λ) (m).

The formula for time is: T (period) = 1 / f (frequency).

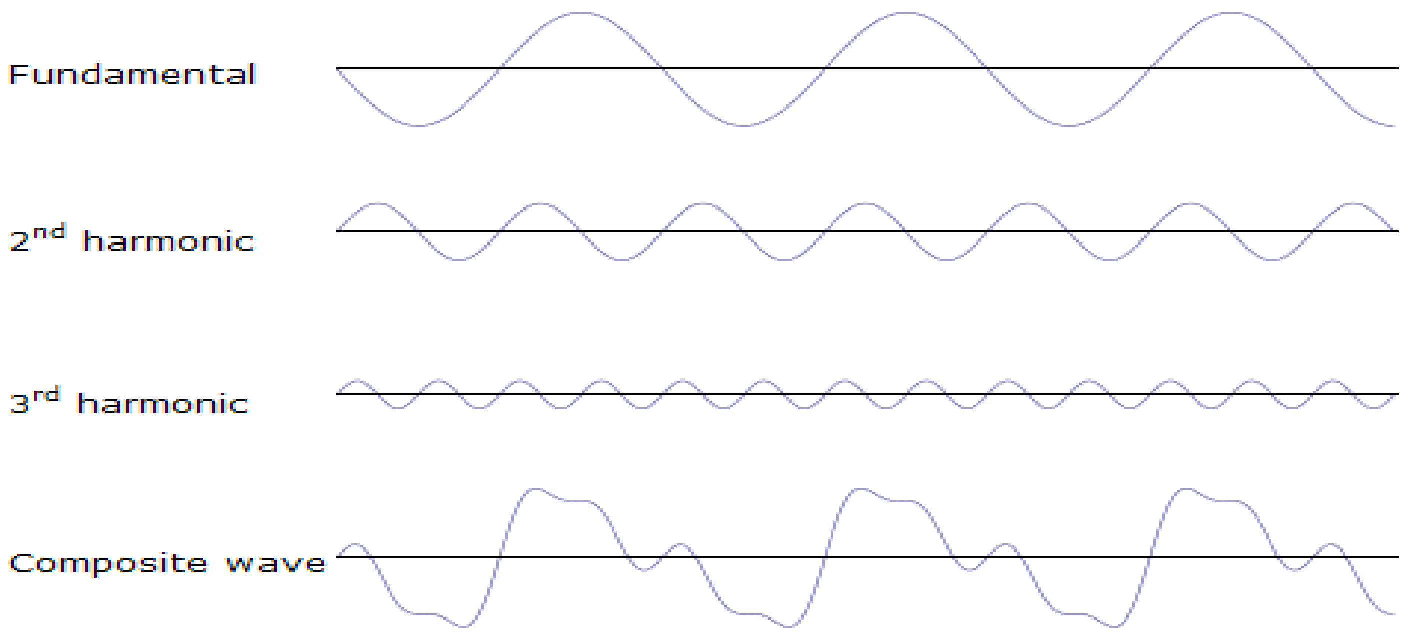
The formula for wavelength is λ (m) = c / f

$\lambda = c / f$ = wave speed c (m/s) / frequency f (Hz).

The unit hertz (Hz) was once called cps = cycles per second.

Fundamental frequency: The lowest frequency of any vibrating object is called the fundamental frequency. The fundamental frequency provides the sound with its strongest audible pitch reference - it is the predominant frequency in any complex waveform.

The fundamental frequency is the frequency we actually hear the sound at.



if the fundamental frequency is 50 Hz (also known as the first harmonic) then the second harmonic will be 100 Hz (50 X 2 = 100 Hz), the third harmonic will be 150 Hz (50 X 3 = 150 Hz), and so on.

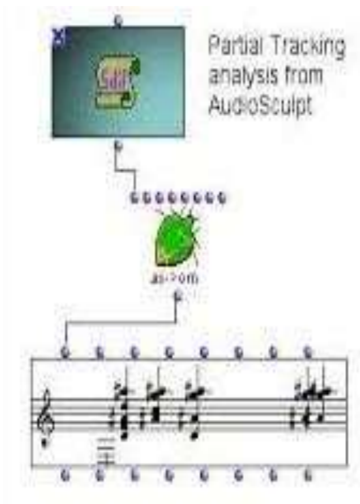
A composite waveform that is shaped like a teardrop. A waveform generated by a synthesizer. A waveform is a variable that varies with time, usually representing a voltage or current.

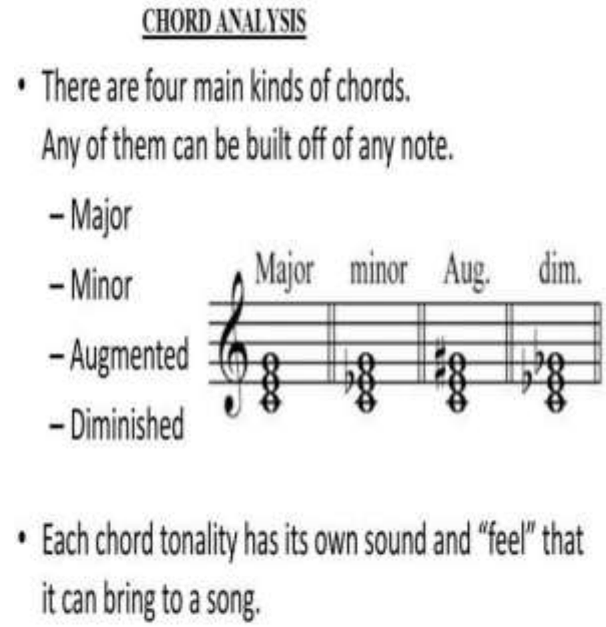
5.6 TRACKING ANALYSIS OF WAVES

Partial Tracking and Chord Sequence Analysis

These two analysis methods aim at tracking and visualizing the sinusoidal (having the form of a sine curve) contents of a signal.

- The partial tracking analysis basically gives a true representation of the contents.
- The chord sequence analysis yields an average representation with steady components in selected sequences





The partial tracking analysis: It allows detecting and visualizing the partials of a sound. The analysis can apply either to harmonic sounds or to inharmonic sounds. (Partial tone means a tone that is a component of a complex sound.)

Chord Sequence Analysis: A chord is a coherent group of partials within fixed temporal limits, with a fixed amplitude and frequency. The chord sequence is made of a succession of such chords.

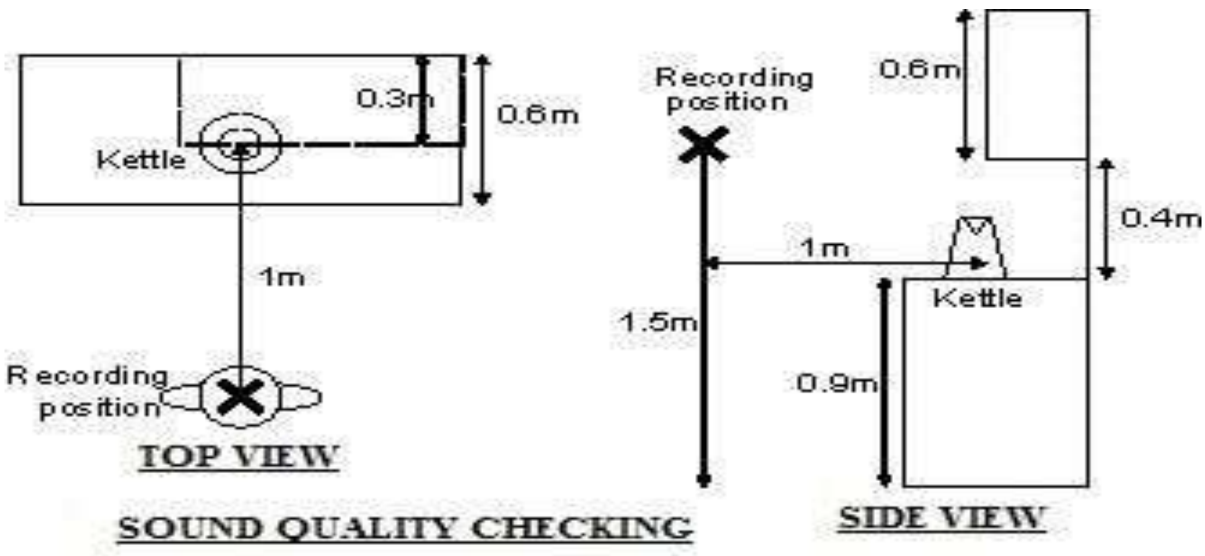
5.7 SOUND QUALITY ANALYSIS

Defining sound quality

There is no definitive explanation of the constituents of sound quality. Definitions of sound quality include examples such as:

"Sound Quality is a perceptual reaction to the sound of a product that reflects the listener's reaction to how acceptable the sound of that product is: the more acceptable, the greater the quality.

- The term Product Sound Quality refers to the adequacy of the sound from a product.
- The environment in which the tests take place and the test procedure can have an effect on the final results, so it is important to define these adequately prior to testing.
- The test procedure and surroundings should be the same for each subject and should be carefully documented in case it is necessary to review the procedure.
- The sound of an object depends on both the source, and the surroundings.



5.8 METHODS FOR CONTROL OF ENGINE NOISE

One typical engine noise classification technique separates the aerodynamic noise, combustion noise and mechanical noise.

1. AERODYNAMIC NOISE

2. COMBUSTION NOISE

3. MECHANICAL NOISE

AERODYNAMIC NOISE-

Aerodynamic noise includes exhaust gas and intake air noise as well as noise generated by cooling fans, auxiliary fans or any other air flow.

1. COMBUSTION NOISE-

Combustion noise refers to noise generated by the vibrating surfaces of the engine structure, engine components and engine accessories after excitation by combustion forces.

2. MECHANICAL NOISE-

Mechanical noise refers to noise generated by the vibrating surfaces of the engine components and engine accessories after excitation by reciprocating or rotating engine components.

3. EXHAUST SYSTEM NOISE:

Exhaust system noise includes the noise from exhaust gas pulses leaves the muffler or tail pipe and noise emitted from the vibrating surfaces of the exhaust system components.

Additional considerations in the reduction of exhaust system noise include proper selection of piping lengths and diameters, proper mounting of exhaust system components and proper positioning of the exhaust outlet.

4. INTAKE SYSTEM NOISE:

Intake system noise includes noise generated by the flow of air through the systems air inlet and noise emitted from the vibrating surface components.

An intake air silencer can be added to the system. To minimize intake system surface radiated noise, proper design, selection and mounting of intake system components are essential.

5. COOLING SYSTEM NOISE:

Water cooled engines are typically cooled by using a radiator as a heat exchanger – with an axial flow fan is used to draw cooling air through the radiator. Air-cooled engines generally use a centrifugal fan in conjunction with shrouding to direct cooling air across the engine.
Fan noise consists of both discrete frequency tones and broadband noise. The broadband components of fan noise are caused by the shedding of vortices from the rotating fan blades and by turbulence in the fans air stream.

Water Cooled Engines can follow

- Use water pump and radiator that have adequate capacities,
- Use a fan with proper aerodynamic blade design.
- Use a shroud to prevent recalculation of air from the high pressure side of the fan in the low pressure side
- Reduce air flow resistance and turbulence in the system.

REMEDIAL MEASURES

1. Stopping it at the source

Improving the engineering in many noisy objects has cut noise nearly by 30 decibels (i.e. snow mobiles)

Government has set up regulations to manufacturers such as GM and Mack truck to reduce vibration in heavy gears, axles and transmissions.

Reducing sound at the sources by an average of 10 decibel cuts soundness in half.

2. Shielding your ears

Without doubt, plugging up your ears is the cheapest and easiest method of noise control.

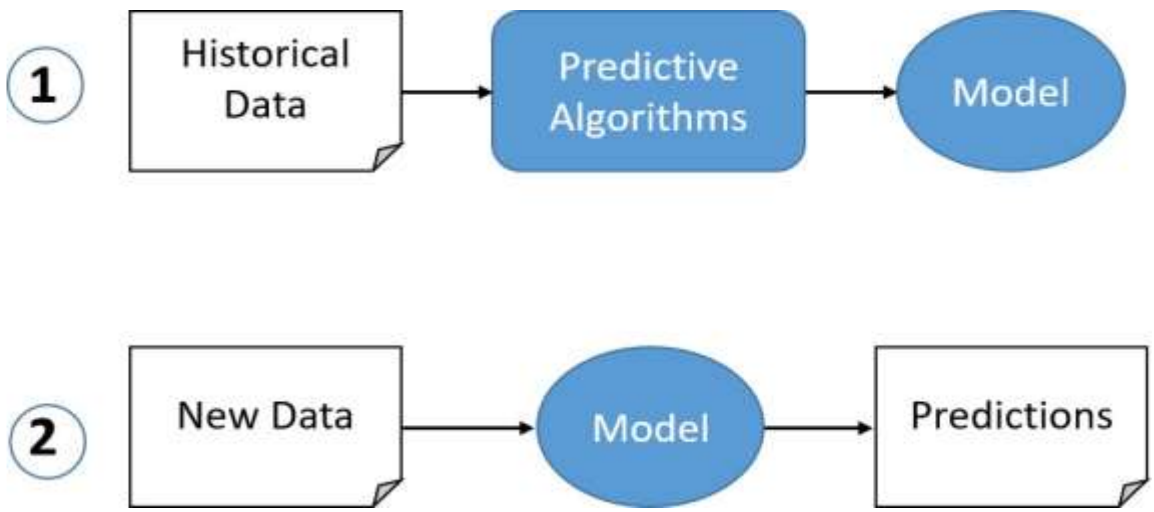
If you have to be around loud noise protecting yourself with earplugs is better than doing.

Excessive exposure to loud noise and or exposure to a quick sound noise could cause serious damage to your ears.

5.9 PREDICTIVE ANALYSIS

Predictive analytics is the practice of extracting information from existing data sets in order to determine patterns and predict future outcomes and trends. Predictive analytics does not tell you what will happen in the future.

Predictive analytics is an area of statistics that deals with extracting information from data and using it to predict trends and behaviour patterns. Predictive analytics statistical techniques include data modelling, machine learning, sound measuring and recording deep learning algorithms and data mining.



5.9 PALLIATIVE TREATMENTS AND ENCLOSURES OF NOISE POLLUTION

- Noise levels in hospitals regularly exceed international recommendations, and the problem is getting worse.
- Excessive noise can impact patients' ability to rest, heal and recover, and has been linked to the development of ICU psychosis, hospitalisation-induced stress, increased pain sensitivity, high blood pressure and poor mental health.
- Patients sleep poorly in hospital, which negatively impacts on their recovery and experience. Sound is a significant contributor to poor sleep quality and quantity.
- The multi-component nature of many noise reduction interventions make it difficult to isolate the effectiveness of a single initiative.

5.10 AUTOMOTIVE NOISE CONTROL PRINCIPLES

GENERAL SOURCE NOISE CONTROL CAN INVOLVE:

Maintenance: - replacement or adjustment of worn or loose parts; - balancing of unbalanced equipment; - lubrication of moving parts; - use of properly shaped and sharpened cutting tools.

Substitution of materials (e.g., plastic for metal), a good example being the replacement of steel sprockets in chain drives with sprockets made from flexible polyamide plastics.

Substitution of equipment: - electric for pneumatic (e.g. hand tools); - stepped dies rather than single-operation dies; - rotating shears rather than square shears; - hydraulic rather than mechanical presses; - presses rather than hammers; - belt conveyors rather than roller conveyors.

Substitution of parts of equipment: - modification of gear teeth - replace gear drives with belt drives; - replace metal gears with plastic gears- replace steel or solid wheels with pneumatic tyres.

Change of work methods - select slowest machine speed appropriate for a job - also select large, slow machines rather than smaller faster ones; - minimise width of tools in contact with workpiece (2 dB(A) reduction for each halving of tool width); - woodchip transport air for woodworking equipment should move in the same direction as the tool; - minimise protruding parts of cutting tools.

Substitution of processes - mechanical ejectors for pneumatic ejectors; - hot for cold working; - pressing for rolling or forging; - welding or squeeze rivetting for impact riveting - welding for rivetting - use cutting fluid in machining processes.

Substitution of mechanical power generation and transmission equipment - electric motors for internal combustion engines or gas turbines- belts or hydraulic power transmissions for gear boxes - replacement of worn moving parts - minimising the number of noisy machines running at any one time.

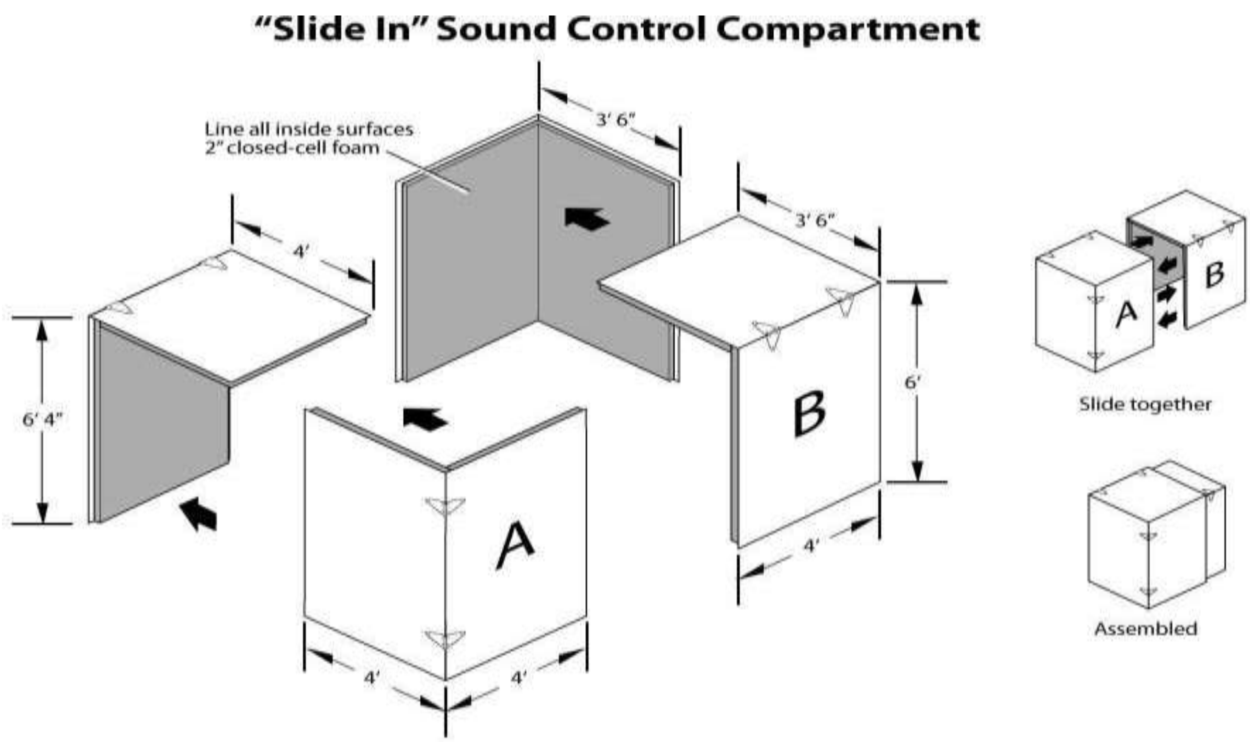
5.11 SOUND IN ENCLOSED AREA

Steel sound enclosures are a highly effective means of noise control for industrial and mechanical equipment. Custom engineered steel enclosures are a workable solution to your noisy industrial equipment.

- Steel sound enclosures are a highly effective means of noise control for industrial and mechanical equipment.
- Acoustic steel enclosures are engineered for superior noise control while allowing for easy access for both ventilation and maintenance.
- Custom engineered steel enclosures are a workable solution to your noisy industrial equipment.

A variety of access options are available to facilitate use of equipment.

- Removable panels
- Maintenance doors
- Double doors
- Sliding doors
- Bi-fold doors
- Pneumatic doors
- Telescoping panels
- Acoustical double-glazed windows



5.12 SOUND ENERGY ABSORPTION

Acoustic absorption refers to the process by which a material, structure, or object takes in sound energy when sound waves are encountered, as opposed to reflecting the energy. Part of the absorbed energy is transformed into heat and part is transmitted through the absorbing body.

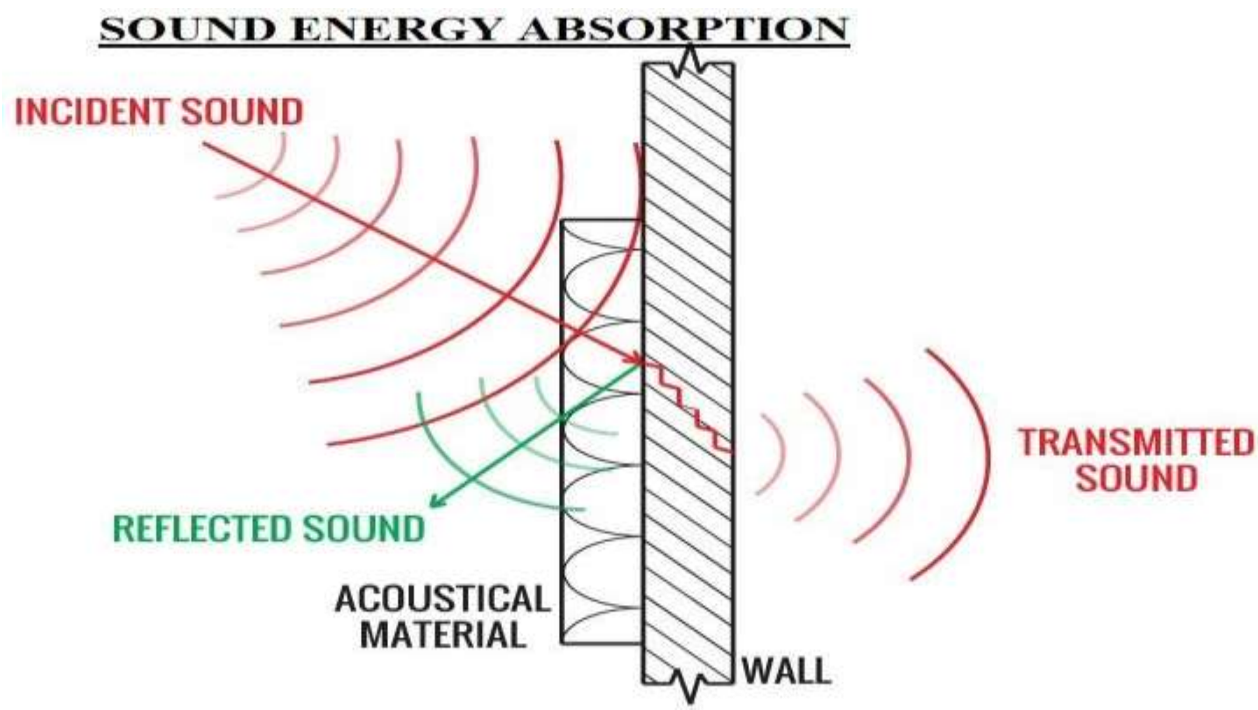
List of Best Sound Absorbing Materials

- Acoustic Foam.
- Acoustic Fabric Panels.
- Sound Deadening Curtains.

- Heavy Moving Blankets.
- Sound Absorbing Underlayment.
- Acoustic Bass Traps.
- Rigid Fiberglass Insulation.
- Acoustic Polyester Panels.

As sound travels through a medium such as water, it gets absorbed – caught by the molecules within the medium. The medium actually changes some of the acoustic energy of the sound wave into heat. One way that this happens is that the acoustic energy of the sound causes the molecules of the medium to start vibrating.

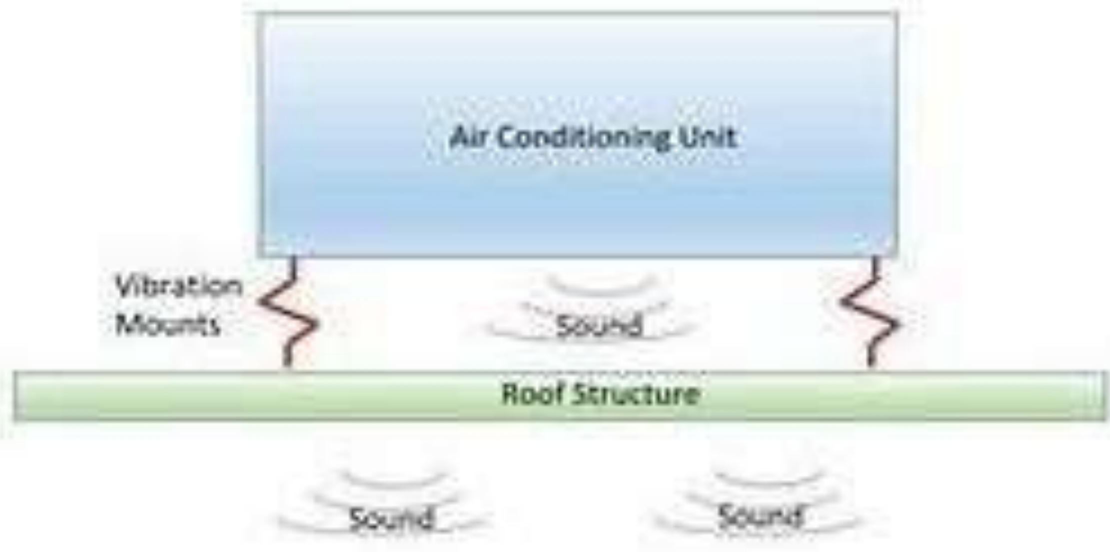
In general, soft, pliable, or porous materials (like cloths) serve as good acoustic insulators.



5.13 SOUND TRANSMISSION THROUGH BARRIERS

Sound transmission through a wall is just one of the ways that sound is transmitted. Soundproofing fundamentally involves the means by which we can control the propagation of sound.

In a typical building structure, the walls consist of 2"x 4" studs spaced a distance of 16" or 24" on center, with a 5/8" sheet of gypsum drywall on each side.



If a sound source is placed on one side of the wall, some of the incident acoustic energy is reflected back off the wall, some of it is absorbed by the wall, and some of it is transmitted through the wall. In general, sound is reflected off of surfaces because the different media have different densities.

The ability to reduce sound transmission through a wall requires an understanding of the mechanisms by which sound is transmitted through the wall. This will determine the appropriate mix of sound barrier and sound absorption materials in an effective soundproofing strategy.

Syllabus-Noise and Vibration Transducers, Analysis Equipment, Signal Processing, and Measuring Techniques: General Introduction to Noise and Vibration Transducers, Measuring Equipment, Measurements, Signal Acquisition and Processing, Acoustical Transducer Principles and Types of Microphones, Vibration Transducer Principles and Types of Vibration Transducers, Sound Level Meters, Noise Dosimeters, Analyzers and Signal Generators, Equipment for Data Acquisition, Noise and Vibration Measurements, Determination of Sound Power Level and Emission Sound Pressure Level, Sound Intensity Measurements, Noise and Vibration Data Analysis, Calibration of Measurement Microphones, Calibration of Shock and Vibration Transducers.

6.1 NOISE AND VIBRATION TRANSDUCERS

Vibration transducers or vibration sensors are used in the manufacturing of machinery. Machines which have an important oscillation can be quickly identified to avoid major damages. Vibration transducers can be connected to an easy-to-read display which allows the user to control the current vibration level.

- Vibration transducers supervise machines in production processes and help people to protect installations against an overload.
- Vibration transducers can detect vibrations in machines and transform them into a normalized signal.
- These normalized signals can be sent to a digital indicator to test the machines.
- This fact allows immediate intervention in the production process to protect machines and even to avoid damages and failures.

Vibration Analyser

Vibration Analysis refers to the process of measuring the vibration levels and frequencies of industrial machinery, and using that information to determine the “health” of the machine, and its components.

Measurements on Structures or Machinery Casings: Accelerometers and Velocity Sensors

- Used in gas turbines, axial compressors, small and mid-size pumps.
- These sensors detect high frequency vibration signals related to bearing supports, casing and foundation resonances, vibration in turbine/compressor vanes, defective roller or ball bearings, noise in gears, etc.

Displacement measurements relative to rotating shafts: Proximity Probes (capacitance or eddy-current)

- Used in turbo machinery supported on fluid film bearings, centrifugal compressors, gears and transmissions, electric motors, large pumps (>300HP), some turbines and fans.
- These sensors detect shaft static displacements, unbalance response, misalignment, shaft bending, excessive loads in bearings, dynamic instabilities, etc.

6.2 A FEW SENSOR TYPES USED FOR COMMON VIBRATION MEASUREMENTS

1) Accelerometers (piezoelectric)

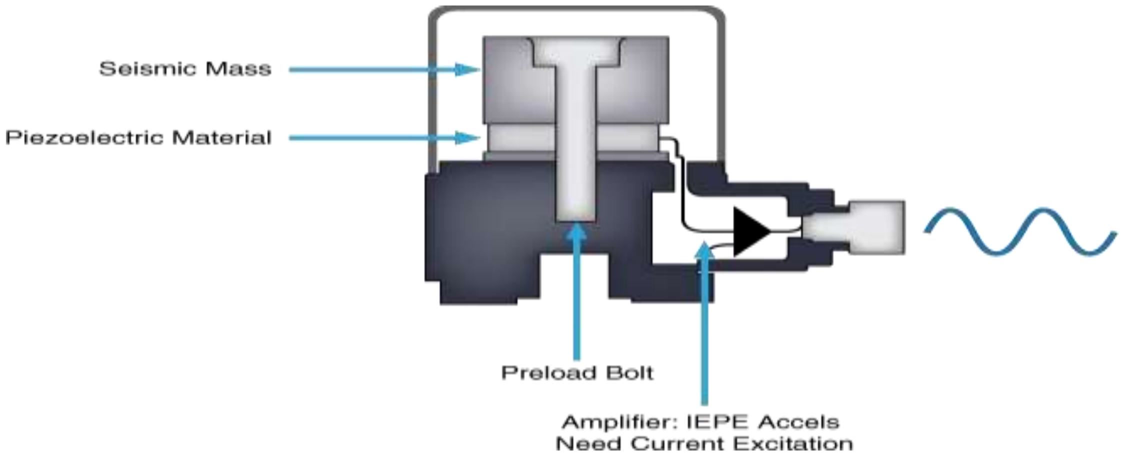
2) Velocity Sensor

3) Proximity Probes (capacitance or eddy current)

4) Laser displacement sensors

6.2.1 ACCELEROMETER

An accelerometer is a device that measures the vibration, or acceleration of motion of a structure. The force caused by vibration or a change in motion (acceleration) causes the mass to "squeeze" the piezoelectric material which produces an electrical charge that is proportional to the force exerted upon it. Since the charge is proportional to the force, and the mass is a constant, then the charge is also proportional to the acceleration.



There are two types of piezoelectric accelerometers (vibration sensors). The first type is a high impedance charge output accelerometer. The second type of accelerometer is a low impedance output accelerometer.

Piezoelectric Accelerometers

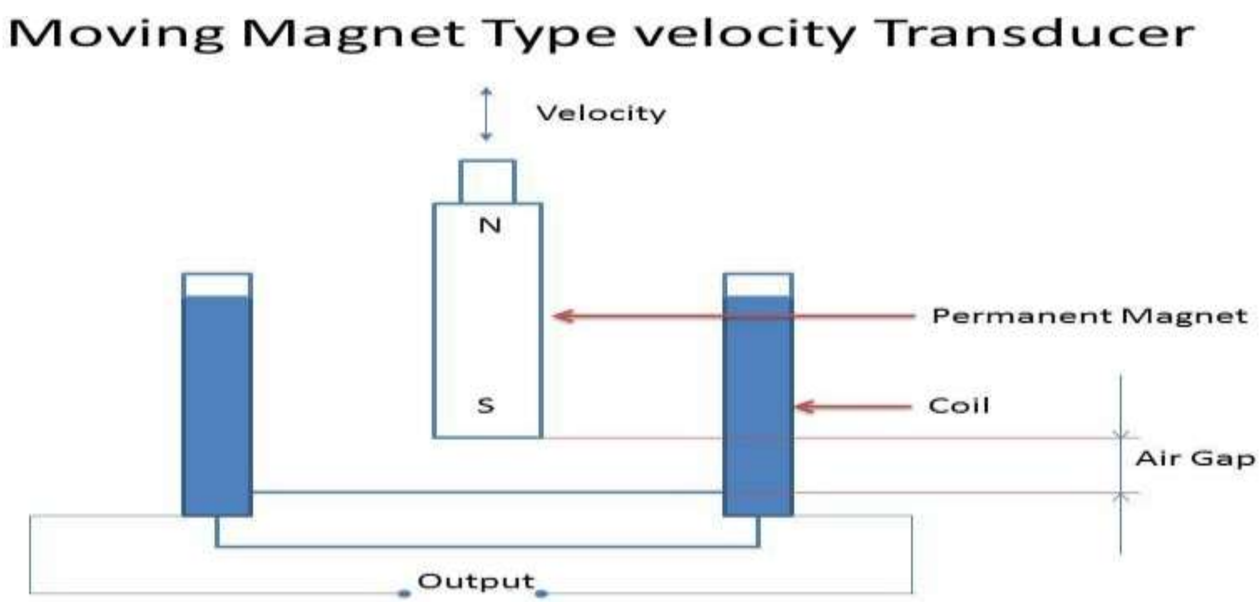
Piezoelectric accelerometers rely on the piezoelectric effect of quartz or ceramic crystals to generate an electrical output that is proportional to applied acceleration. The piezoelectric effect produces an opposed accumulation of charged particles on the crystal. This charge is proportional to applied force or stress.

Piezoelectric Material

There are two types of piezoelectric material that are used in PCB accelerometers: quartz and polycrystalline ceramics. Quartz is a natural crystal, while ceramics are man-made. Each material offers certain benefits, and material choice depends on the particular performance features desired of the accelerometer. Quartz is widely known for its ability to perform accurate measurement tasks and contributes heavily in everyday applications for time and frequency measurements.

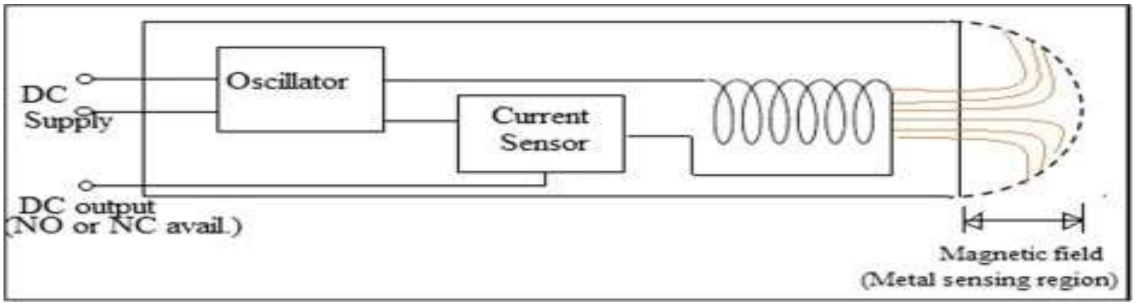
6.2.2 VELOCITY SENSORS

When a coil of wire is moved through a magnetic field, a voltage is induced across the end wires of the coil. The induced voltage is caused by the transferring of energy from the flux field of the magnet to the wire coil. As the coil is forced through the magnetic field by vibratory motion, a voltage signal representing the vibration is produced.



6.2.3 CAPACITIVE AND EDDY CURRENT SENSORS

Capacitive sensors use the electrical property of "capacitance" to make measurements. Capacitance is a property that exists between any two conductive surfaces within some reasonable proximity. Changes in the distance between the surfaces change the capacitance. It is this change of capacitance that capacitive sensors use to indicate changes in position of a target. High-performance displacement sensors use small sensing surfaces and as result are positioned close to the targets.

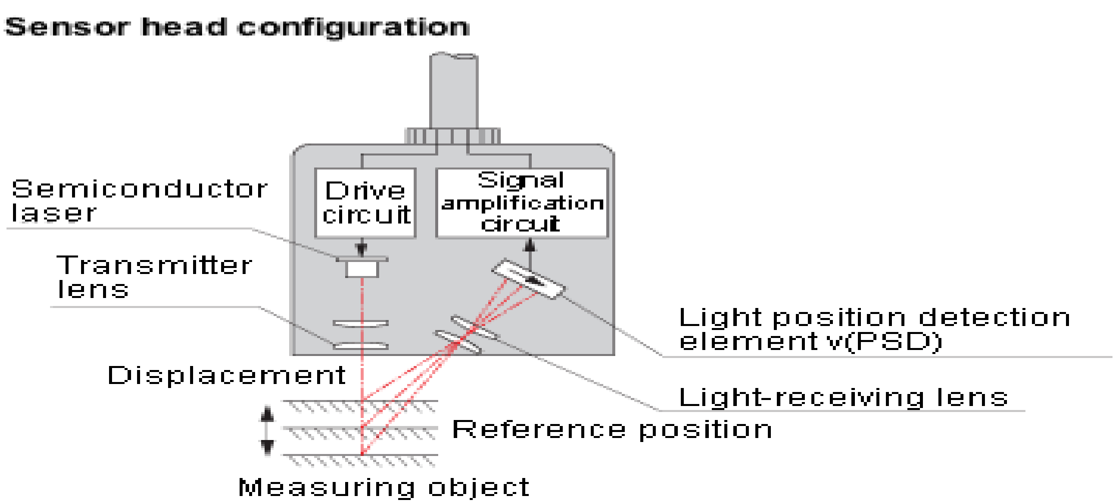


Working principle

Eddy currents are formed when a moving (or changing) magnetic field intersects a conductor, or vice-versa. The relative motion causes a circulating flow of electrons, or currents, within the conductor. These circulating eddies of current create electromagnets with magnetic fields that oppose the effect of the applied magnetic field. The stronger the applied magnetic field, or greater the electrical conductivityy of the conductor, or greater the relative velocity of motion, the greater the currents developed and the greater the opposing field. Eddy current probes sense this formation of secondary fields to find out the distance between the probe and the target material.

6.2.4 LASER DISPLACEMENT SENSOR

The Charge coupled device (CCD) laser displacement sensor uses a triangulation measurement system. Conventional laser displacement sensors employ a Position sensitive detector (PSD) as the light-receiving element.. The light reflected by a target passes through the receiver lens and is focused on the PSD or CCD. The PSD uses the light quantity distribution of the entire beam spot entering the light receiving element to determine the beam spot center and identifies this as the target position.



ACCELEROMETERS

Advantages	Disadvantages
Simple to install	Sensitive to high frequency noise
Good response at high frequencies	Require external power
Stand high Temperature	Require electronic integration for velocity and displacement
Small size	

VELOCITY SENSORS

Advantages	Disadvantages
Simple to install	Low resonant frequency & phase shift
Good response in middle range frequencies	Cross noise
Stand high temperature	Big and heavy
Do not require external power	Require electronic integration for displacement
Lowest cost	

PROXIMITY SENSORS

Advantages	*Disadvantages*
Measure static and dynamic displacements	Electrical and mechanical noise
Exact response at low frequencies	Bounded by high frequencies
No wear	Not calibrated for unknown metal materials
Small and low cost	Require external power
	Difficult to install

ACCELERATION SENSORS

Capacitive accelerometers: Used generally in those that have diaphragm supported seismic mass as a moving electrode and one/two fixed electrodes. The signal generated due to change in capacitance is post-processed using LC circuits etc., to output a measurable entity.

Piezoelectric accelerometers: Acceleration acting on a seismic mass exerts a force on the piezoelectric crystals, which then produce a proportional electric charge. The piezoelectric crystals are usually preloaded so that either an increase or decrease in acceleration causes a change in the charge produced by them. But they are not reliable at very low frequencies.

Potentiometric accelerometers: Relatively cheap and used where slowly varying acceleration is to be measured with a fair amount of accuracy. In these, the displacement of a spring mass system is mechanically linked to a viper arm, which moves along a potentiometric resistive element. Various designs may have either viscous, magnetic or gas damping.

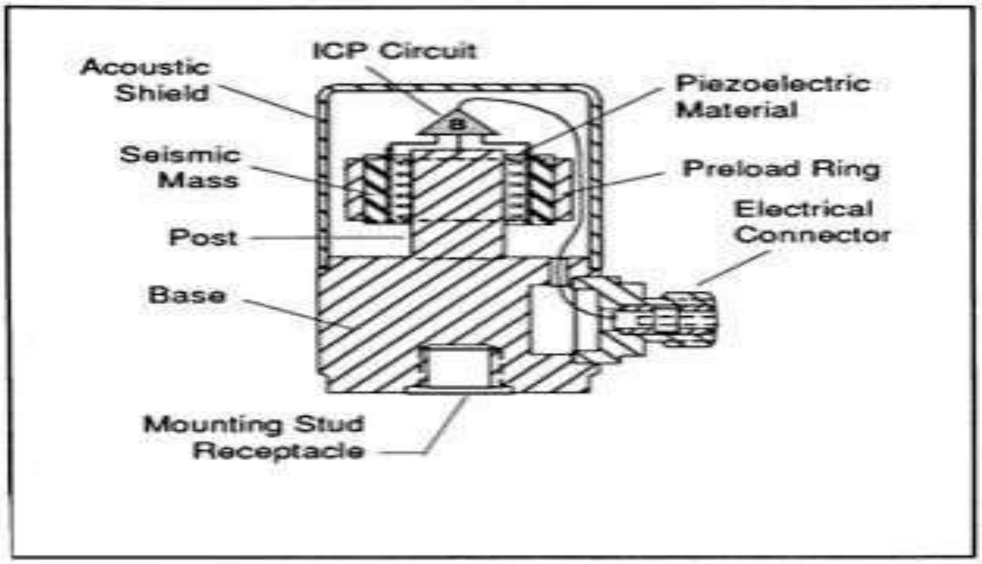
Reluctive accelerometers: They compose accelerometers of the differential transformer type or the inductance bridge type. The AC outputs of these vary in phase as well as amplitude. They are converted into DC by means of a phase-sensitive demodulator.

Servo accelerometers: These use the closed loop servo systems of force-balance, torque-balance or null-balance to provide close accuracy. Acceleration causes a seismic mass to move. The motion is detected by one of the motion-detection devices, which generate a signal that acts as an error signal in the servo-loop. The demodulated and amplified signal is then passed through a passive damping network and then applied to the torquing coil located at the axis of rotation of the mass. The torque is proportional to the coil current, which is in turn proportional to the acceleration.

Strain Gage accelerators: these can be made very small in size and mass. The displacement of the spring-mass system is converted into a change in resistance, due to strain, in four arms of a Wheatstone bridge. The signal is then post-processed to read the acceleration.

SHEAR MODE ACCELEROMETER

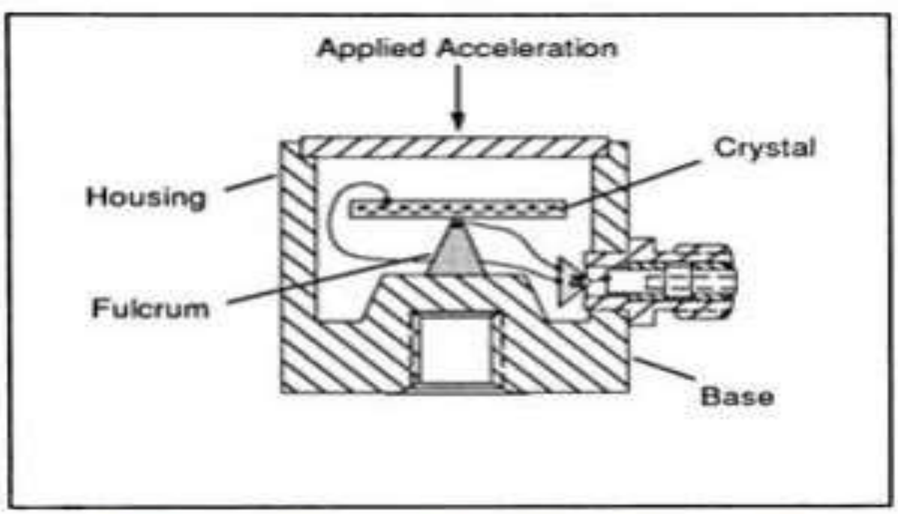
Shear mode designs bond, or "sandwich," the sensing crystals between a center post and seismic mass. A compression ring or stud applies a preload force required to create a rigid linear structure. Under acceleration, the mass causes a shear stress to be applied to the sensing crystals. By isolating the sensing crystals from the base and housing, shear accelerometers excel in rejecting thermal transient and base bending effects. Also, the shear geometry lends itself to small size, which minimizes mass loading effects on the test structure



Shear Mode Accelerometer

FLEXURAL MODE ACCELEROMETER

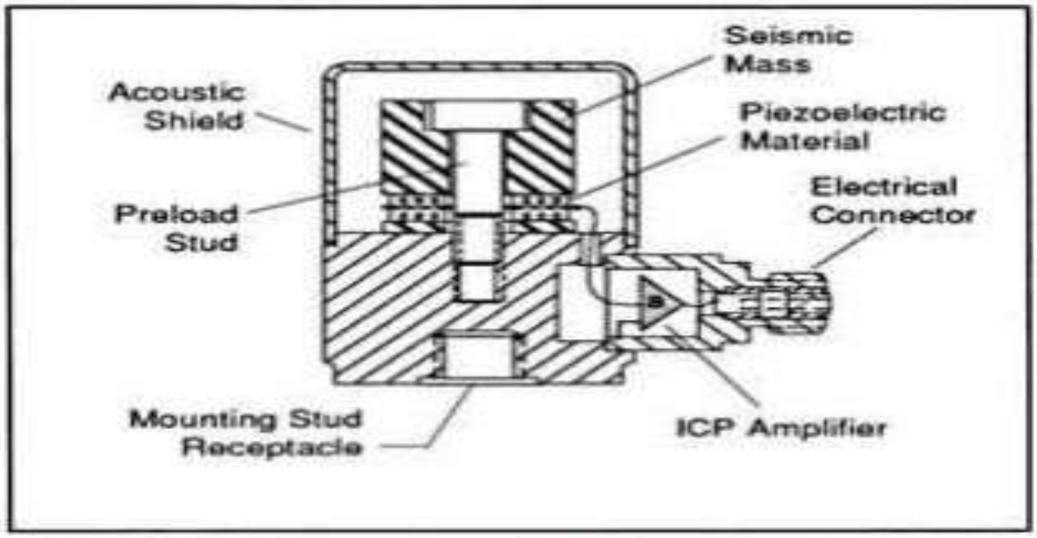
Flexural mode designs utilize beam-shaped sensing crystals, which are supported to create strain on the crystal when accelerated. The crystal may be bonded to a carrier beam that increases the amount of strain when accelerated. This design offers a low profile, light weight, excellent thermal stability, and an economical price. Insensitivity to transverse motion is also an inherent feature of this design. Generally, flexural beam designs are well suited for low-frequency, low-g-level applications like those which may be encountered during structural testing.



Flexural Mode Accelerometer

COMPRESSION MODE ACCELEROMETER

Compression mode accelerometers offer simple structure, high rigidity, and historical availability. There are basically three types of compression designs: upright, inverted, and isolated. Upright compression designs sandwich the piezoelectric crystal between a seismic mass and rigid mounting base. An elastic stud or screw secures the sensing element to the mounting base. When the sensor is accelerated, the seismic mass increases or decreases the amount of force acting upon the crystal, and a proportional electrical output results. The larger the seismic mass is, the greater the stress and, hence, the output are.



Upright Compression Accelerometer

6.3 SIGNAL ACQUISITION AND PROCESSING

Noise and vibration of automotive vehicles are an increasingly important issue in the automobile industry, for implications on both environmental noise pollution and comfort perceived by driver and passengers. Since noise and vibration performances affect the overall image of a vehicle, they are now considered important factors in the entire vehicle design process.

In this regard, an accurate experimental evaluation of vehicle noise and vibration levels in both stationary conditions and urban driving conditions are often necessary for undertaking a refinement process of vehicle sound quality, satisfying the development targets.

In order to monitor sound generation in terms of both air-borne and structure-borne noise, the source, transfer path and receiver have to be investigated by noise measurement. For this purpose, different techniques can be employed. Some of them make use of instrumentation (i.e. condenser microphone, sound level meter, sound intensity probe, acoustic holography) which requires particular measurement environments, as it ensures sufficient measuring accuracy only in free field or anechoic (free from echo) conditions.

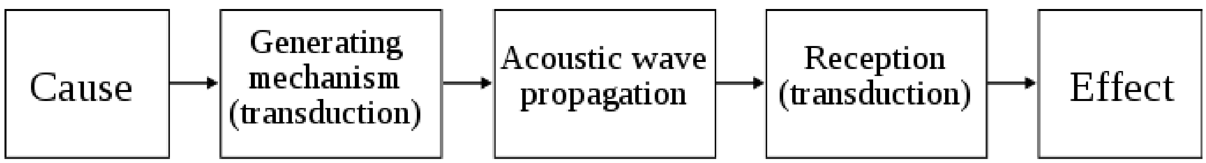
Vibration measurements by using proper transducers allow to minimize the structure-borne vibration transmitted from vehicle power plant to chassis and body structure. Experimental modal analysis is another standard tool in vehicle NVH development for determining the dynamic characteristics of a system.

6.4 ACOUSTICAL TRANSDUCER PRINCIPLES AND TYPES OF MICROPHONES

Acoustics is the branch of physics that deals with the study of all mechanical waves in gases, liquids, and solids including topics such as vibration, sound, ultrasound and infrasound.

Acoustic or sonic analysis is the measurement of sound waves caused by component contacts inside equipment. It is a term commonly used in other fields such as the music recording industry, but its application in monitoring bearing lubrication is relatively new.

The study of acoustics revolves around the generation, propagation and reception of mechanical waves and vibrations.



There are many kinds of cause, both natural and volitional. There are many kinds of transduction process that convert energy from some other form into sonic energy, producing a sound wave. The wave carries energy throughout the propagating medium. Eventually this energy is transduced again into other forms, in ways that again may be natural and/or volitionally contrived. The final effect may be purely physical or it may reach far into the biological or volitional domains.

MICROPHONE

A microphone is a transducer that converts sound into an electrical signal. Microphones are used in many applications such as telephones, hearing aids, public address systems etc.

Several different types of microphone are in use, which employ different methods to convert the air pressure variations of a sound wave to an electrical signal.

The most common are

- **Dynamic microphone** which uses a coil of wire suspended in a magnetic field
- **Condenser microphone** which uses the vibrating diaphragm as a capacitor plate
- **Piezoelectric microphone** which uses a crystal of piezo electric material.

Microphones typically need to be connected to a preamplifier before the signal can be recorded or reproduced.

Microphones are categorized by their transducer principle, such as condenser, dynamic, etc., and by their directional characteristics. Sometimes other characteristics such as diaphragm size, intended use or orientation of the principal sound input to the principal axis (end- or side-address) of the microphone are used to describe the microphone

Types of micro phones are,

- **Condenser microphones**: This uses a capacitor to convert acoustical energy into electrical energy. Condenser microphones require power from a battery or external source. The resulting audio signal is stronger signal than that from a dynamic.
- **Electret condenser microphones:** An electret microphone is a type of electrostatic capacitor-based microphone, which eliminates the need for a polarizing power supply by using a permanently charged material.
- **Dynamic microphones:** In a dynamic microphone, sound waves cause a movable wire or coil to vibrate in a magnetic field and thus induce a current, to then be converted back to sound.
- **Ribbon microphones:** A ribbon microphone, also known as a ribbon velocity microphone, is a type ofmicrophone that uses a thin aluminum, duraluminum or nanofilm of electrically conductive ribbon placed between the poles of a magnet to produce a voltage by electromagnetic induction.
- **Carbon microphones:** It is a type of microphone, a transducer that converts sound to an electrical audio signal. It consists of two metal plates separated by granules of carbon
- **Piezoelectric or crystal microphones**: is a form of microphone that senses audio vibrations through contact with solid objects. Unlike normal air microphones, contact microphones are almost completely insensitive to air vibrations but transduce only structure-borne sound.
- **Fiber optic microphones:** It converts acoustic waves into electrical signals by sensing changes in light intensity, instead of sensing changes in capacitance or magnetic fields as with conventional microphones.
- **Laser microphones:** It can be used to pick up sound at a distance from the microphone equipment. A laser beam is aimed at the surface of a window or other plane surface that is affected by sound. The vibrations of this surface change the angle at which the beam is reflected, and the motion of the laser spot from the returning beam is detected and converted to an audio signal.
- **Liquid microphones**: The sound waves from a human voice cause a diaphragm to vibrate which causes a needle or rod to vibrate up and down in water that has been made conductive by a small amount of acid. As the needle or rod vibrates up and down in the water, the resistance of the water fluctuates which causes alternating current in the circuit.
- **MEMS: Micro-electro-mechanical systems** is also called a microphone chip or silicon microphone. A pressure-sensitive diaphragm is etched directly into a silicon wafer by MEMS processing techniques, and is usually accompanied with integrated preamplifier. Most MEMS microphones are variants of the condenser microphone

design. Digital MEMS microphones have built in analog-to-digital converter (ADC) circuits

- **Speakers as microphones:** A loudspeaker, a transducer that turns an electrical signal into sound waves, is the functional opposite of a microphone. Since a conventional speaker is constructed much like a dynamic microphone (with a diaphragm, coil and magnet), speakers can actually work "in reverse" as microphones.

6.5 SOUND LEVEL METER

A sound level meter is used for acoustic (sound that travels through air) measurements. It is commonly a hand-held instrument with a microphone. The diaphragm of the microphone responds to changes in air pressure caused by sound waves. That is why the instrument is sometimes referred to as a Sound Pressure Level (SPL) Meter. This movement of the diaphragm, i.e. the sound pressure deviation (pascal Pa), is converted into an electrical signal (volts V).

A microphone is distinguishable by the voltage value produced when a known, constant sound pressure is applied. This is known as the microphone sensitivity. The instrument needs to know the sensitivity of the particular microphone being used. Using this information, the instrument is able to accurately convert the electrical signal back to a sound pressure, and display the resulting sound pressure level (decibels dB SPL).

Sound level meters are commonly used in noise pollution studies for the quantification of different kinds of noise, especially for industrial, environmental, mining and aircraft noise.

6.6 NOISE DOSIMETER

A noise dosimeter (American) or noise dosimeters (British) is a specialized sound level meter intended specifically to measure the noise exposure of a person integrated over a period of time.

Noise dosimeters were relatively large devices with a microphone mounted near the ear and having a cable going to the instrument body, it usually belt worn. These devices had several issues, mainly the reliability of the cable and the disturbance to the user's normal work mode, caused by the presence of the cable.

6.7 DETERMINATION OF SOUND POWER LEVEL AND EMISSION SOUND PRESSURE LEVEL

The total sound energy emitted by a source per unit time is the sound power. All share as level the same unit of measure: the decibel (dB).

sound pressure level SPL is actually a ratio of the absolute, Sound Pressure and a reference level(usually the Threshold of Hearing, or the lowest intensity sound that can be heard by most people). SPL is measured in decibels (dB).

How is Sound Power Measured?

Acoustic sound power is not measured directly but is derived from the measurement of sound intensity on a surface enclosing the test article as shown in figure 2. The units of sound intensity are W/m^2, so total sound power can be calculated by multiplying the average sound intensity over the entire closed surface by the surface area:

$$W_{total} = \bar{I} A_S \cdot$$

where $\bar{I}$ is the average intensity over the enclosed surface, and A_S is the total area of the enclosed surface.

Characteristic values that describe noise emission

To describe the noise emitted by a machine, the following characteristic values are of particular importance, as they describe the noise directly emitted independently of extraneous noise and of the room in which it is housed.

- **Emission sound pressure level at the workplace L_p**: This is a measure of the sound pressure level caused by the machine at its workplace independently of room-related effects or extraneous noise. It is thus equivalent to the sound pressure level at the workplace if the machine is set up outside in a silent environment (ideal case).
- **Sound power level L_W**: This is a measure of the total sonic energy directly emitted by the machine per unit of time.

The relationship between the sound pressure level and sound power level is relatively easy to represent for a machine under free field conditions (unhindered sound propagation) and without any appreciable extraneous noise. The sound power level L_W can then be calculated from the mean sound pressure level L_p on a measuring surface enclosing the machine and from the measuring surface area S by means of the following formula:

$$L_W = L_p + 10 \lg (S/1\ m^2) \quad dB \quad \text{or} \qquad (1)$$

$$L_W = L_p + L_S \quad dB \qquad (2)$$

Where: L_p = mean sound pressure level on measuring surface S

S = measuring surface area

$L_S = 10 \lg (S/1\ m^2)$ – measuring surface dimension (3)

DETERMINATION OF SOUND POWER LEVEL AND EMISSION SOUND PRESSURE LEVEL

The primary noise emission value to be declared or stated is the mean A-weighted sound power level, LWA,m.

Standards for noise emission—the sound emitted by a product independent of its location allow a manufacturer to make a measurement of a specific piece of equipment under specified operating conditions and report the noise level, usually in the form of a "guaranteed level." Usually, but not always, noise emission information is reported as the A-weighted sound power level.

1. Internal control of production with assessment. The manufacturer takes full responsibility for initial certification, documentation, and ongoing monitoring of production units. A "notified body" must be contracted to verify the manufacturer's documentation and noise-level conformance on a regular basis.
2. Unit verification. The manufacturer submits an application to a notified body, which is then contracted to examine the equipment and carry out the certification and documentation process.
3. Full quality assurance procedure. The manufacturer takes full responsibility for initial certification, documentation, and ongoing monitoring of production units. If the manufacturer has a certified quality assurance system in place, only periodic audits by a notified body are required.

6.8 SOUND INTENSITY MEASUREMENTS

Sound intensity level also known as acoustic intensity is defined as the power carried by sound waves per unit area in a direction perpendicular to that area. The SI unit of intensity, which includes sound intensity, is the watt per square meter (W/m2). One application is the noise measurement of sound intensity in the air at a listener's location as a sound energy quantity.

Sound intensity is not the same physical quantity as sound pressure. Hearing is directly sensitive to sound pressure which is related to sound intensity. In consumer audio electronics, the level differences are called "intensity" differences, but sound intensity is a specifically defined quantity and cannot be sensed by a simple microphone. The rate at which sound energy passes through a unit area held perpendicular to the direction of propagation of sound waves is called intensity of sound.

One method of sound intensity measurement involves the use of two microphones located close to each other, normal to the direction of sound energy flow. A signal analyzer is used to compute the cross power between the measured pressures and the sound intensity is derived from (proportional to) the imaginary part of the cross power.

Loudness is related to the amplitude of sound waves (or pressure amplitude/ displacement relative to atmospheric pressure, typically), whereas intensity is the rate at which power (rate of energy transfer, or work per unit time) is transferred across a given area.

6.9 CALIBRATION OF MEASUREMENT MICROPHONES

The calibration microphone is that mic used for measurement rather than recording purposes. These types of microphones usually have a flat response because the main idea is to have a accurate and also uncolored picture of audio source. Measurement microphones are accurate and reliable devices designed to be used for quantify acoustics signals.

There are 2 ways of calibrating a measurement microphone, level and sound calibration.

Level Calibration

For level calibration, a piston phone is used for as a precise sound source for the calibration. As a piston phone relies on air pressure, the ambient pressure, humility and air in the environment has to be analyzed and monitored before and during calibration. With this, piston phone are generally only made to reproduce low frequencies typically 250 Hz.

Sound Calibration

Sound calibrators are another sound source used in calibration and they are not affected by ambient pressure and cavity volume. Sound calibrators work electronically and are considered as an electrodynamic source for calibration, usually generating a 1000 Hz tone to the microphone. Due to sound calibrators relying on an electrodynamic sound source, there is a slight increase in chances of error making them less precise than mechanical-based piston phones.

A microphone's sensitivity can also depend on the nature of the sound field it is exposed to. For this reason, microphones are often calibrated in more than one sound field, for example a pressure field and a free field. Depending on their application, measurement microphones must be tested periodically (every year or several months, typically), and after any potentially damaging event, such as being dropped or exposed to sound levels beyond the device's operational range.

6.10 CALIBRATION OF SHOCK AND VIBRATION TRANSDUCERS

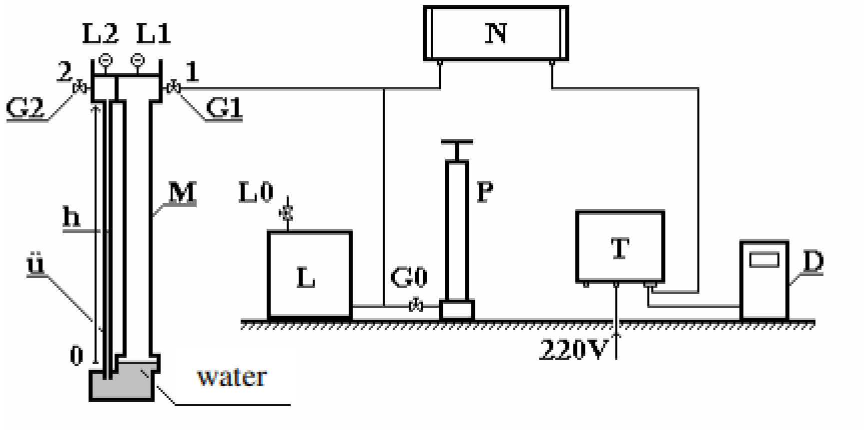
Calibration is a process when the output signal of the sensor is compared to the value measured by an accurate device, and the relationship between the measured and the accurate value is determined.

Instrument error can occur due to a variety of factors: drift, environment, electrical supply, addition of components to the output loop, process changes, etc. Since a calibration is performed by comparing or applying a known signal to the instrument under test, errors are detected by performing a calibration. An error is the algebraic difference between the indication and the actual value of the measured variable.

The pressure transducer is connected to an air reservoir L, and the pressure in the reservoir is measured by a manometer filled with water. The pressure transducer is connected to the reservoir and has an electric current output. This way the pressure measured by the manometer and the output current of the pressure transducer can be related.

The scheme of the measurement rig is shown in Figure. The pressure transducer (N) receives its electrical power from the power supply (T). The pressure transducer and the manometer are connected to the reservoir tank via a T-junction.

The height of the water column (h) of the manometer can be read from the mm scale attached to the glass pipe. The height has to be read at the horizontal tangent of the curved water surface (the meniscus).



Scheme of the measurement rig

The output signal of the pressure transducer can be measured by a digital multimeter (D). As the output of the sensor varies between 4 mA and 20 mA, so the digital multimeter should be used in the 20 mA setting.

DISADVANTAGES OF INDIVIDUAL CALIBRATION	ADVANTAGES OF INDIVIDUAL CALIBRATION
1. Entire loop is not verified within tolerance 2. Mistakes on re-connect 3. Less efficient use of time to do one calibration for each loop instrument as opposed to one calibration for the loop	1. Correct instrument will be adjusted 2. More compatible with multifunction calibrators