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

ME376 MAINTENANCE ENGINEERING

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

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

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

Course code	Course Name	L-T-P-Credits	Year of Introduction
ME376	**Maintenance Engineering**	**3-0-0-3**	**2016**
Prerequisite: Nil			

Course Objectives:

- To enable the student to understand the principles, functions and practices of maintenance activities.
- To develop ability in formulating suitable maintenance strategies to achieve reliable manufacturing system.
- To introduce the different maintenance categories and failure analysis tools.
- To equip with essential system diagnosis techniques so as to identify and take appropriate actions on error symptoms and causes of failures.
- To illustrate the techniques used for maintenance management.
- To empower with the skills to manage a manufacturing system to achieve continuous system availability for production.

Syllabus:

Maintenance – reliability – maintainability – availability – maintenance systems – condition monitoring – monitoring systems – failure analysis – maintenance effectiveness – quality assured maintenance – maintenance planning and scheduling – maintenance organization – maintenance costs – maintenance budgeting – human factor in maintenance – computer-aided maintenance management system – maintenance integration.

Expected outcome:

The students will be able to

i. Understand the relationship of key concepts in reliability engineering and application to maintenance strategies in a manufacturing environment.
ii. Establish maintenance strategies according to system characteristics and design transition programs to implement these strategies.
iii. Manage the manufacturing organization with highest possible availability.

Text Books:

1. Gupta A. K., Reliability, Maintenance and Safety Engineering, University Science Press, New Delhi, 2009.
2. Rao S. S., Reliability-Based Design, McGraw-Hill, Inc, New York, 1992.
3. Srivastava S. K., Maintenance Engineering and Management, S. Chand & Company Ltd., New Delhi, 1998.
4. Venkataraman, Maintenance Engineering and Management, Prentic-Hall of India Pvt. Ltd., New Delhi, 2007.

Reference Books:

1. Davies, Handbook of Condition Monitoring, Chapman & Hall, 1996.
2. Garg M. R., Industrial Maintenance, S. Chand & Co., 1986.
3. Higgins L. R., Maintenance Engineering Hand book, McGraw Hill, 5th Edition, 1988.
4. Mishra R. C. and Pathak K., Maintenance Engineering and Management, PHI Learning Pvt. Ltd., New Delhi, 2009.

Course Plan

Module	Contents	Hours	End Sem. Exam. Marks
I	Maintenance – basic concepts, purpose, functions and objectives of maintenance.	1	15%
	Principles, benefits and effects of maintenance	1	
	Inter-relationship between productivity, quality, reliability and maintainability – maintenance productivity – quality in maintenance.	1	
	Reliability – basic concepts – bathtub curve – failure rate – mean time before failure.	1	
	System reliability – reliability of series and parallel systems.	1	
	Maintainability – mean time to failure – mean time to repair.	1	
	Availability – inherent, achieved and operational availability – reliability, availability and maintainability (RAM).	1	
II	Maintenance strategies / systems – types – basis for selection. Breakdown maintenance – corrective maintenance	1	15%
	Preventive maintenance – process flow – frequency in preventive maintenance.	1	
	Predictive maintenance – components – advantages and disadvantages.	1	
	Condition based maintenance and condition monitoring – monitoring systems.	1	
	Performance monitoring – visual, tactile and aural monitoring – leakage monitoring.	1	
	Temperature monitoring – thermography – advantages.	1	
	Thickness monitoring – acoustic monitoring – smell/odour monitoring.	1	
FIRST INTERNAL EXAMINATION			
III	Vibration monitoring – vibration fundamentals – vibration analysis.	1	15%
	Vibration transducers – types.	1	
	Machinery vibration trouble shooting – machinery vibration standard, severity chart and acceptable limits.	1	
	Lubricant monitoring – components and techniques – filter debris analysis & filtergrams.	1	
	Ferrography – spectroscopic oil analysis program.	1	

	Crack monitoring – techniques.	**1**	
	Corrosion monitoring – techniques.	**1**	
IV	Reliability centered maintenance (RCM) – steps – flow diagram – basic guidelines.	**1**	**15%**
	Defect and failure – definitions – basics of failures – failure generation – failure analysis.	**1**	
	Fault tree analysis (FTA)	**1**	
	Event tree analysis (ETA)	**1**	
	Root cause analysis (RCA)	**1**	
	Failure modes and effects analysis (FMEA)	**1**	
	Failure mode effect criticality analysis (FMECA)	**1**	
SECOND INTERNAL EXAMINATION			
V	Terotechnology – definitions – terotechnology system – terotechnology process – strategies.	**1**	**20%**
	Total productive maintenance (TPM) – features –methodology – basic systems of TPM – TPM and terotechnology.	**1**	
	Six sigma maintenance.	**1**	
	Lean maintenance – 5-zero maintenance concept – 5-S maintenance concept.	**1**	
	Business centered maintenance (BCM) – six pillars – success factors.	**1**	
	Maintenance effectiveness – overall equipment effectiveness – key performance indicators – maintenance performance measuring indices.	**1**	
	Quality assured maintenance – need – maintenance work quality – use of c-chart for quality control in maintenance.	**1**	
VI	Maintenance planning and scheduling.	**1**	**20%**
	Maintenance organization – objectives and characteristics – centralized and decentralized maintenance.	**1**	
	Maintenance costs – classification of maintenance costs – maintenance cost analysis – cost effectiveness analysis.	**1**	
	Maintenance budgeting – types of maintenance budget – preparation of maintenance budget.	**1**	
	Human factor in maintenance – manpower planning for maintenance – objectives and stages of manpower planning – training for maintenance personnel.	**1**	
	Computer-aided maintenance management system (CMMS) – functions, applications and advantages of CMMS.	**1**	
	Maintenance integration – various steps in integration – scheme of integration of maintenance function with other functions.	**1**	

Question Paper Pattern

Maximum marks: 100 **Time: 3 hrs**

The question paper should consist of three parts

Part A

There should be 2 questions each from module I and II

Each question carries 10 marks

Students will have to answer any three questions out of 4 (3X10 marks =30 marks)

Part B

There should be 2 questions each from module III and IV

Each question carries 10 marks

Students will have to answer any three questions out of 4 (3X10 marks =30 marks)

Part C

There should be 3 questions each from module V and VI

Each question carries 10 marks

Students will have to answer any four questions out of 6 (4X10 marks =40 marks)

Note: Each question can have a maximum of four sub questions, if needed.

COURSE COUTCOME

CO No.	Course Outcome
CO1	Students will be able to define basic concepts of reliability, maintainability and availability.
CO2	Students will be able to use various maintenance strategies and types of maintenance.
CO3	Students will be able to select various maintenance measuring instruments and various methods adopted to measure them.
CO4	Students will be able develop Maintenance planning and scheduling
CO5	Establish maintenance strategies according to system characteristics and design transition programs to implement these strategies.
CO6	Manage the manufacturing organization with highest possible availability.

CO-PO-PSO MAPPING

CO Vs PO															
ME376															
COURSE COUTCOME	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
C376.1	-	-	-	-	-	3	3	2	-	3	-	3	-	-	3
C376.2	-	-	-	-	-	3	3	3	-	3	-	3	-	-	3
C376.3	-	-	-	-	-	3	2	3	-	3	-	3	-	-	3
C376.4	-	-	-	-	-	3	2	3	-	3	-	3	-	-	3
C376.5	-	-	-	-	-	3	3	3	-	3	-	3	-	-	3
C376.6	-	-	-	-	-	3	3	3	-	3	-	3	-	-	3

QUESTION BANK

MODULE 1			
SL NO	**QUESTIONS**	**CO**	**KL**
1	Explain the maintenance functions	CO1	K1
2	Compare quality and reliability	CO1	K3
3	What is maintainability and how the maintainability is improved	CO1	K2
4	Illustrate failure mode with a Bath Tube curve	CO1	K2
5	Explain Reliability of series and parallel and standby systems with examples	CO1	K2
6	Explain any two types of availability	CO1	K2
7	Define Maintenance and explain the basic steps in maintaining a two wheeler on regular basis	CO1	K3
8	What are the objectives of maintenance?	CO1	K3
9	What are the principles of Maintenance?	CO1	K2
10	What are the benefits of Maintenance?	CO1	K2

MODULE 2			
SL NO	**QUESTIONS**	**CO**	**KL**
1	Compare online and offline condition Monitoring	CO2	K3
2	Explain the procedure of preventive Maintenance	CO2	K2
3	Explain five different types of corrective Maintenance	CO2	K2
4	Define Thermography with an example	CO2	K1
5	Define OMP, Also explain the importance of odour monitoring in an industry	CO2	K2
6	Illustrate thickness measurement by using LVDT	CO2	K3
7	What is Breakdown Maintenance?	CO2	K2
8	What is corrective maintenance?	CO2	K2
9	What is Predictive Maintenance (PdM)?	CO2	K2
10	Write some components of a Predictive Maintenance Programme	CO2	K2

MODULE 3			
SL NO	**QUESTIONS**	**CO**	**KL**
1	Explain any four different methods for crack monitoring in a metal piece	CO3	K2
2	Explain the four basic operations involved in practice of spectrometric analysis procedure	CO3	K2

3	Explain the causes of vibrations in machines	CO3	K3
4	Illustrate the working of vibration holograph	CO3	K2
5	Explain Radiography testing of cracks in solid materials.	CO3	K1
6	Write short notes on infrared spectroscopy	CO3	K2
7	Explain the lubricant monitoring by ferrography	CO3	K2
8	What is Vibration Monitoring?	CO3	K2

MODULE 4			
SL NO	**QUESTIONS**	**CO**	**KL**
1	Define FMEA in maintenance. Explain the steps involved in FMEA	CO4	K2
2	Explain the process of Reliability Centred Maintenance	CO4	K2
3	Explain the process of Root cause Analysis	CO4	K2
4	Enumerate the causes of failure of machine elements	CO4	K3
5	Define the four principles of Reliability Centred Maintenance with an example	CO4	K2
6	Explain how can be failures classified on the nature of failure	CO4	K4

MODULE 5			
SL NO	**QUESTIONS**	**CO**	**KL**
1	Explain the pillars of 5S	CO5	K2
2	What all targets can be achieved in an industry by implementing TPM?	CO5	K2
3	Explain the concepts of business centred maintenance (BCM).	CO5	K2
4	Define overall equipment effectiveness (OEE).	CO5	K2
5	Briefly explain the use of c-chat for quality control.	CO5	K2
6	Explain terotechnology process and it features	CO5	K2
7	Enumerate the features of TPM	CO5	K2
8	Explain the zero maintenance concepts	CO5	K2

MODULE 6			
SL NO	**QUESTIONS**	**CO**	**KL**
1	What are the types of maintenance budgets? Explain the steps involved in preparation of maintenance budgets	CO6	K2
2	Discuss about the functions, applications and advantages of computer aided maintenance management system (CMMS).	CO6	K2

3	Discuss the classification of maintenance costs. Also explain how the cost of maintenance of a machine can be justified with an example	CO6	K2
4	Prepare a sample of maintenance plan and schedule of a work shop.	CO6	K3
5	Enumerate the objective of manpower planning.	CO6	K2
6	Describe the procedure of maintenance planning with flow chart.	CO6	K4
7	Explain the applications of computer in maintenance planning.	CO6	K2
8	Explain the structure of Functional Maintenance Organization	CO6	K2

APPENDIX 1

CONTENT BEYOND THE SYLLABUS

SL No	WEB SOURCE REFERENCES
1	http://www.nptel.ac.in

Maintenance

Introduction:

We can define maintenance as the set of activities developed to ensure proper running of equipment and systems, ensuring that technical intervention is taken at the right opportunities with the right scope and in accordance with good technical practices and legal requirements, in order to avoid loss of function or reduction of efficiency and, should any of these occur, ensure that they are returned to good operating conditions at the earliest possible delay, all at an optimized overall cost.

Maintenance is an important factor in quality assurance, which is another basis for the successful competitive edge. Inconsistencies in equipment lead to variability in product characteristics and result in defective parts that fail to meet the established specifications. Beyond just preventing break downs, it is necessary to keep equipment operating within specifications (i.e. process capability) that will produce high level of quality.

Good maintenance management is important for the company's cost control. As companies go in for automation to become more competitive, they increasingly rely on equipment to produce a greater percentage of their output. It becomes more important that, equipment operate reliably within specifications. The cost of idle time is higher as equipment becomes more high-tech and expensive e.g. NC/CNC machines and robots.

Maintenance Functions:

The specific functions of each sub-section of maintenance must be accurately assessed and spelt out so that the supervisory staff can achieve its own departmental objective. The basic maintenance functions involve the following steps

a) Develop maintenance policies; procedures and standards for company-wide incorporation.

b) Design practicable and implementable schedules of all maintenance work; and spell1out maintenance work specification or master process sheets. .

c) Ensure the availability of production plant and equipment to carry out planned/preventive maintenance.

d) Carry out repairs and rectify or overhaul production equipment to ensure good operational status and availability.

e) Ensure scheduled inspection and lubrication of machinery.

f) Carry out calibration as per the calibration plan.

g) Maintain and carry out repairs of buildings, utilities and allied equipment.

h) Ensure and carry out faithful recording and documentation of all maintenance work.

i) Periodic inspection of all assets to know conditions leading to stoppage of production.

j) Review all, recorded documents and specifications for procurement of new equipment, and be a member of facilities investment decision making body, to ensure; maintenance requirements are looked into and taken care of.

k) Standardize equipment for replacement and purchase.

l) Carry out frequent analysis of pertinent documents so that corrective actions can be taken.

m) Initiate procurement action necessary foe maintenance work.

n) Prepare spare parts and material requirement lists.

o) Ensure proper inventory control on the spare parts and there replacement.

p) Initiate and carry out energy conservation programs.

q) Design and enforce safety standards as required.

r) Ensure segregation of, and collection of combustible waste material, such as oil and cotton waste dipped in oil.
s) Recruit ·and train personnel to carry out maintenance work, and provide adequate replacements for skilled personnel, who may have retired or moved away; update older workmen about newer skills.
t) Plan and prepare maintenance budget.
u) Ensure budgetary expenditures are evenly distributed and kept within planned budget.
v) Develop and apply cost and budgetary controls.
w) Continuously apply cost reduction techniques.
x) Ensure cost effective maintenance.
y) Develop and provide proper management information system to the management, particular attention to be paid for the top management.
z) Upgrade management skills of supervisory and executive codes.

Objectives of maintenance

The more specific objectives of maintenance management are as follows:

a) To optimize the reliability of equipment and infrastructure;
b) To ensure that equipment and infrastructure are always in good condition;
c) To carry out prompt emergency repair of equipment and infrastructure so as to secure the best possible availability for production;
d) To enhance, through modifications, extensions, or new low-

cost items, the productivity of existing equipment or production capacity;

e) To ensure the operation of equipment for production and for the distribution of energy and fluids;

f) To improve operational safety;

g) To train personnel in specific maintenance skills;

h) To advise on the acquisition, installation and operation of machinery;

i) To contribute to finished product quality;

j) To ensure environmental protection.

k) Minimizing the loss of productive time because of equipment failure (i.e. minimizing idle time of equipment due to break down).

l) Minimizing the repair time and repair cost.

m) Minimizing the loss due to production stoppages.

n) Efficient use of maintenance personnel and equipment.

o) Prolonging the life of capital assets by minimizing the rate of wear and tear.

p) To maximize efficiency and economy in production through optimum use of facilities.

q) To minimize accidents through regular inspection and repair of safety devices.

r) To minimize the total maintenance cost which includes the cost of repair, cost of preventive maintenance and inventory carrying costs, due to spare parts inventory.

s) To improve the quality of products and to improve productivity.

Principles of maintenance planning

a) **Have a Separate Department for Planners:** Planners should be organized into a separate department from the craft maintenance crews so that they can specialize just in planning and scheduling. Planners plan the work and the crews execute the planned work.

b) **Focus on Future Work :** Planners should focus on future work and maintain at least two weeks of work backlog that is planned, approved, and ready to schedule/execute. 3-4 weeks is better.

c) **Component Level Files:** Planners maintain a secure file system based on equipment/asset numbers. Best practice is to organize assets on an individual component level and not by manufacturer or vendor. This information allows the planners to utilize equipment data and information learned on previous work to prepare and improve work plans, especially on repetitive tasks.

d) **Estimate the Job Based on Planner Expertise :** Planners are typically senior level technicians who can use their personal experience to develop work plans that will avoid anticipated work delays, quality or safety problems.

e) **Recognize the Skills of the Craft :** Planners must decide which skill set is required for which job and how much management the job requires. Furthermore they must understand and determine scope of the work request and the strategy of execution (repair or replace, for example).

f) **Measure Performance with Work Sampling :** It is important to continuously measure the effectiveness of a planning and scheduling program. Measure how much wrench time technicians are actually spending versus how much time they are doing on other activities such as obtaining parts, or waiting for instructions.

Benefits of Maintenance:

The high involvement of capital cost in any production system calls for proportional returns from the equipment. This is only possible when the equipment keeps delivering it normal performance. It is often noticed that the maintenance schedules provided by the manufacturer do not yield the required results in terms of the production output and the life of the equipment. Thus it becomes necessary to properly maintain the equipment with extra caution and care in order to achieve ·the desired levels of production or service. The following benefits can be derived from a well-organized maintenance system:

a) The minimization of downtime of equipment/systems
b) Improvement in total availability of the system

c) Extended useful life of the equipment
d) Minimization of operating costs of equipment
e) Minimization of maintenance costs in the future
f) Safety of the personnel
g) Improved confidence of the operating personnel/users.

The consequences of downtime can be very serious when the machine is working in a production line, as its failure will shut down the total system. Following a proper maintenance schedule with adequate back-up supply of required spare parts can drastically reduce the downtime and thus improve the equipment availability. The normal wear and tear of equipment can also be reduced by proper maintenance. In certain cases, the safety of the personnel is of prime importance and this also can be assured by proper planned preventive maintenance. For example, all the aircraft systems need to be inspected before and after a flight as safety of the passengers as well as that of aircraft is of prime importance.

Effects of Maintenance

Maintenance, being an important function in any production system, has far-reaching effects on the system. If the right kind of maintenance function is not selected for a particular environment, it may lead to the serious problem of either over-maintenance or under-maintenance. The selection of a particular maintenance policy is also governed by the past history of the equipment. Cost effective maintenance will help boost the productivity in a production system. It is, therefore, most important for the team, involved in maintenance work, to know how much to maintain.

The life of any equipment also depends on the nature of maintenance function. It is known from experience that optimum maintenance will prolong the life of the equipment, and on the other hand, carelessness in maintenance would lead to an early failure as well as reduced life of the equipment. Further, proper maintenance will help to achieve the production targets. If the availability of the equipment is high, the reliability of the production system will also be high.

Another important effect of the maintenance function is the working environment. If the equipment is in good working condition, the operator feels comfortable to use it, otherwise there is a tendency to let the equipment deteriorate further, and the relationship between the maintenance group and the operating group is strained. To get the desired results in a maintenance ope11tation, there should be selective development of skilled, semi-skilled and unskilled labour and proper division of responsibilities among them in order to make full use of the skilled workforce available. Evaluating maintenance is not easy, it is therefore, important to ensure that the work being done is, in fact necessary. The schedules and programs must be justified and based on the practical experience under the similar conditions.

Reliability

Introduction :

In the present scenario of global competition and liberalization, it is imperative that industries become fully conscious of the need to produce reliable products meeting international standards. Even though the "Reliability Engineering" has taken birth during World War II with a significant contribution by defense personnel, today it has taken a new shape by blending itself in all phases of the product life cycle from proposal to manufacturing.

Reliability has gained increasing importance in the last few years in manufacturing organisations, the government and civilian communities. With recent concern about government spending, agencies are trying to purchase systems with higher reliability and lower maintenance costs. As consumers, we are mainly concerned with buying products that last longer and are cheaper to maintain, i.e., have higher reliability. The reasons for wanting high product or component or system reliability are obvious:

- Higher customer satisfaction
- Increased sales
- Improved safety
- Decreased warranty costs
- Decreased maintenance costs, etc.

It is a known fact that reliability program increases the initial cost of every device, instrument or system and also it is true that the reliability decreases when the complexity of the system increases. In this type of complex situation, reliability of a product or service is best assured when it is designed by the design engineer and built in by production engineer, rather than conducting externally an experiment by a reliability engineer.

Another important difference between quality and reliability is that one can manufacture reliable systems using less reliable components by altering product configuration, whereas it is not possible to manufacture high quality systems with less quality components.

Definition of reliability

The reliability of a product (or system) can be defined as the probability that a product will perform a required function under specified conditions for a certain period of time.

More specific, reliability is the probability that a product or part will operate properly for a specified period of time (design life) under the design operating conditions (such as temperature, volt, etc.) without failure. In other words, reliability may be used as a measure of the system's success in providing its function properly. Reliability is one of the quality characteristics that consumers require from the manufacturer of products.

If we have a large number of items that we can test over time, then the Reliability of the items at time t is given by

$$R(t) = \frac{\text{number of survivors at time } t}{\text{number of items put on test at time } t=0}$$

At time t = 0, the number of survivors is equal to number of items put on test. Therefore, the reliability at t = 0 is

$$R(0) = 1 = 100\%$$

After this, the reliability, R(t), will decline as some components fail (to perform in a satisfactory manner).

Reliability = 1.00 means certain to work as intended.
Reliability = 0.99 means 99 percent likely to work as intended.
Reliability = 0.50 means 50 percent likely to work as intended.
Reliability = 0.00 means absolutely certain not to work as intended.

The Concept of the Bath-tub Curve

The so-called bath-tub curve represents the pattern of failure for many products – especially complex products such as cars and washing machines. The vertical axis in the figure is the failure rate at each point in time. Higher values here indicate higher probabilities of failure.

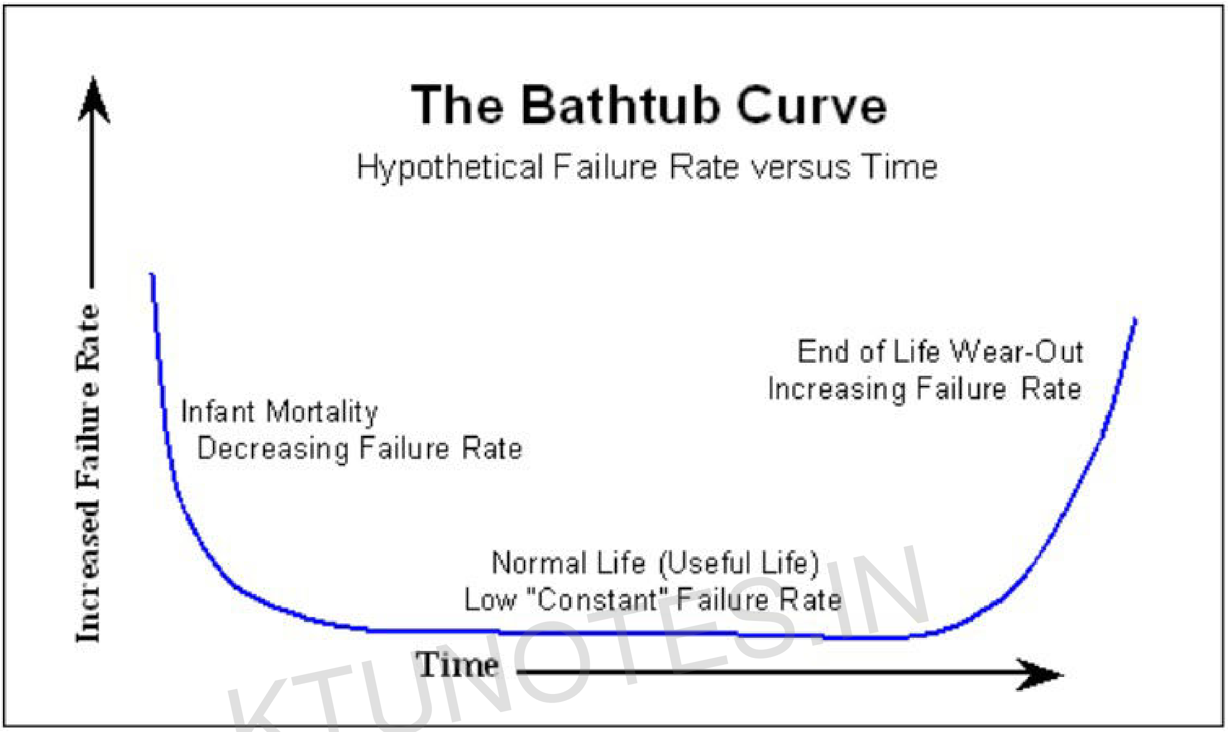


Fig. Failure Rate Curve (Bathtub curve)

The bath-tub curve shown in Fig. is divided into three regions: infant mortality, useful life and wear-out.

Infant Mortality:

This stage is also called early failure or debugging stage. The failure rate is high but decreases gradually with time. During this period, failures occur because engineering did not test products or systems or devices sufficiently, or manufacturing made some defective products. Therefore the failure rate at the beginning of infant mortality stage is high and then it decreases with time after early failures are removed by burn-in or other stress screening methods. Some of the typical early failures are:

- poor welds
- poor connections

- contamination on surface in materials
- incorrect positioning of parts, etc.

Useful life:

This is the middle stage of the bath-tub curve. This stage is characterised by a constant failure rate. This period is usually given the most consideration during design stage and is the most significant period for reliability prediction and evaluation activities. Product or component reliability with a constant failure rate can be predicted by the exponential distribution (which we come to later).

Wear-out stage:

This is the final stage where the failure rate increases as the products begin to wear out because of age or lack of maintenance. When the failure rate becomes high, repair, replacement of parts etc., should be done.

The failure rate

The failure rate (usually represented by the Greek letter λ) is a very useful quantity. This is defined as the probability of a component failing in one (small) unit of time.

Let N_F = number of failures in a small time interval, say, Δt.

N_S = number of survivors at time t.

The failure rate can then be calculated by the equation:

$$\lambda(t) = \frac{N_F}{N_s * \Delta t}$$

For example, if there are 200 surviving components after 400 seconds, and 8 components fail over the next 10 seconds, the failure rate after 400 seconds is given by

$$\lambda(400) = 8 / (200 \times 10) = 0.004 = 0.4\%$$

This simply means that 0.4% of the surviving components fail in each second.

We can define failure rates for individual components, and also for complex products like cars or washing machines. In the latter case we need to be clear about what is meant by a failure – for a car, for example, these can range from complete breakdown to relatively minor problems. And we should also remember that failures in complex products are generally repairable, whereas this may not be true for individual components.

System Reliability:

Reliability is now a well recognized and rapidly developing branch of engineering. Manufacturing of a perfect component is almost impossible because of inherent variations and the cost for parts improvement is very high and the approach becomes unwieldy with large and complex systems. Since reliability study is considered essential for proper utilization and maintenance of engineering systems and equipment,it has gained much importance among the practicing engineers and manufacturers.

The system designer is encountered with several problems while planning and designing the system for a reasonable level of reliability. Therefore a thorough reliability analysis needs to be attended at the design stage itself. The various means of increasing the system reliability and the constraints associated with them must be known. Reliability of a system can be improved by any one or combination of the following two methods namely

- Improving the components
- By using redundancy technique

A number of techniques are available to enhance the system reliability. Some of the important techniques are shown in Table below.

SLNO	TECHINIQUE	REMARKS
1.	Parts improvement method	Leads to higher cost
2.	Effective and creative design	Failures cannot be completely eliminated
3.	System simplification	Leads to poor quality
4.	Use of over rated components	Leads to higher cost
5.	Structural redundancy	Effective method for higher reliability
6.	Maintenance and repair	Best for high reliability

Combination of structured redundancy and maintenance and repair yield maximum reliability nearing to 1.

In general it is not possible to produce components with high reliability due to number of constraints, such as cost, non-availability of production facilities etc., In such cases redundancy comes handy to the reliability engineer. In simple words, redundancy is the existence of more than one means for carrying out a given function.

The following are the methods for introducing redundancy in to a system for improving reliability.

- Element redundancy
- Unit redundancy

Types of System Reliability Models:

The objective of system engineer is to estimate various reliability parameters of the system. The system may vary from simple to complex. The system can be analyzed by decomposing it into smaller sub systems and estimating reliability of each subsystem to assess the total system reliability. The procedure to determine the system reliability is as follows.

1. Identify the sub systems and elements of the given system.
2. Identify corresponding individual reliabilities of the sub systems and elements.
3. Draw a block diagram to represent the logical manner in

which these units are connected.

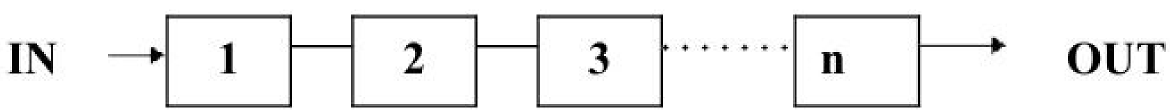
4. Determine the constraints for the successful operation of the system.
5. Apply rules of probability theory to determine the system reliability.

To determine an appropriate reliability or reliability model for each component of the system by applying the rules of the probability according to the configuration of the components with in the system is also known as system reliability. Several methods exist to improve the system reliability like using large safety factors, reducing the complexity of the system, increasing the reliability of the components etc. There are several types of configurations available, such as

1. Series configuration
2. Parallel configuration

Series Configuration:

In series configuration all components must be connected in series in order to make the system to perform continuously. In this system all components are considered critical in that sense that their function must be performed in order to make the system to operate successfully. Under this concept if any one component connected serially fails, the System will fail. The reliability block diagram as shown in Figure represents the series configuration.



The characteristics of series configuration are

- The components are interconnected in such a way that the entire System will work satisfactorily if all the components work without fail.
- The entire system will fail even if one of its components fails. System reliability can be determined by

using component reliabilities.

Example :

A system is composed of 3 independent serially connected components (refer above figure)

$R_1 = 0.95$
$R_2 = 0.87$
$R_3 = 0.82$

Note:

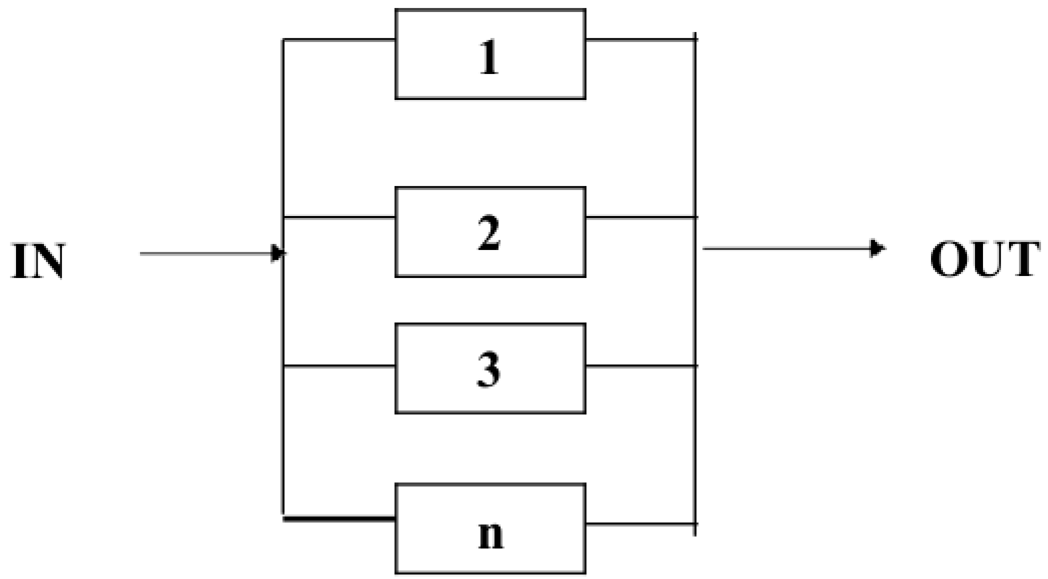
all R_s must be given for a common duration, e.g., 10 hours of operation.

Rsystem = 0.95*0.87*0.82 = 0.6777

Serial system reliability is smaller than any individual reliability of the components.

Parallel Configuration:

A system can have several components to perform the same operation and the satisfactory performance of any one of these components is sufficient to ensure the successful operation of the system. The elements for such a system are also said to be connected in parallel configuration as shown in Figure.



The characteristics of a system with parallel configuration are

- The system will function satisfactorily even any one of the parallel units operates satisfactorily.
- The entire system will fail only when all the units in the system fails.

Example

The system is composed of 2 identical servers connected in parallel connected in parallel

$R_1 = 0.6777$

$R_2 = 0.6777$

$$R_{system} = 1 - ((1 - 0.6777)*(1 - 0.6777)) = 0.8961$$

Parallel system reliability is greater than any individual reliability of the components

Maintainability

When a system fails to perform satisfactorily, repair is normally carried out to locate and correct the fault. The system is restored to operational effectiveness bymaking an adjustment or by replacing a component.

Maintainability is defined as the probability that a failed system will be restored to specified conditions within a given period of time when maintenance is performed according to prescribed procedures and resources. In other words, maintainability is the probability of isolating and repairing a fault in a system within a given time. Maintainability engineers must work with system designers to ensure that the system product can be maintained by the customer efficiently and cost effectively. This function requires the analysis of part removal, replacement, tear-down, and build-up of the product in order to determine the required time to carry out the operation, the necessary skill, the type of support equipment and the documentation.

Mean time to Failure (MTTF) and Mean time between Failures (MTBF)

MTTF applies to non-repairable items or devices and is defined as "the average time an item may be expected to function before failure". This can be estimated from a suitable sample of items which have been tested to the point of failure: the MTTF is simply the average of all the times to failure.

For example, if four items have lasted 3,000 hours, 4000, hours, 4000 hours and 5,000 hours, the MTTF is 16,000/4 or 4,000 hours.

The MTBF applies to repairable items. The definition of this refers to “between” failures for obvious reasons. It should be obvious that

MTBF = Total device hours / number of failures

For example, consider an item which has failed, say, 4 times over a period of 16,000 hours. Then MTBF is 16,000/4 = 4,000 hours. (This is, of course, just the same method as for MTTF.)

Availability

Reliability is a measure that requires system success for an entire mission time. No failures or repairs are allowed. Space missions and aircraft flights are examples of systems where failures or repairs are not allowed. Availability is a measure that allows for a system to repair when failure occurs.

The availability of a system is defined as the probability that the system is successful at time t. Mathematically,

$$\text{Availability} = \frac{System\,up\,time}{system\,up\,time + system\,down\,time}$$

$$= \frac{MTTF}{MTTF + MTTR}$$

Availability is a measure of success used primarily for repairable systems. For non-repairable systems, availability, A(t) , equals reliability, R(t). In repairable systems, A(t) will be equal to or greater than R(t).

Three frequently used availability terms are explained below.

Inherent availability, as seen by maintenance personnel (excludes preventive maintenance outages, supply delays, and administrative delays) is defined as:

$$A_i = MTBF/(MTBF + MTTR)$$

Achieved availability, as seen by the maintenance department , (includes both corrective and preventive maintenance but does not include supply delays an administrative delays) is defined as:

$A_a = MTBM/(MTBM+MAMT)$
Where MTBM is mean time between corrective and preventive maintenance actions and MAMT is the mean active maintenance time.

Operational availability, as seen by the user , is defined as:

$A_o = MTBM/(MTBM + MDT)$
Where MDT is mean down time.

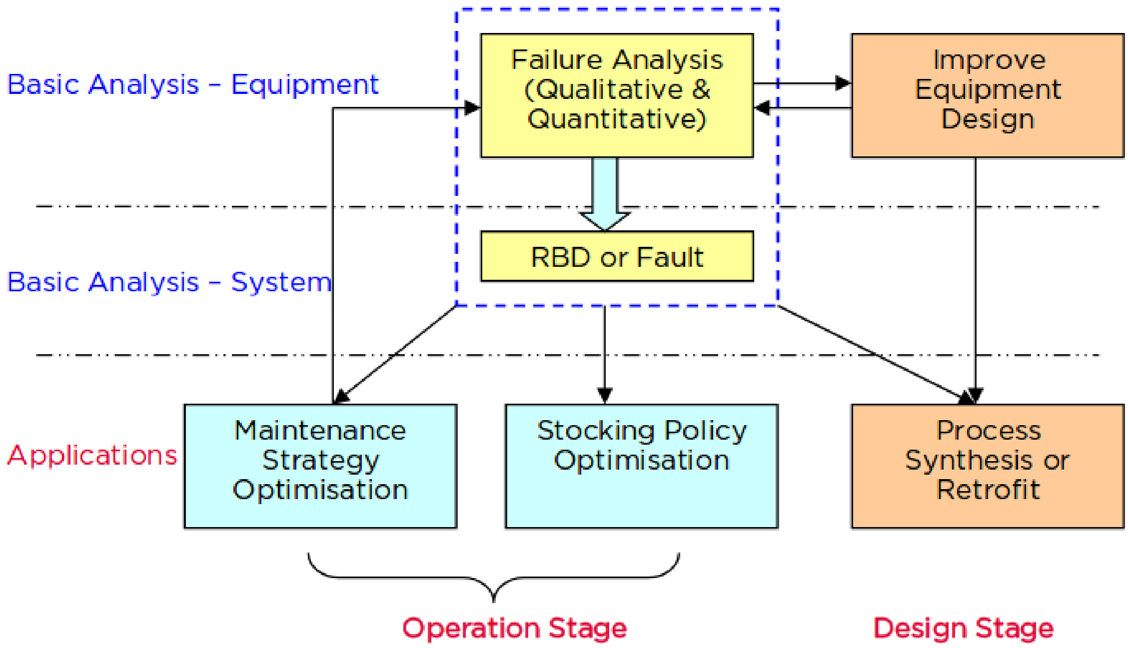
Reliability, Availability, and Maintainability (RAM)

Reliability, availability, and maintainability (RAM) are three system attributes that are of tremendous interest to systems engineers, logisticians, and users. Collectively, they affect economic life-cycle costs of a system and its utility.

RAM has a direct impact on profit through lost production and maintenance costs. The main objectives of RAM analysis are to increase system productivity, increase the overall profit, as well as reduce the total life cycle cost — which includes lost production cost, maintenance cost, operating cost, etc.

Role of RAM Analysis

Figure illustrates the interactions and applications of RAM analysis. For an existing process, maintenance data are usually recorded in the CMMS (Computerised Maintenance Management System).



Failure mode and distribution parameters can be obtained for each unit in the system. Reliability Block Diagrams (RBD)or Fault Trees(FT) can beused to represent the logic relationships betweencomponent failures and system failures, and provide the basis for a RAM study. Withthe failure distribution data input into an RBD/FT, engineers will be able to understand the RAM performances of the current system and carry on further developments and optimisations.In fact,there is a direct relationship between RBD and FT, but most engineers find RBD easier to use, as it can be more easily related to a process flowsheet. The approach to RAM analysis adopted by Process Integration Limited exploits RBDs.

In the operation stage, RAM analysis can be implemented to optimise maintenance strategy as well as stocking policy for spare parts. The maintenance strategy will then affect the failure records in the CMMS,which in turn help engineers revise the maintenancestrategy throughtime. New failure records will be saved in the CMMS during theoperating stage.

In the design stage, RAM analysis can be integrated into the design of the system configuration, which will ensure the optimum design with balanced RAM performance and total investment.Moreover, the qualitative and quantitative analysis of process unit failures can help designers to modify the structure of a specific process unit to improve the process design.

RAM analysis run throughout both operating and design phases to enable the process to achieve high profitability.

Benefits of RAM Analysis

The following benefits can be obtained from RAM analysis.

- Decision making
  - What maintenance policy should be applied
  - Investment decisions on maintenance
- Resource utilisation
  - Inspection intervals
  - Optimum spare part purchasing
- Appropriate maintenance scheduling
  - Understanding the financial implications of maintenance
  - Decision making based on modelling
- Cost management
  - Managing the cost related to unavailability
  - Cost of maintenance
- Integration with other business activities
  - All projects on a site have an effect on process RAM
  - RAM needs to involve the whole organization
- Meeting the business demand
  - Reduce outages caused by breakdowns
  - Reduce the loss of revenues caused by unavailability

Maintenance Strategies

Outlined below are the more widely used maintenance strategies. Typically we see plants employing either run-to-failure (only fix after a breakdown) or preventive maintenance (on a predetermined schedule). However, depending on the value of the asset or its criticality in the plant's operations, we may see this strategy escalated to predictive or even RCM-based maintenance.

Breakdown maintenance (Run-to-failure)

Run-to-failure maintenance is an acceptable strategy for equipment that is of minimal importance to operations (rarely used or duplicates the function of some other equipment) or has low cost. In this strategy, assets are deliberately allowed to operate until they break down, at which point reactive maintenance is performed. No maintenance, including preventive maintenance, is performed on the asset up until the failure event. However, a plan is in place for ahead of the failure, so that the asset can be fixed without causing any production issues.

Under the run to fail method, it is important to have spare parts and staff on hand to replace the failed part and to maintain equipment availability. This strategy should not be confused with reactive maintenance, because of the active plan to allow the asset to run to failure. This strategy is useful for assets that, on breakdown, pose no safety risks and have minimal effect on production.

A common example of run to failure maintenance is the maintenance plan for a general-purpose light bulb. The bulb is allowed to run until it fails. At this time, the plan to fix the asset is carried out. A new light bulb is obtained from stocks and replaced at a convenient time.

Advantages

- Minimal planning – Since maintenance does not need to be scheduled in advance, the planning requirements are very low. Maintenance only needs to happen after breakdown has occurred.

- Easy to understand – Because of the plan's simplicity, this system is easy to understand and implement.

Disadvantages

- Unpredictable – Because most asset failures are unpredictable, it is difficult to anticipate when manpower and parts will be needed for repairs.

- Inconsistent – The intermittent nature of failures means efficient planning of staff and resources can be difficult.

- Costly – All costs associated with this strategy need to be considered when it is implemented. These costs include production costs and breakdown costs, in addition to direct parts and labour costs associated with performing the maintenance.

- Inventory costs – The maintenance team needs to hold spare parts in inventory, to accommodate for intermittent failures.

Corrective Maintenance

Corrective maintenance is a maintenance task performed to identify, isolate, and rectify a fault so that the failed equipment, machine, or system can be restored to an operational condition within the tolerances or limits established for in-service operations. It is any maintenance performed to return equipment to proper working order. Depending on the context of its use it may refer to maintenance due to a breakdown, or maintenance identified through a condition monitoring program.

Corrective maintenance performed due to a breakdown could be either planned or unplanned. In this case, planned corrective maintenance is likely to be the result of a run-to-failure maintenance plan, while unplanned corrective maintenance could be due to a breakdown not stopped by preventative maintenance, or a breakdown due to a lack of a maintenance plan. Unplanned, maintenance is much more costly than planned maintenance.

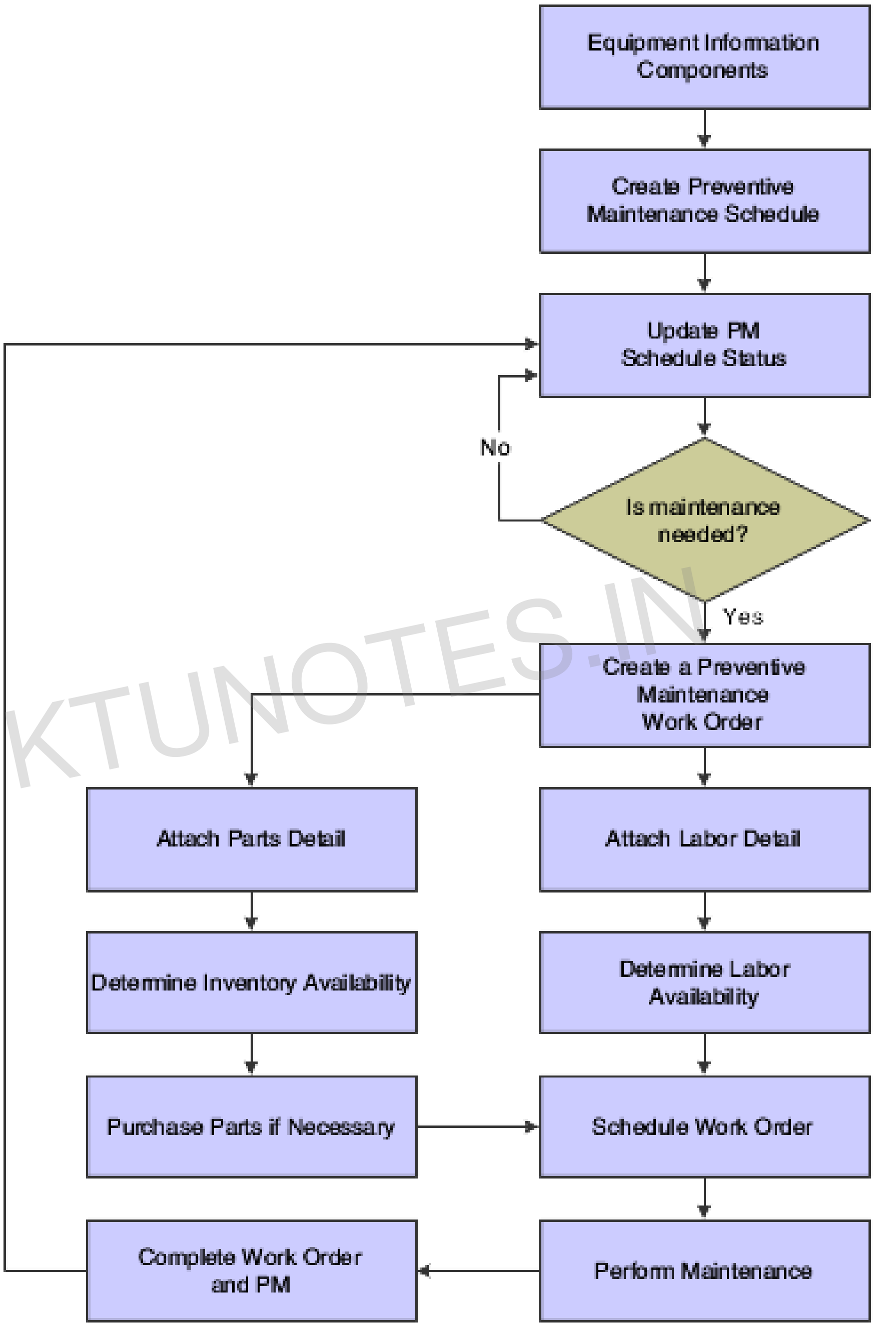
Maintenance performed due to condition monitoring program is planned maintenance. It will be scheduled due to a condition trigger. Provided the root cause of the need for maintenance is also addressed, this is an ideal maintenance type

Preventive (scheduled) maintenance (PM)

This strategy is employed by most companies and almost *all* small to mid-sized companies make exclusive use of it. Preventive maintenance consists of assets being taken offline, inspected at periodic, predetermined intervals and repaired if necessary. Although it’s a relatively easy strategy to set up and execute, it can prove quite costly in the long run as a majority of the time these inspections are a straightforward pass.

Preventive maintenance is planned so that any required resources are available. The maintenance is scheduled based on a time or usage trigger. A typical example of an asset with a time-based preventive maintenance schedule is an air-conditioner which is serviced every year, before summer. A typical example of an asset with a usage-based preventive maintenance schedule is a motor-vehicle which might be scheduled for service every 10,000km.

Preventive maintenance is more complex to coordinate than run-to-failure maintenance because the maintenance schedule must be planned. Preventive maintenance is less complex to coordinate than predictive maintenance because monitoring strategies do not have to be planned nor the results interpreted.



Advantages of preventive maintenance

Advantages compared with less complex strategies

Planning is the biggest advantage of preventive maintenance over less complex strategies. Unplanned, reactive maintenance has many overhead costs that can be avoided during the planning process. The cost of unplanned maintenance includes lost production, higher costs for parts and shipping, as well as time lost responding to emergencies and diagnosing faults while equipment is not working. Unplanned maintenance typically costs three to nine times more than planned maintenance. When maintenance is planned, each of these costs can be reduced. Equipment can be shut down to coincide with production downtime. Prior to the shutdown, any required parts, supplies and personnel can be gathered to minimize the time taken for a repair. These measures decrease the total cost of the maintenance. Safety is also improved because equipment breaks down less often than in less complex strategies.

Advantages compared with more complex strategies

Preventive maintenance does not require condition-based monitoring. This eliminates the need (and cost) to conduct and interpret condition monitoring data and act on the results of that interpretation. It also eliminates the need to own and use condition monitoring equipment.

Disadvantages of preventive maintenance

Disadvantages compared with less complex strategies

Unlike reactive maintenance, preventive maintenance requires maintenance planning. This requires an investment in time and resources that is not required with less complex maintenance strategies.

Maintenance may occur too often with a preventive maintenance strategy. Unless, and until the maintenance frequencies are optimized for minimum maintenance, too much or too little preventive maintenance will occur.

Disadvantages compared with more complex strategies

The frequency of preventative maintenance is most likely to be too high. This frequency can be lowered, without sacrificing reliability when condition monitoring and analysis is used. The decrease in maintenance frequency is offset by the additional costs associated with conducting the condition monitoring.

Failure Developing Period (FDP)

The FDP is the time period from when it is possible to detect a failure until we have a breakdown.A failure is when a system or equipment is operating correctly within given parameters, but has signs of problems.

For example a centrifugal pump may be cavitating, but is still providing the required flow for the operation;

we have a failure, but not a break down. The cavitations in our example will eventually develop into a breakdown. The breakdown occurs when the pump is unable to perform its intended function.

The FDP is the time difference between the failure and the break down. If the pump started to cavitate at 6 am and it broke down 6 pm 6 days later, the FDP is 156 hours.

Inspection Frequency

The theoretical answer to the question is very simple. The inspection frequency should roughly be FDP/2. For example, if the estimated failure developing period is 14 days and we need some time to plan and schedule the corrective maintenance for that failure to avoid a break down. I think a reasonable inspection frequency is 7 days (FDP/2) in this case. If the inspection frequency is longer than 14 days, we may miss both the failure and we will have a breakdown. So, our rule of thumb is Inspection frequency = FDP/2.

The real problem is that we don’t know what the FDP is. There is no standard, no documentation and most plants do not have any history on FDP.

Predictive maintenance (PdM)

The aim of predictive maintenance (PdM) is first to predict when equipment failure might occur, and secondly, to prevent the occurrence of the failure by performing maintenance. Monitoring for future failure allows maintenance to be planned before the failure occurs. Ideally, predictive maintenance allows the maintenance frequency to be as low as possible to prevent unplanned reactive maintenance, without incurring costs associated with doing too much preventive maintenance.

Predicting failure can be done with one of many techniques. The chosen technique must be effective at predicting failure and also provide sufficient warning time for upcoming maintenance. Some techniques include vibration analysis, oil analysis, thermal imaging, and equipment observation. These are described in detail in condition-based maintenance page. Choosing the correct technique for performing condition monitoring is an important consideration that is best done in consultation with equipment manufacturers and condition monitoring experts.

When predictive maintenance is working effectively as a maintenance strategy, maintenance is only performed on machines when it is required. That is, just before failure is likely to occur. This brings several cost savings:

- Minimizing the time the equipment is being maintained
- Minimizing the production hours lost to maintenance,

and

- Minimizing the cost of spare parts and supplies.

These cost savings come at a price, however. Some condition monitoring techniques are expensive and require specialist and experienced personnel for data analysis to be effective.

Advantages of predictive maintenance

Compared with preventive maintenance, predictive maintenance: ensures that a piece of equipment requiring maintenance is only shut down right before imminent failure. This reduces the total time and cost spent maintaining equipment.

Disadvantages of predictive maintenance

Compared with preventive maintenance, the cost of the condition monitoring equipment needed for predictive maintenance is often high. The skill level and experience required to accurately interpret condition monitoring data is also high. Combined, these can mean that condition monitoring has a high upfront cost. Some companies engage condition monitoring contractors to minimize the upfront costs of a condition monitoring program.

Not all assets have failures that may be more cost-effectively maintained using preventative maintenance or a run-to-failure maintenance strategy. Judgment should be exercised when deciding if predictive maintenance is best for a particular asset. Techniques such as reliability-centered maintenance provide a systematic method for determining if predictive maintenance is a good choice as an asset maintenance strategy for the particular asset of interest.

Condition-based maintenance (CBM)

Condition-based maintenance (CBM) is a maintenance strategy that monitors the actual condition of the asset to decide what maintenance needs to be done. CBM dictates that maintenance should only be performed when certain indicators show signs of decreasing performance or upcoming failure. Checking a machine for these indicators may include non-invasive measurements, visual inspection, performance data and scheduled tests. Condition data can then be gathered at certain intervals, or continuously (as is done when a machine has internal sensors). Condition-based maintenance can be applied to mission critical and non-mission critical assets.

Unlike in planned scheduled maintenance (PM), where maintenance is performed based upon predefined scheduled intervals, condition based maintenance is performed only after a decrease in the condition of the equipment has been observed. Compared with preventive maintenance, this increases the time between maintenance repairs, because maintenance is done on an as-needed basis.

The goal

The goal of condition based maintenance is to spot upcoming equipment failure so maintenance can be proactively scheduled when it is needed – and not before. Asset conditions need to trigger maintenance within a long enough time period before failure, so work can be finished before the asset fails or performance falls below the optimal level.

Advantages

- CBM is performed while the asset is working, this lowers disruptions to normal operations
- Reduces the cost of asset failures
- Improves equipment reliability
- Minimizes unscheduled downtime due to catastrophic failure
- Minimizes time spent on maintenance
- Minimizes overtime costs by scheduling the activities
- Minimizes requirement for emergency spare parts
- Optimized maintenance intervals (more optimal than manufacturer recommendations)

- Improves worker safety
- Reduces the chances of collateral damage to the system

Disadvantages

- Condition monitoring test equipment is expensive to install, and databases cost money to analyze
- Cost to train staff – you need a knowledgeable professional to analyze the data and perform the work
- Fatigue or uniform wear failures are not easily detected with CBM measurements
- Condition sensors may not survive in the operating environment
- May require asset modifications to retrofit the system with sensors
- Unpredictable maintenance periods

Example of condition based maintenance

Motor vehicles come with a manufacturer-recommended interval for oil replacements. These intervals are based on manufacturers' analysis, years of performance data and experience. However, this interval is based on an average or best guess rather than the actual condition of the oil in any specific vehicle. The idea behind condition based maintenance is to replace the oil only when a replacement is needed, and not on a predetermined schedule.

In the example of industrial equipment, oil analysis can perform an additional function too. By looking at the type, size and shape of the metal particulates that are suspended in the oil, the health of the equipment it is lubricating can also be determined.

CBM = Cost Savings + Higher system reliability

Condition based maintenance allows preventive and corrective actions to be scheduled at the optimal time, thus reducing the total cost of ownership. Today, improvements in technology are making it easier to gather, store and analyze data for CBM. In particular, CBM is highly effective where safety and reliability is the paramount concern such as the aircraft industry, semiconductor manufacturing, nuclear, oil and gas, et cetera.

Types of condition based maintenance

- **Vibration analysis** – rotating equipment such as compressors, pumps, motors all exhibit a certain degree of vibration. As they degrade, or fall out of alignment, the amount of vibration increases.

Vibration sensors can be used to detect when this becomes excessive.

- **Infrared** – IR cameras can be used to detect high temperature conditions in energized equipment

- **Ultrasonic** – detection of deep subsurface defects such as boat hull corrosion

- **Acoustic** – used to detect gas, liquid or vacuum leaks

- **Oil analysis** – measure the number and size of particles in a sample to determine asset wear

- **Electrical** – motor current readings using clamp on ammeters

- **Operational performance** – sensors throughout a system to measure pressure, temperature, flow etc.

Data collection

Data can be collected from the system by two different methods:

- Spot readings can be performed at regular intervals using portable instruments

- Sensors can be retrofitted to equipment or installed during manufacture for continuous data collection

Critical systems that require considerable upfront capital investment, or that could affect the quality of the product that is produced, need up to the minute data collection. More expensive systems have built in intelligence to self-monitor in real time. For example, sensors throughout an aircraft monitor numerous systems while inflight and on the ground to help identify issues before they become life threatening. Typically, CBM is not used for non-critical systems and spot readings suffice.

Challenges of condition based maintenance

- Condition based maintenance requires an investment in measuring equipment and staff up-skilling so the initial costs of implementation can be high.

- CBM introduces new techniques to do maintenance, which can be difficult to implement due to resistance within an organization.

- Older equipment can be difficult to retrofit with sensors and monitoring equipment, or can be difficult to access during production to spot measure.

- With CBM in place, it still requires competence to turn performance information from a system into actionable proactive maintenance items.

Thermography

Thermography was first utilized in the inspection of electrical equipment to locate high resistance connections or faulty components. It has also been used in finding areas of reduced insulation in buildings and refractory materials, and even leaks in building roofs. Thermography is now being used for the inspection of rotating machinery. It has been found effective in identifying faults in bearings, couplings, and shorts in motor cores.

Infrared thermography is an effective means to identify excessive heat loss in systems or materials. Every object radiates electromagnetic energy invisible to the human eye but visible to specialized equipment. Thermal imaging radiometers can detect and measure infrared radiation, and produce a map of colours or varying shades of gray that show the surface temperatures of the object. The lighter colours or shades represent the warmest temperatures, and the darker colours or shades the coolest. By analyzing the temperature signatures of the equipment, problem areas are quickly identified and recorded along with all of the related temperature information.

Advantages

- A non-contact, non-destructive means of testing.

- Reduce downtime.

- Virtually eliminates unnecessary work.

- Reduce unnecessary material expenses.

- Avoid catastrophic failures.

- Direct maintenance to the root of the problem.

Thermography can also be used for alignment of shafts. Figure below illustrates this.

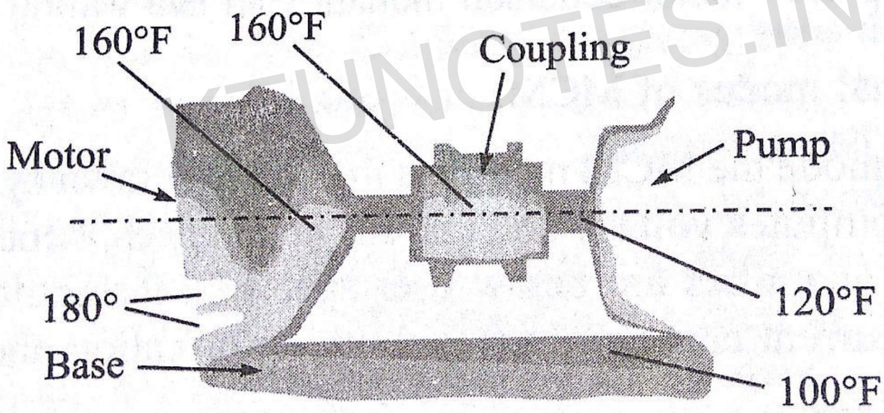
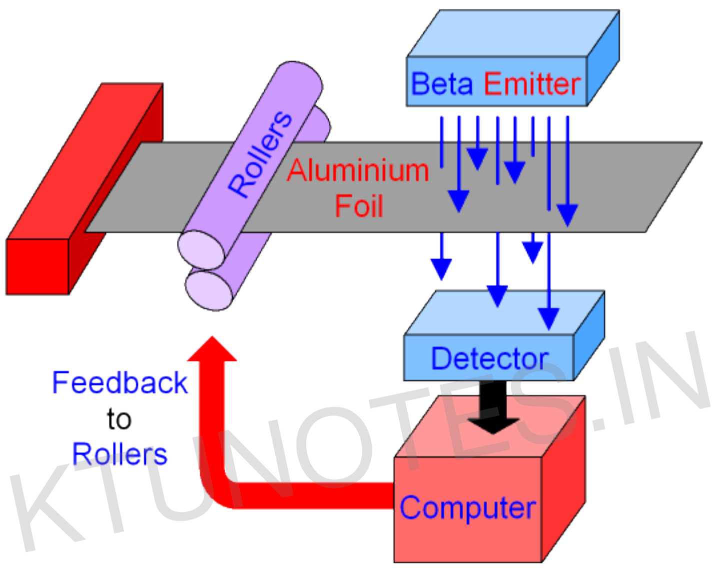


Figure 3.6 Thermography of shaft coupling.

Thickness Monitoring

Thin-film thickness monitors are a family of instruments used to measure the thickness of a thin film, not only after it has been made, but while it is still being deposited, and some can control either the final thickness of the film, the rate at which it is deposited, or both. Not surprisingly, the devices which control some aspect of the process tend to be called controllers, and those that simply monitor the process tend to be called monitors.

The manufacture of Aluminium foil (for cooking) is a good example. A radioactive source is placed above the foil and a detector below it.



Some of the radiation is absorbed by the foil and some radiation passes through to the detector. The thicker the foil, the less radiation passes through to the detector. The amount of radiation arriving at the detector is monitored by the computer. The computer sends a signal (called feedback) to control the gap between the rollers. The gap between the rollers controls the thickness of the foil.

Acoustic Monitoring

This is similar to ultrasonic testing, but basically used for detection of crack growth through piezoelectric crystal placed on the member to be inspected. The electrical current from the transducer is proportional to the energy disseminated by the crack development. Unlike radiography or hydraulic tests, where in overall inspection and testing of the body or member can be done, here it is local to anticipated presence of defect only.

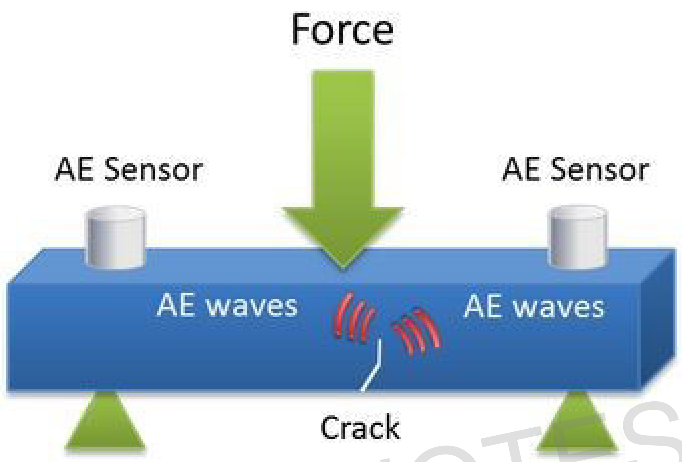


Figure 1. Acoustic emission due to crack growth in a solid material under stress.

Acoustic emission is an amazing, promising and challenging subject of the modern technology and science. It is a well-known from everyday life phenomenon: sound of breaking glass, falling tree, cracking ice are some examples of fracture sound we may hear from different objects subjected to stress. Scientifically defined, acoustic emission is a phenomenon of sound and ultrasound wave generation by materials that undergo deformation and fracture processes (Figure 1). Sources generating AE in different materials are unique. For examples, in metals, primary macroscopic sources are crack jumps, processes related to plastic deformation development and fracturing and de-bonding of inclusions. Quantitative and qualitative characteristics of acoustic emission waves, generated by sources of different nature depend directly on material properties and environmental factors.

Leaks, friction, knocks, chemical reactions, changes of size of magnetic domains are other examples of sources generating acoustic emission waves. These sources belong to another, secondary class of acoustic emission that is usually distinguished from the primary class of sources related to deformation and fracture development. Understanding the nature of emitted sound, characteristics of sounds and what they represent, can be used for development of useful technological solutions in non-destructive testing, material studies, control of production, medical examinations, analysis of chemical reactions and many other fascinating applications.

Module III

VIBRATION MONITORING

Vibration is the back and forth or repetitive motion of an object from its point of rest. When a force is applied to the mass, it stretches the spring and moves the weight to the lower limit. When the force is removed, the stored energy in the spring causes the weight to move upward through the position of rest to its upper limit. Here, the mass stops and reverses direction traveling back through the position of rest to the lower limit. In a friction-free system the mass would continue this motion indefinitely. All real systems are damped, that is they will gradually come to their rest position after several cycles of motion, unless acted upon by an external force. The characteristics of this vibratory motion are period, frequency, displacement, velocity, acceleration, amplitude and phase. Continued vibration of this spring mass system would only repeat the characteristics shown in this single cycle.

All rotating machines produce vibrations that are a function of the machine dynamics, such as the alignment and balance of the rotating parts. Measuring the amplitude of vibration at certain frequencies can provide valuable information about the accuracy of shaft alignment and balance, the condition of bearings or gears, and the effect on the machine due to resonance from the housings, piping and other structures. Vibration measurement is an effective, non-intrusive method to monitor machine condition during start-ups, shutdowns and normal operation. Vibration analysis is used primarily on rotating equipment such as steam and gas turbines, pumps, motors, compressors, paper machines, rolling mills, machine tools and gearboxes. Vibration analysis is used to determine the operating and mechanical condition of equipment. A major advantage is that vibration analysis can identify developing problems before they become too serious and cause unscheduled downtime. This can be achieved by conducting regular monitoring of machine vibrations either on continuous basis or at scheduled intervals. Regular vibration monitoring can detect deteriorating or defective bearings, mechanical looseness and worn or broken gears. Vibration analysis can also detect misalignment and unbalance before these conditions result in bearing or shaft deterioration. Trending vibration levels can identify poor maintenance practices, such as improper bearing installation and replacement, inaccurate shaft alignment or imprecise rotor balancing.

Some of the common problems that can be avoided by vibration monitoring are as follows,

- Severe machine damage.
- High power consumption
- Machine unavilability
- Unnecessary maintenance
- Quality problem

VIBRATIONS FUNDAMENTALS

Modern vibration monitoring has its genesis in the mid-1950s with the development and application of basic vibration sensors, which are the heart of modern computerized condition monitoring systems. Trending a machine's vibration levels over an extended period of time can potentially provide early warning of impending excessive vibration levels and/or other problems and thus provide plant operators with valuable information for critical decision making to schedule a timely shutdown of a problem machine for corrective action, e.g., rebalancing the rotor.

Machine vibration is very complex. Sometimes overall level of the vibration is only indication of operating condition of a machine. Since the amolitude is not occuring at just one frequency, it is very difficult to locate any specific fault in this. Therefore it is esssential to determine the individual amplitudes and frequencies for the identification of fault. A plot of amplitudes and frequencies of all the vibrating components of the machine is known as vibration signature and these signatures are the caharacteristics of a machine. Any change in such signature indicates impending failure and its location.

VIBRATION ANALYSIS

Vibration analysis consists in listening inside the machine. Each component vibrates differently and generates a characteristic noise that leaves a typical fingerprint in the spectrum in the form of a linear pattern. If damage is present, the pattern stands out from the noise floor. This allows the specialist to recognize, for example, whether the problem comes from unbalance, misalignment or bearing damage. In addition to an accurate diagnosis it is generally also possible to determine whether urgent action is necessary or whether it can wait until the next scheduled servicing.

Vibration analysis - The benefits

The bottom line is that vibration analysis benefits both the operator and the maintenance technician:

- Enables the identification of machine faults
- Provides information on root causes
- Localizes the affected components

- Optimizes spare parts logistics
- Allows early planning of maintenance measures.

Methods and signal forms in vibration analysis

- **Order analysis**: Variant of FFT analysis used for machines with variable RPM; instead of the frequency, the multiple of the rotational speed (order) is analyzed in the spectrum;
- **FFT analysis**: often used for detecting the most common machine faults, such as misalignment or unbalance.
- **Envelope analysis**: used for diagnosis of damaged gear toothing and roller bearings.
- **Cepstrum**: facilitates the diagnosis of gear and bearing damage.
- **Time waveform**: suitable for analysis of the measured signal and for detecting beats and transients (random pulses).
- **Orbit**: used for analysis of shaft vibrations – especially in shafts with sleeve bearings.
- **Phase measurement**: used together with the FFT analysis to differentiate machine faults, such as unbalance, misalignment or loose parts.
- **Resonance analyses**: for identification of natural frequencies and natural vibrations in a machine or structure. Methods include impact tests, recording of the run-up and coast-down curve and measurement of the shaft bending lines.

VIBRATION TRANSDUCERS

Device that accepts an input energy in one form and produces an output energy in some other form with a known relatioship between the input and output, is known as Transducer. The output of a transducer may be either in the same form as input or in some other form.

Vibration Transducers takes vibration of a machine or equipment as input energy and convert it into electrical signal output in various forms. Some of the vibration Transducers are described briefly as follows:

Accelerometer

An accelerometer is composed of an internal mass compressed in contact with a relatively stiff force-measuring load cell (usually a piezoelectlic crystal) by a relatively soft preload spring. For an accelerometer, the system damping is a negligible effect and thus for explanation purposes the damping is assumed here to be zero.

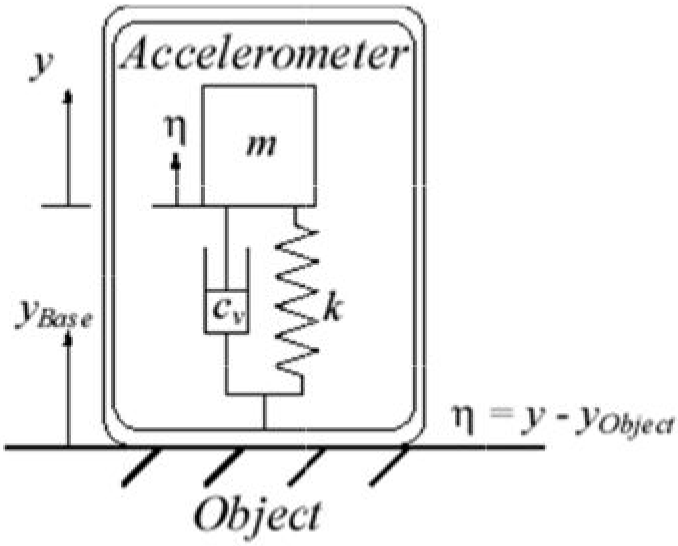
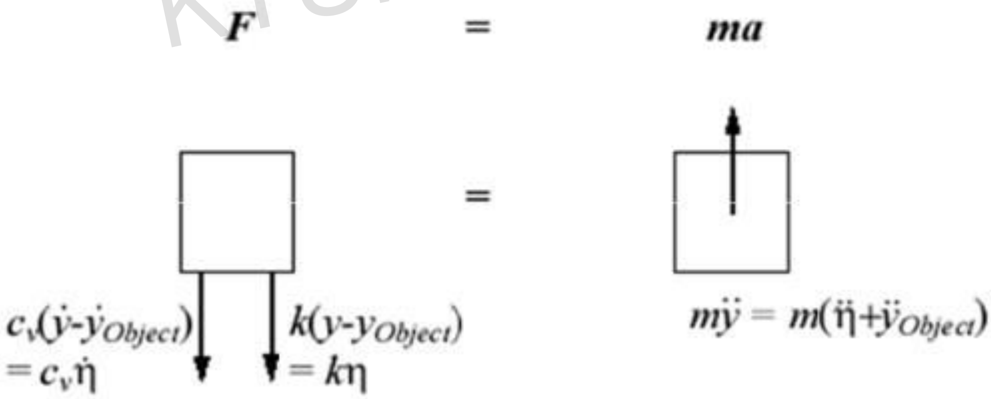


Fig 1. Uni axial accelerometer

Fig 2. Free Body Diagram for force balance



The equation of motion then becomes,

$$m\ddot{\eta} + c_v \dot{\eta} + k\eta = -m\ddot{y}_{object}$$

The accelerometer load cell is usually a piezoelectric crystal and thus registers only compressive loads, necessitating a preload spring to keep it in compression. However, the piezoelectric crystal is inherently quite stiff in comparison to the preload spring. Therefore, the load cell essentially registers "all" the dynamic force required to accelerate the internal mass.

Velocity Transducers

The velocity pickup is a very popular transducer or sensor for monitoring the vibration of rotating machinery. This type of vibration transducer installs easily on machines, and generally costs less than other sensors. For these two reasons, this type of transducer is ideal for general purpose machine applications. Velocity pickups have been used as vibration transducers on rotating machines for a very long time, and they am still utilized for a variety of applications today. Velocity pickups are available in many different physical configurations and output sensitivities. When a coil of was 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 vthration is produced. The velocity pickup is a self-generating sensor requiring no external devices to produce a vibration signal as shown in Fig. 3. This type of sensor is made up of three components: a permanent magnet, a coil of wire, and spring supports for the coil of wire. The pickup is filled with an oil to dampen the spring action.

Due to gravity forces, velocity transducers are manufactured differently for horizontal or vertical axis mounting. With this in mind, the velocity censor will have a sensitive axis that must be considered when applying these sensors to rotating machinery. Velocity sensors are also susceptible to cross axis vibration, which if great enough may damage a velocity sensor. The higher output sensitivity is useful in situations where induced electrical noise is a problem. The larger signal for a given vibration level will be less influenced by the noise level. Velocity pickups will have differing frequency responses depending on the manufacturer. However, most pickups have a frequency response range in the order of 10 to 1000 Hz. This is an important consideration when selecting a velocity pickup for a rotating machine application. The pickup's frequency response must be within the expected vibration frequencies of the machine. A velocity transducer has internal moving parts, its use is less popular in hostile environments whom relatively higher ruggedness is demanded, as mom inherent with an accelerometer.

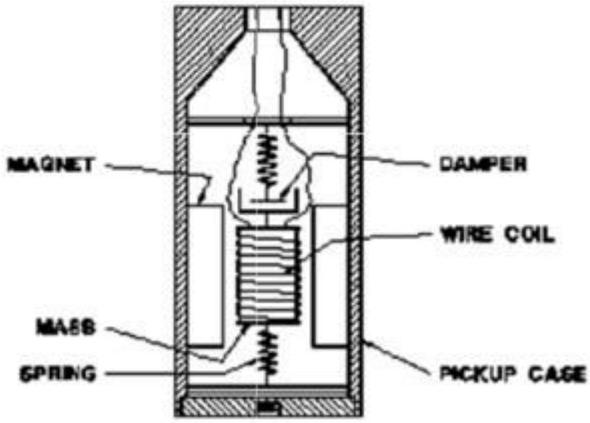
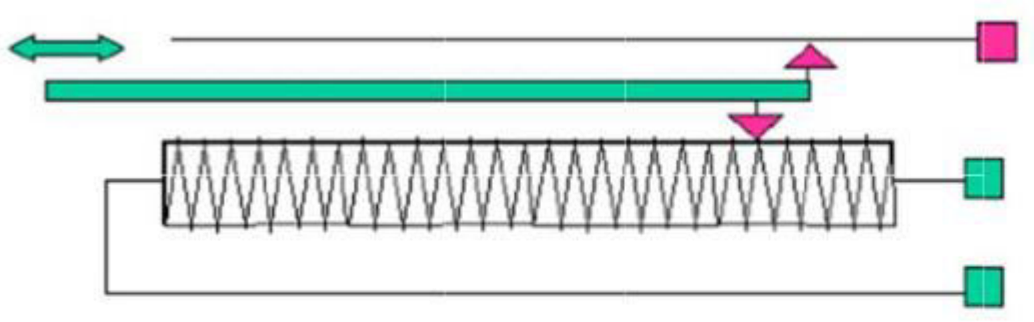


Fig 3. Velocity Transducer

Displacement Transducers

The displacement transducer, in its most elementary form, consists of a fixed part and a mobile part. The mobile part is attached to the mobile contact of the breaker under test, and moves with the contacts, while the fixed part acts as a reference as shown in Fig. 9.6. The internals of many types of rotating machinery have a number of quite small annular radial clearance gaps between the rotor and the stator, e.g., journal bearings, annular seals, balance drums, and blade-tip clearances. Therefore, one obvious potential consequence of excessive rotor vibration is rotor-stator rubbing contact or, worse, impacting. Both accelerometers and velocity transducers measure vibration of non-minting parts of a machine and thus cannot provide any direct information on rotor motion relative to the stator. Two types of non-contacting transducers that emerged in the 1950s are the capacitance type and the inductance type. The capacitance-type displacement transducer works on the principle of measuring the electrical capacitance of the gap between transducer lip and the target whose position is measured. The capacitance method is well suited for highly precise laboratory measurements, but its high sensitivity to material (e.g., oil) variations or contaminants within the clearance gap would make it a calibration "nightmare" for industrial applications. In contrast, inductance-type displacement transducer sysWms have proved to be the optimum rotor-to-stator position measurement method and are now installed on nearly all major rotating machines in power plants, petrochemical and process plants, naval vessel propulsion drive systems, and many others.

Fig 4.



Displacement Transducer

MACHINERY VIBRATION TROUBLE SHOOTING

- When a machine is running, it produces some oscillatory motion as a part of their operation and these are not to be worried about. These type of vibrations are called as "Normal vibration" or "Benign".
- The presence of normal vibration indicates that the machine is running properly without any fault.

Some of the normal vibrations are:

- Blade passing frequency.
- Gear mesh frequencies.
- Broadband turbulence from fluid handling machines suck as fan and pumps.
- Pure tones and hums of most electrical motors.
- When normal vibrations exceed the normal level and the increase of vibrations are not corresponding to load change, then it may become a cause of worry.
- There are many other serious vibrations that are to be worried about. These vibrations need "Vibration Troubleshooting".

Some of the abnormal vibrations for which we should worry about are:

- Large shaking motions.
- Abnormal noise.
- Vibrations above the normal vibration.
- Vibrations that do not change corresponding to load change.

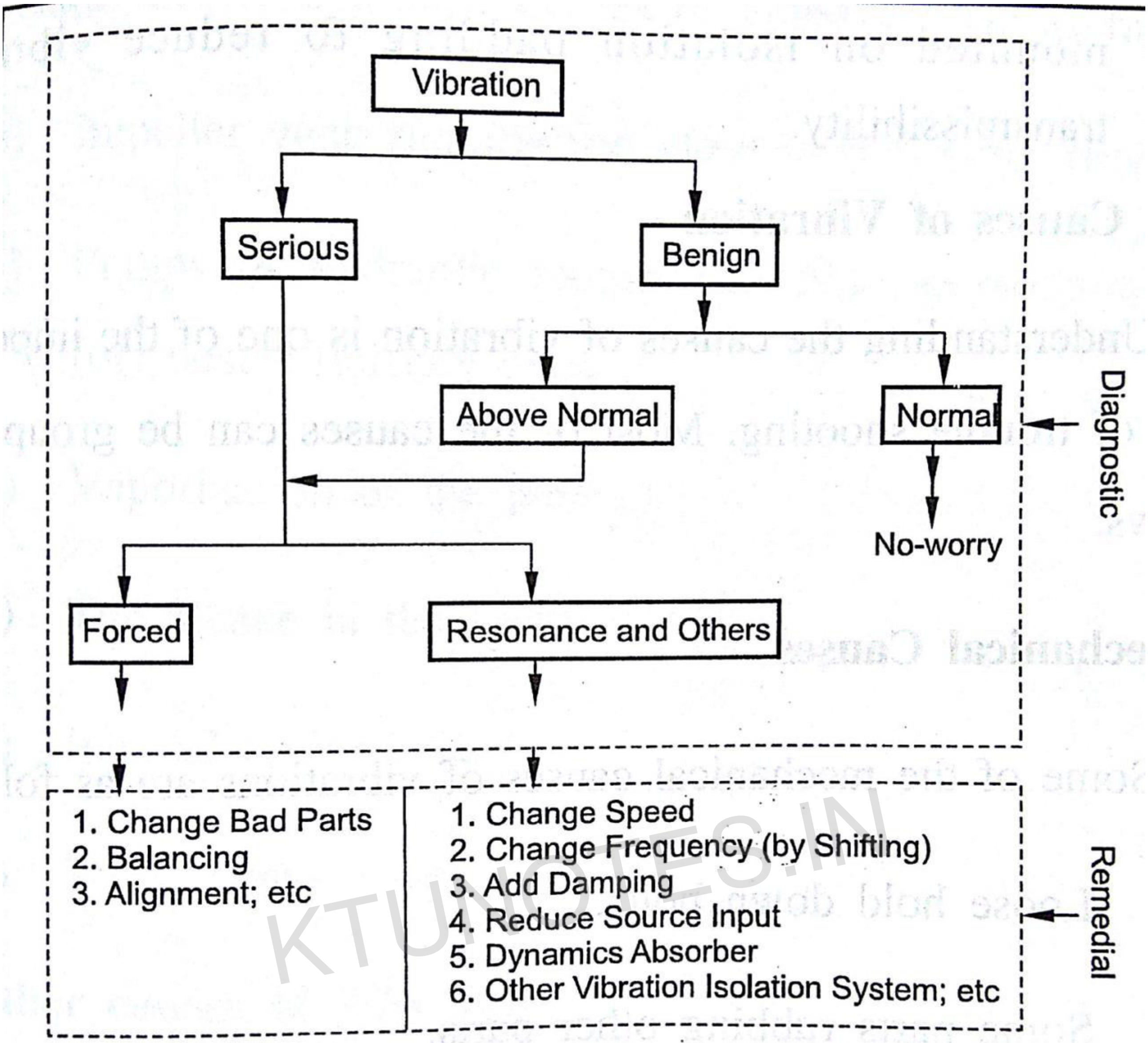


Fig. 3.2: Vibration Trouble Shooting Flowchart

Vibration Isolation

- It is a method of limiting the transmission of vibration to surrounding structures or preventing ambient vibration from reaching machines performing precision work.
- The machines, which are sensitive to shock (or) vibration from other machines or processes need to be isolated to obtain desired efficiency.
- There are several methods of isolation of vibrations.
- One of the ways is by using a large mass foundatio mounted on isolation padding to reduce vibratio4 transmissibility.

Causes of Vibration

Understanding the causes of vibration is one of the important steps of trouble shooting. Most of the causes can be grouped as follows:

1. Mechanical Causes

Some of the mechanical causes of vibrations are as follows

1) Loose hold down bolts.
2) Some parts robbing other parts.
3) Product attaching to a rotating component.
4) Operation at very low capacity.
5) Gears that are not meshing properly.
6) Pump and driver misalignment
7) A bent or warped shaft.
8) Improper design of base.
9) The mass of the ease is too small. etc.

2. Hydralic cause of vibration

Some of the hydraulic causes of vibrations ate as follows:

1. Impeller vane running too close to the pump cutwater.
2. Pumps or hydraulic motors etc. Not operating at rated (or) best efficiency point.
3. Vaporization of the product
4. Turbulence in the system.
5. Internal recirculation.
6. Water hammer etc.

3. Other causes of vibration

1. Electrical troubles.
2. Harmonic vibration from nearby equipment.
3. Dynamic loading of mechanical components.
4. Seal "slip-stick" at the seal faces. etc.

MACHINERY VIBRATION STANDARD, SEVERITY CHART AND ACCEPTABLE LIMITS

- VDI 2056/1964 (German) or its equivalent BS4675, IS02372 or ISO/IS 3954 etc. vibration standards are usually used for vibration signal within the frequency range of 10 Hz to 1000

Hz. IS 4729 is applicable to rotating electrical machines with power ranging from 015 kW to 1000 kW (or) more.

- Some of these standards give normal vibration levels and damage factors for various macbim tool spindles etc.
- These standards guide us to set vibration alarms and such alarm levels can be based on followings:

1. Trend based alarm.
2. Narrow band alarm.
3. Percentage change alarm.
4. Statistical, by point, bearing, machine, direction or machine family etc.
5. Fined alarm based

Table 3.1: Acceptable Vibration Limit

Vibration Limits of Equipments, Electrical motors	Overall Velocity (mm/s) Peak 10 ~ 1000 Hz)	Overall acceleration Peak (0 ~ 5000 Hz)
(1000 ~ 2000 RPM)	5	0.5
Above 2000 RPM	5	1.0
Generator	5	0.5
Centrifugal Fan < 600 RPM	7.6	0.5
6000 ~ 1000 RPM	7.6	1.0
1000 ~ 2000 RPM	7.6	1.5
> 2000 RPM	7.6	2.0
Vane-axial fans	5	0.5
Blowers	7.6	0.5
Pumps	5	0.5
Centrifugal	5	3.0
Compressors	5	3.0
Cooling Tower	10	2.0
Gear Boxes		
Reciprocating	25	10.0
Engines		
Turbines	5	0.5
Twin Screw	25	15.0
Compressors		

VIBRATION SEVERITY CHART

- For conventional vibration overall measurement, they, exist a number of general machinery vibration severity charts developed through the year.
- Developing a universal overall level Spike Energy severity chart for general machinery applications is almost impossible because too many variables such as different machine types, operating conditions, accelerometers, mounting methods and ambient conditions are involved.
- On the other hand, it is possible to develop an overall Spike Energy severity chart based on empirical data for certain type of machines.
- For setting alarm level at different points of machine, general machinery vibration severity chart is used by vibration analyst.

Machinery Condition	Velocity (mm/sec peak)	Velocity (VdB) (dB ⇒ Decibel)
Very Rough	$V > 16$	$VdB > 121$
Rough	$8 < V < 16$	$115 < VdB < 121$
Slightly Rough	$4 < V < 8$	$109 < VdB < 115$
Fair	$2 < V < 4$	$103 < VdB < 109$
Good	$1 < V < 2$	$97 < VdB < 103$
Very Good	$0.5 < V < 1$	$91 < VdB < 97$
Smooth	$0.25 < V < 0.5$	$85 < VdB < 91$
Very Smooth	$0.125 < V < 0.25$	$79 < VdB < 85$
Extremely Smooth	$V < 0.125$	$VdB < 79$

LUBRICANT MONITORING

- Lubricants are used to minimize friction and wear between two mating surfaces and to extract heat.
- They also remove debris from the contact area:

Examples: Combustion products in case of IC engines, chips in the case of metal cutting operation.

- Monitoring or proper lubrication in machine is very essential, due to which lubricant analysis is widely used in condition monitoring of lubricated machineries and hydraulic systems.
- These lubricant analysis can be grouped into three categories and they are:

I. **Fluid Properties Analysis:** To gather information on lubricant's physical and chemical properties such as viscosity, acid number, demulsibility, additives.

II. **Fluid Contamination Analysis:** To check the presence of contaminants such as glycol, fuel, water, dirt etc. in the oil.

III. **Fluid Wear Debris Analysis:** To know about the concentration and characterization of wear metals and other contaminants, suspended in used oil, mainly from the machine components, through which the oil interfaces and generates some wear metals and wear particles.

IV. **To know about the fluid chemical properties:** For assessing the condition of lubricating and hydraulic oils and their ability to perform their intended functions, mostly categories (0 & are used. There are several methods of analysis of lubricants. Some of them are discussed below.

a) **Spectrometry:** Spectrometer is used to measure the quantities and types of metallic elements in a sample of oil.

b) **Viscosity:** Viscosity monitoring is an important part of lubricant monitoring as decrease in viscosity may indicate fuel dilution or contamination by water and other fluids and increase in viscosity may indicate thermal breakdown and oxidation of oil or using wrong oil.

c) **Dilution:** By using Gas Chromatography (GC) or Fourier transform infrared spectroscopy (FTIR), dilution of a engine oil can be measured. It is very essential to measure dilution because heavy dilution of a oil is unfavourable for a engine, since it involves a lower viscosity and reduces the resistance of the oil film.

d) **Water detection:** Water is one of the more common contaminants which has several negative effects on the performance of oil. They are

  - Formation of rust.
  - Increased wear rate.

- Creation of weak or strong acids from chemical reactions between additives and base oils.
- Biological formation & growth in low temperature applications.
- Loss of critical additives and additive function.

Thus detection of water in lubricant is very important.

e) **Acid Number:** Acidity of an oil or lubricant is measured by titration through a base.

Fig below shows graphical representation of depicting the evolution of total acid number as a function of time.

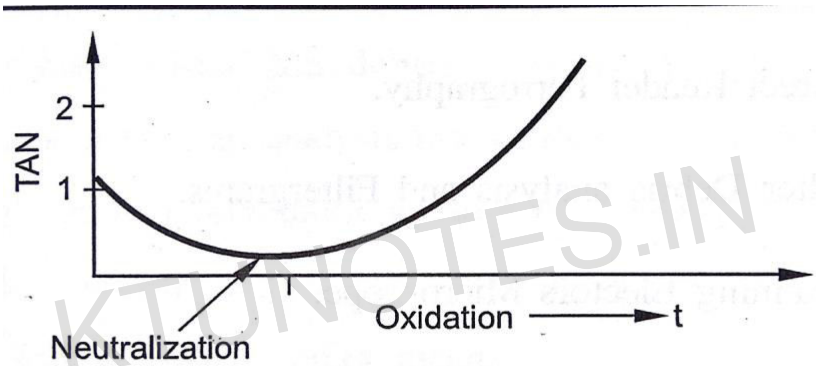


Fig. 3.3: Total Acid Number Diagram

f) **Total Base Number:** By titration through acid, the alkalinity of oil is measured and it is expressed in mg KOH/g.

g) **Particle Counting:** This test is very useful for a hydraulic system with high sensitivity. In this test certain quantity of hydraulic oil flows through a sensor, where all the insoluble material in the oil is detected and counted using the principle of light absorption.

Components and Techniques of Lubricant Monitoring

The components or techniques that are mostly considered in lubricant monitoring are as follows:

1. Sources of wear debris.
2. The distinction between size, amount, shape and chemical breakdown.
3. Numerical Methods Monitoring.

4. Direct Reader Ferrography.
5. Filter Debris analysis and Filtergrams.
6. Scanning Electon Microscope.
7. Magnetic plugs.
8. Visual Method monitoring.
9. Used engine oil, Test kit and other oil test kits.
10. Lab tests.
11. Lubricant contamination control.
12.

Filter Debris Analysis & Filtergrams

- In recent days, due to increasing fineness of filter elements in high precision machinery lubricating oil systems, monitoring of filter debris analysis is gaining increased significance for the early failure detection of moving parts.
- Filters are usually used in lubricating and hydraulic systems to keep the fluid clean.
- The debris collected in the filters is often examined for wear prediction.
- Diagnostic Filter System is a recent filter debris analysis method, where the debris is removed from the filter element onto an analysis membrane by back flushing with solvent (or) solvent-air mixture by flushing debris off the filter element with a solvent or by ultrasonic removal in a solvent (or) by other means.
- Then the collected debris is evaluated for amount, size distribution and morphology.
- By using spectroscopy (or) by infrared (IR) spectroscopy (or) ferrography, the chemical composition of the debris can be obtained, Advantages of employing filter debris analysis are:

I. The full flow nature of the filter element allows all the fluid in system to pass through the filter element.
II. The coherent surface capturing fluid system debris efficiently over time, which results in a high concentration of debris in fluid or magnetic chip detectors.
III. The filter element retains debris of all types.

Filtergrams are nothing but the images of debris segregation and concentration and these are prepared by filtering a sample of oil through 3 to 8 mm celluloSe nitrate membrane filter. One drop of clarifying solution is added and in an oven the slide is
baked. It sets the cellulose nitrate on the slide and optically clarifies it. For ferrous materials, filtergrams are often similar with ferrograms.

FERROGRAPGHY

Ferrography is a specialized type of oil analysis used to study particle wear on machine components through analysis of contaminants in lubricating oil. It can be used to predict and diagnose errors occurring on machinery. Ferrography is related to triblogy, which is the study of friction between interacting surfaces. Since the advent of ferrography in the 1970s it has been used in many industrial settings as a form of preventative maintenance.

Ferrography is a staple in failure prevention maintenance. Continuous monitoring of the lubricating oil allows a change from expensive and often unnecessary preplanned maintenance to the more cost-effective failure prevention. Ferrography is unique because it can deliver information about enclosed parts as lubricating oil circulates through these areas and is still accessible. Rinsing vital components with particle free lubricant and analyzing the output can offer a detailed report of machine wear without disassembling anything.

Since its initial application in the military, ferrography has been found to be helpful in,

- ships
- coal mining
- diesel engines
- gas turbines in the aerospace industry
- agricultural industry
- naval aircraft

Ferrography is generally of 2 types and they are,

1) Analytical Ferrograpgy

2) Direct-reading Ferrography

Analytical ferrography

Analytical ferrography works through magnetic separation of contaminant particles and a professional analysis of the particles. A sample of the machine's lubricating oil is taken and diluted, then run across a glass slide. This glass slide is then placed on a magnetic cylinder that attracts the contaminants. Non-magnetic contaminants remain distributed across the slide from the wash. These contaminants are then washed, to remove excess oil, heated to 600 °F for two minutes, and the slide is analyzed under a microscope. After analysis, the particles will be ranked according to size. Particles over 30 microns in size are considered "abnormal" and indicate severe wear.

Direct-reading ferrography

Direct-reading ferrography is a more mathematical approach to ferrography. Essentially, the buildup on the glass slide is measured by shining a light across the slide. The blockage of the light by the buildup of particles is then used, over time, to calculate an average. An increase in blockage indicates higher amounts of machine wear. This method is less expensive, as expert analysis is not required, and can be automated. However, once an issue is identified, less information is available to diagnose the problem.

Benefit of Ferrograghy,

- Ferrography provides early detection of abnormal wear of the lubricated critical internal components of mechanical systems.
- It analysrs the debris in system lubricants and shows particle size, shape and colour as well as quantity.
- It also reveals which system component is wearing and to what degree and point out the cause of wear.

SPECTROMETRIC OIL ANALYSIS PROGRAM

Spectrometric Oil Analysis Program (SOAP) is a method used by aircraft operators, including several Air forces of the World, to test the health of aircraft engines by performing frequent laboratory testing of the engine oil. The tests reveal the chemical composition of any metal particles suspended in the oil samples. By comparing the results to the known chemical composition of various engine parts, abnormal wear of engine parts can be identified, and servicing of the engine can be initiated, thus sometimes avoiding further costly repairs or even catastrophic engine failure.

Spectrometric Oil Analysis Program (SOAP) is a powerful analytical tool/technique for elemental analysis of structural metal 8: other material particles (up to approximately 5 micron in size) entrained inmachinery Oil Samples. Generation of Wear metals 8: other particles in an 'Engine-Oil' system canindicate the changing conditions of its various parts, like Oil Pump, Gears, Bearings, 81 other metallic parts. The various elements (Metals 81 Non-Metals) present in the base oil are identified 8: measured in parts per million (ppm) by weight. This term is specifically used in the Aviation industry, 8: the corresponding term in the Military sector (especially US Armed Forces) is Jet Oil Analysis Program (JOAP). Spectrometric or Spectrochemical Oil analysis was first used on an industrial scale in 1960. Analysis is done by the use of Atomic Spectroscopic methods like Atomic Absorption 8: Atomic Emission Spectrometry.

SOAP is a Proactive Condition Monitoring/Maintenance tool/technique which helps to assess the relative wear conditions of the lubricated/Oil-wetted parts on the basis of the concentration of the Wear particles in the Used Oil. Besides, it can also indicate the rate of Wear 81 its source. Hence, it can provide an early warning of Abnormal Wear occurring (Wear Anomaly), 8: also about Failure of any engine cornponent. By carrying out analysis of Used Oil (for a particular machine/engine) at periodical intervals, which is also called 'Trend Analysis', Baseline Data can be recorded which can be used for addressing problems related to specific internal engine components based on the knowledge about the metals used for the construction of the engine. Such an analysis can also be used for comparison purposes 8: also to predict 'Failure' of a machine.

The main advantages of a well-planned SOAP are:

1. Prevention of Catastrophic Failures which endangers Safety of personnel,
2. Reduction/Prevention of non-scheduled Downtime.
3. Reduction of expenditure due to repairs.
4. Prolonged Machinery Life.
5. Increase in Efficiency of Machines.

The basic limitation of a SOAP analysis is its inability to detect larger particles, especially larger than 10µm. For analysis of larger particles, other methods like 'Ferrography' have to be used.

CRACK MONITORING

- For quality assurance and metallographic analysis to access the quality of metals and quality of procedures during making, shaping and treating of metals in industries, crack monitoring is mostly used.
- It is also used in Condition Based Monitoring (CBM) and Condition Monitoring of many metallic components.
- Crack monitoring programmes do not measure total crack depth and width.
- They measure the change in crack width. This change in crack width is also known as crack displacement.
- The change in width measured by the sensors may be driven by any combination of the following factors:

1. Structural and machine overloading.

2. Fatigue and aging of components.
3. Differential thermal expansion.
4. Chemical change in various components of machine.
5. Shrinkage and twisting of different Components by temperature and humidity changes etc.

Some techniques that are used for crack monitoring are:

I. Magnetic flux.
II. Dye-penetrant test.
III. Electric resistance.
IV. Eddy current test.
V. Ultrasonic test.
VI. Radiographic test etc.

CORROSION MONITORING

- Corrosion Monitoring includes comprehensive monitoring of all critical components of industrial objects, assets, facilities and plants for sign of corrosion.
- The principles of corrosion monitoring equipment is based on corrosion or chemical wear of the material.
- It is essential to identify the location, rate and underlying causes of corrosion to obtain reliable operation of a machine or machine component.
- Based on the results of corrosion monitoring, the remaining life of object that is affected by corrosion can be predicted.

Some of the corrosion monitoring techniques are as follows;

(i) Electric Resistance Method.
(ii) Linear Polarization Resistance (LPR) Method.
(iii) Hydrogen Monitoring Method.
(iv) Galvanic or Zero Resistance Method.
(V) Weight Loss Method.

INTRODUCTION

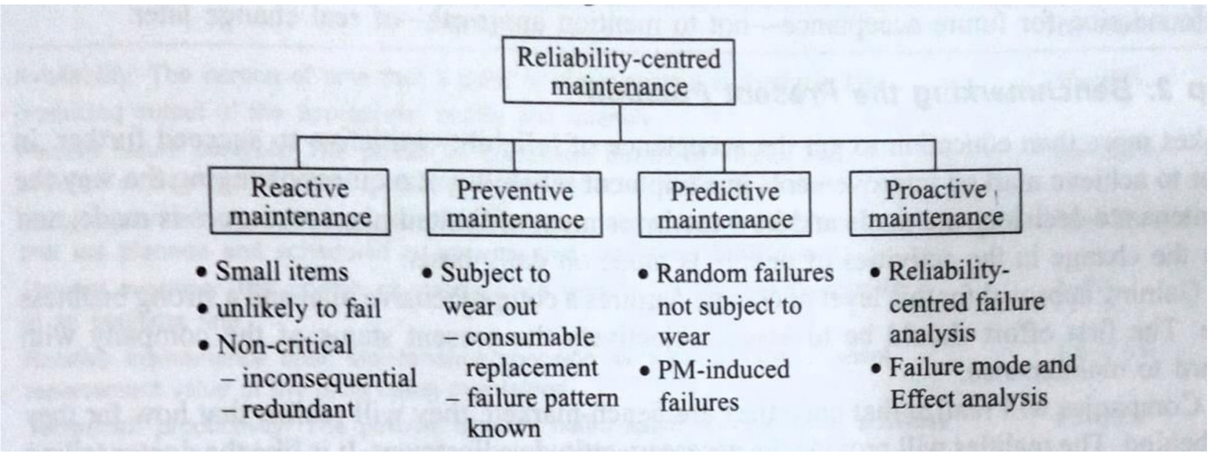
Reliability,. differs from conventional experimental statistics. Reliability provides the means to estimate the likelihood that a system will achieve its mission in a given duration and operating conditions. It is important to be knowledgable about the methods of reliability engineering in advance so as to understand reliability-centred maintenance (RCM). A brief outline of reliability concept was provided in Chapter 2 while discussing various other related issues such as maintainability, availability etc.

The following paragraphs provide a brief description about the management perspective on reliability and the ways and means to implement the new concepts.

Whether the industry produces steel, refines petroleum, or manufactures cars, the bottom line is the profit margin. The managers and industry leaders want equipment up and running at full capacity, so the output goals are met with a shrinking maintenance budget. These are the realities facing maintenance managers. So, it is the job of maintenance personnel to keep the equipment running smoothly even under these difficult conditions. A reliability-based maintenance management approach can provide the solution. The theory behind equipment failure patterns and the benefits of early detection are briefly explained in Chapter 2. The following topics are enumerated in this chapter:

- Practical steps towards achieving the objective of introducing reliability-centred maintenance
- Reliability block diagrams
- Active and standby redundancy
- Basic guidelines for reliability-centred maintenance (RCM)
- Case study of implementing RCM techniques in railways
- Failure modes effects and criticality analysis (FMI,CA)
- Root cause failure analysis (RCM)
- Logic tree in maintenance management
- Event tree analysis
- Common failure modes and causes and failure in an electromechanical system
- Criticality analysis 'criticality matrix
- Difference between RCM and root cause analysis
- Model for determining reliability figures
- use of softwareare in carrying out reliability-centred maintenance

A broad outline of RCM is given in Figure 4.1.



PRACTICAL STEPS TOWARDS ACHIEVING RELIABILITY-CENTRED MAINTENANCE

Here are five practical steps towards achieving the objective of introducing reliability-centred maintenance.

Step 1: Educate from Top to Bottom on Reliability-Centred Maintenance

Here are some practical ways for spreading the -reliability gospel" in any organization:

• Shatter the old myths: For example, as reliability-centred persons, it is well-known that overhauling or replacing motors on scheduled time intervals actually lowers reliability because the rebuilt or new ones are more likely to fail early in their life (infant mortality). But others in the organization may still base their understanding of maintenance on older concepts. Resistance to change rx ill persist until they understand the limitations of traditional approaches.

• Presentation to the staff the better way: New concepts and methods will not take root without a clear understanding of both how and why they are better. For example, it is imperative that explanation on how accurate data on heat exchanger efficiency establishes what is "normal" and \\ by timely inspections are needed to detect degradation early enough to plan and schedule corrective maintenance.

• Use multiple formats: Delivering the messages via creative and varied means will dramatically reduce the number of exposures for people to understand the new philosophy. Quick learning points in regular meetings, informal conversations, and distributing short articles can be as effective as formal training.

• Make the employees understand the importance of their benefit in following the new techniques: Employees do not follow the new procedures just because they have understood the concepts. So, help is needed to make them understand how reliable equipment benefits them personally. For example, the production manager meets his output goal, the maintenance supervisor does not get calls in the middle of the night, and the technician gets out of fire-fighting mode.

• Planting of lots of small seeds in different places will eventually cultivate a broad understanding of reliability concepts and an appreciation for the benefits that are gained. This exposure will lay the foundation for future acceptance—not to mention approval—of real change later.

Step 2: Benchmarking the Present Position

It takes more than education to get the acceptance of reliability initiative to succeed further. in order to achieve marked improvements in equipment reliability, it requires changing the way the maintenance decisions are made and how the investment of limited plant resources is made, and how the change in the activities of people is made on daily basis. Gaining approval for this level of change requires a comprehensive plan and a strong business case. The first effort should be to assess objectively the present status of the company with regard to maintenance.

Companies will realize that once they are bench-marked, they will realize that how far they are behind. The realities will provide the necessary attitude adjustment. It is like the doctor telling the patient that his/her blood pressure is more than the normal or the cholesterol level is higher than the average. As such a strict regiment of diet and exercises is needed to maintain normal health. So, what is a measuring stick for maintenance and reliability?

For safety, the International Standards Organization has defined to calculate lost time incident rate(LTIR) and recordable incident rate (RIR). It is understood that an RIR of 0.5 and LTIR of 0.05 are considered to be high. Similar norms are not available for reliability centred maintenance.

Benchmarking maintenance and reliability can be involved work as the experts may agree or disagree on various metrics to be measured and on the method of assessment to be adopted. However, the unbiased opinion may prove to save considerable cost in lost production due to failure of certain critical equipment.

For those who want to implement an internal benchmarking process, a core list of maintenance and reliability metrics is provided in Table 4.1, although they are indicative only and the real values vary from industry to industry.

The next step is to assess the present maintenance practices vis-à-vis the best practices. Examples of top-notch practices include operator-driven maintenance, designing out failures, condition-based maintenance, and use of an enterprise reliability information system. If all the right things are carried out, good results will be achieved. So, there should be a good correlation between the best practices 'score' and the performance outcomes 'score.' Although communi-cating the results to the management will be a tricky affair in the case of wide gap between the perception and reality, the same would need to be done sooner or later to give a wake up call.

Step 3: Establishing a Long-term Vision

Once the benchmark is established, the next challenge is to define where toproceed further. The ke) to establishing a vision is to begin with the goal in mind. The metrics from the benchmark are used to set specific, measurable targets for the performance outcomes within 3 to 5 years in the future.

Key stakeholders are to be involved in the goal-setting process. Maintenance supervisors, engineers, reliability specialists, and production managers will all have to- involved to ahieve the goals. During the visioning process, the leaders whoplan the activities may have to concentrate on the goal rather than the on the details of how to achieve the results. The same needs to be worked out later.

Step 4: Building up of a Business Case

The reason to carry out the steps to achieve reliability-centred maintenance is to improve the bottom line on the net profits by reducing the overall maintenance costs.

Some examples of improvement are given below:

• A 5 percent increase in availability = 5 percent increase in revenue for a continuous process plant that can sell all that it makes. For example, a plant that produces Rs. 1,000 crore per year generates another Rs. 50 crore in revenue. Reducing overtime from 20 to 10 percent moves 10 percent of labour from overtime rates to straight time rates. If the overtime multiplier is 1.5 and a plant has a Rs. 10 crore labour budget towards overtime Rs. 1 crore is saved.

• Increasing the planned work from 50 to 80 percent moves 30 percent of the corrective work from unplanned to planned. Since a planned job costs 2/3rd less, 20% saving is effected. So for a corrective maintenance budget of Rs. 50 crore, Rs. 10 crore is saved roughly. Building a compelling business case is thus a necessity to build a world-class maintenance organization.

Step 5: Conducting a Pilot Programme

It may be necessary to conduct a pilot programme so as to get the real feel of the benefits of following an organized maintenance scheme. The pilot serves the following critical functions:

• Reduce initial investment. The pilot may cost only 10 percent of the full programme, so the budget approvals are likely to be fast.

• Business case needs to bep roved, particularly to accounts-personnel for gaining their support.

• Test lab. As something new is being tested it is essential to study "what works" and "what does not work" without the pressure and scrutiny of a huge project.

Selecting a pilot project is critical. Ideally, an operationally-important yet a small-sized project which can be completed in 3 to 6 months time can be chosen to prove the theories established earlier.

In many cases it becomes difficult to convince all the members of the maintenance team as well as the management including marketing, finance, purchase and so on to accept the implementation of RCM in a given organization. It is suggested that the fear associated with changes be minimized and the overall opposition reduced so as make the scheme a success. (Figure 4.2)

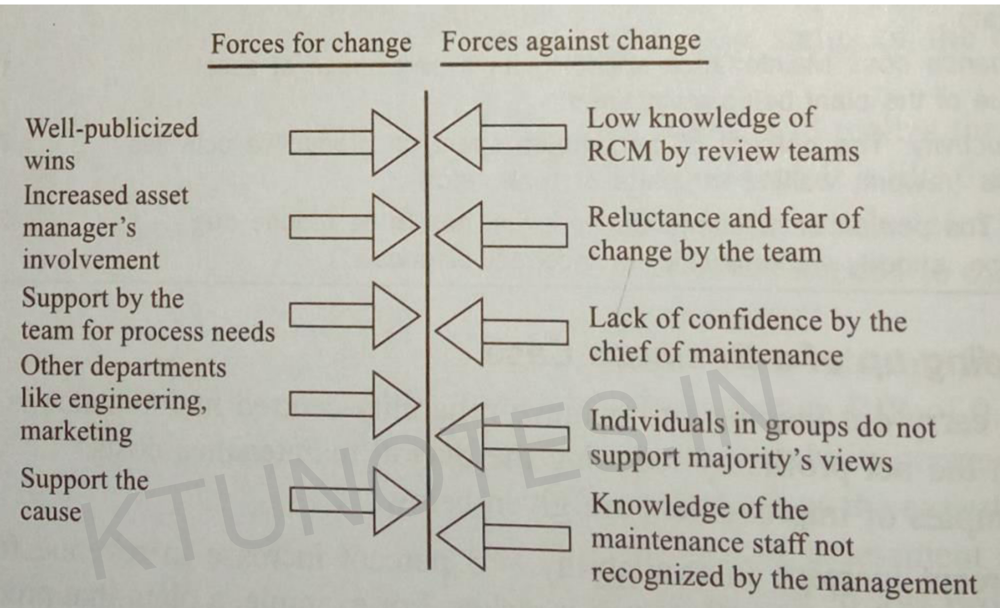


Figure 4.2 Forces for and against RCM implementation.

RELIABILITY-CENTRED MAINTENANCE

RCM is the systematic process with which to optimize reliability and associated maintenance tactics with respect to operational requirements. Economic optimization of machine reliability relative to organizational goals is the primary objective of the RCM process. RCM helps us ensure that if we spend on improving reliability, we are getting the full money back,plus some some acceptable return on the investment.

RCM guides the reliability investment with improvement measures and techniques including lubricatioin management and analysis such that the economic optimization is realized. The figure explains the entire process of RCM.

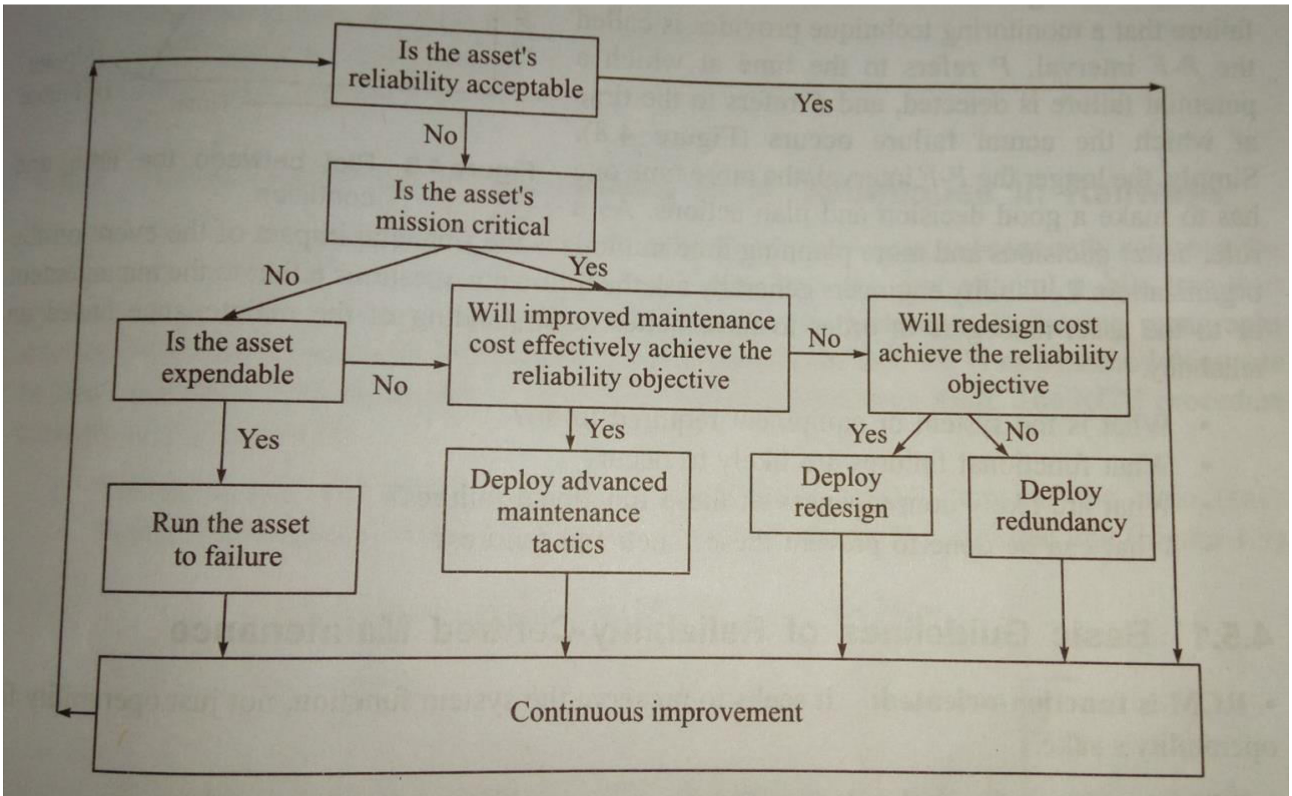
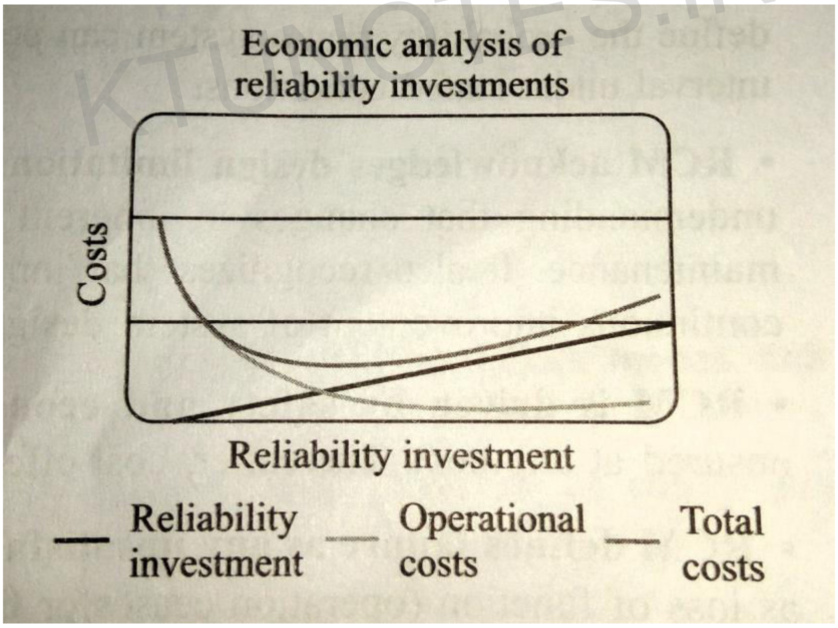


Figure 4.6 Process of RCM explained by a Flow Diagram

Figure 4.7 illustrates the law of diminishing marginal returns,



It applies to the implementation of reliability improvement measures. Generally speaking, money invested in reliability improvement tends to yield a higher return-on-investment than any money subsequently invested. The objective is to reach the point of optimization at which the benefits of reliability, expressed as total operating costs, are maximized through cost-reduction. RCM is a set of systematic engineering procedures for achieving and maintaining that objective.

Identifying the root cause of the failure is the main function in RCM. Just as blood carries clues about the health of the human body, oil carries important information about the health of machinery. In some cases, oil analysis provides the very earliest warning of trouble. In other cases, it provides confirmatory information. Occassionally, it carries no information at all about a failure. Like the physician employs all the techniques and specialists available to detect and understand problems related to health, the machinery engineer must select the right mix of analysis techniques and technologies to make the very best decision.

The warning time in advance of a functional failure that a monitoring technique provides is called the P-F interval. P refers to the time at which a potential failure is detected, and F refers to the time at which the actual failure occurs (Figure 4.8). Simply, the longer the P-F interval, the more time one has to make a good decision and plan actions.

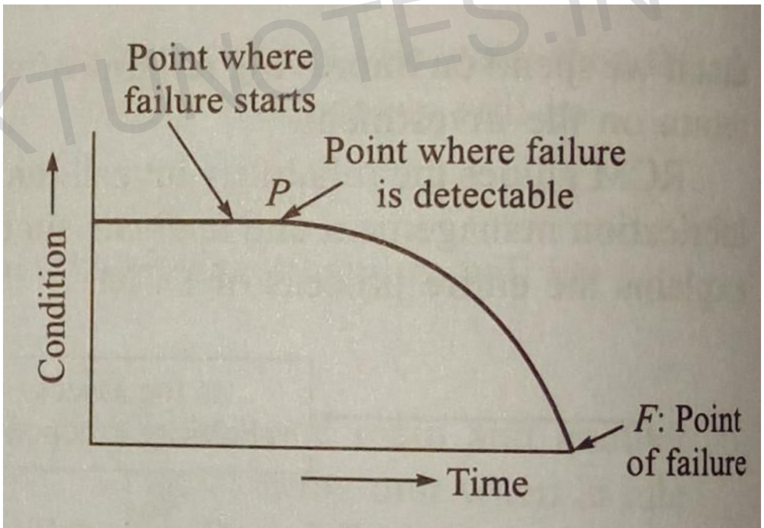


Figure 4.8 Plot between the time and condition.

As a rule, better decisions and more planning time minimizes the financial impact of the event on organization. Reliability engineers generally ask the following questions either to the managem or to the asset managers in order to have better understanding of the maintenance based reliability.

- What is the system or equipment required to do?
- What functional failures are likely to occur?
- What are likely consequences of these functional failures?

- What can be done to prevent these functional failures?

Basic Guidelines of Reliability-Centred Maintenance

• RCM is function-oriented: It seeks to preserve the system function, not just operability to operability's sake.

• RCM is system focused: It is more concerned with systems than components.

• RCM is reliability-centred: It treats failure statistics in an actuarial manner. It seeks to define the probability that a system can perform its intended function for a specified operating interval under stated conditions.

• RCM acknowledges design limitations: It seeks to maintain inherent reliability with the understanding that changes in inherent reliability are the province of design rather than maintenance. It also recognizes that input from the maintenance organization is critical to continuous improvement of system design.

• RCM is driven by safety and economics: Safety (human and environment) must be ensured at any cost. Thereafter, cost-effectiveness is the evaluative criteria.

• RCM defines failure as any unsatisfactory condition: Therefore, a failure can be defined as loss of function (operation ceases or falls below minimum capacity requirements), or a loss of acceptable quality (operation continues).

• RCM uses a logic tree to screen maintenance tasks: Thisprovides a consistent approach to maintenance of all kinds of equipment.

• RCM tasks must be effective: The techniques must be technically sound and cost-effective.

• RCM tasks must be applicable: The tasks must reduce the number of and/or the impact of failures.

• RCM acknowledges four types of activities:

1. Run-to failure
2. Time-directed maintenance
3. Condition-based maintenance
4. Failure-finding/proactive maintenance

DEFECT AND FAILURE

Although the both term defect and failure has some differences, they are normally taken to mean the same. Failure occurs in any component due to it's defects. Defect means fault, mistake, flaw, vice, deficiency or shortcoming of any type or situation. Five major sources of defects are as follows:

(i) Failure due to unintentional damage

(ii) Workmanship - Misalignment, poor welding. etc.

(iii) Design Design that doesnot fit the actual requirement and conditions.

(iv) Material Defect at manufacturing, sourcing, storage or handling stages etc.

(v) Operation Wrong operation & operational problems etc.

Some common industrial definitions of failure are as follows:

* Failure is a loss of asset availability.
* Failure is any secondary defect.
* Failure in any loss that interrupts the continuity of production.
* Failure is the unavailability of equipment.
* Failure is not meeting target expectations.
* Failure is a deviation from the status quo.

Failure Rate: The frequency with which an engineered system or component fails is called Failure Rate. The failure rate of a system usually depends on time. The Mean Time Between Failure (MTBF) is often used instead of the failure rate.

Failure Mode: Failure Mode generally means the category, types style, way, mood in which a system or component fails. In all failure analysis, the term failure mode is often used.

Failure Code: Failure Code is simply a code that illustrates the reason why an asset or equipment fails. Codes can be a number or simply a alphabetic abbreviation. Mostly failure codes are used in computerized maintenance management systems. It provides a convenient method of getting statistics about equipment failure or breakdown.

BASICS OF FAILURE

According to a few experts, the causes for more than 90% of all plant failures can be detected with a careful physical examination using low power magnification and some basic physical testing. There are several reasons due to which failure occurs in components. Some of the basic reasons of failures are as follows:

(i) Fatigue Failure: When repeated loading and unloading is applied on any component, such as hydraulic cylinders, automotive connecting rod etc., the fatigue strength of the material comes into play, when this fatigue strength is exceeded, cracks can develop in the asset or equipment.

In ring or bush materials, when load exceeds the elastic limit, the failure occurs is called as **True Brinelling Failure**.

(ii) Corrosion: Corrosion can greatly affect the failure in a component. It reduces the fatigue strength and thereby it will increase the chances of failure. Corrosion usually results in increased vibration, subsequent increase in radial clearance or loss of preload etc.

(iii) Ductile Overload Failure and Brittle Overload Failure: The type of failures, where a great deal of distortion of failed part can be observed is called Ductile Failure. On the other hand, the type of failures where no visible distortion of the failed part can be observed is called Brittle Failure.

(iv) Stress Concentration: It is a physical or metallurgical condition which increases the local stress in a part by some factor. Stress concentration has a great effect on crack initiation because of their effect on increasing the local stress. When a part is relatively lightly stressed, the cracking will start at only one point.

(v) Contamination: It is one of the leading causes of premature bearing failure. Some of the symptoms of contamination are dents or scratches embedded in the bearing raceways and balls or rollers. It may include airborne dust, dirt or any abrasive substance that gets into the bearing.

(vi) Wear: A variety of mechanisms result in loss of material by mechanical removal which lead the material to fail.

(vii) Hydrogen Embrittlement: If tensile stresses are applied to a hydrogen embrittled component, it may undergo failure P These type of failures are frequently unexpected and sometimes catastrophic. Since Hydrogen embrittlement failure occurs without any externally applied load or at loads significantly below yield stress, it is considered as an insidious type of failure.

FAILURE GENERATION

Failure or defects may be generated or induced at various stages of equipment or component life cycle, such as:

(i) Design Stage: Failure on a component may occur due to some design efficiencies such as incorrect assumptions of duty condition or Factor Of Safety (FOS) etc.

(ii) Manufacturing Stage: Sometimes, to make a product cheaper, the manufacturer takes lower factor of safety and design properties, due to which the product deviates from required close tolerances. Sometimes, due to unavailability of required material, the manufacturer uses some inferior material so that the production cost doesnot increase and delivery is not delayed. These factors may lead to failure at operation stage.

(iii) Erection Stage: Some factors such as inadequate stress relieving after major welding, no pre stressing of big bolts and non use of facilities like torque wrenches for uniform tightening etc. affect the equipment. Though these factors are not easily noticeable during inspection, they may induce failure at Erection Stage.

(iv) Commissioning Stage: During commissioning stage, either to save time or due to non-availability of full lead at that time, often proper procedures are not followed and full load tests are not done, which may lead to permanent failure.

(v) Operation Stage: Due to wrong operating practices and
inadequate care, many faults may generate in operation stage.
Some of the examples to generate fault at this stage are overloading of machine, improper cleaning and lubrication of machine etc.

(vi) Maintenance Stage: Defects may also occur at maintenance and repair stage by using wrong dismantling procedure, use of improper tools, improper cleaning and lubrication, non uniform tightening and improper torque on bolts etc.

(vii) Environmental Degradation: Due to change in environmental conditions, such as more corrosive and abrasive fumes and dusts, more moisture, more radiation and magnetic fluxes etc. many defects are generated in an component.

Failures can be classified into following types:

(a) Failure based on inherent reliability characteristics.

(b) Dependent failure.

(c) Manufacturing (or) burn in failures.

(d) Wear-out failures.

(e) Operation induced failures.

(f) Maintenance induced failures.

(g) Equipment damage due to accident, environment degradation etc.

FAILURE ANALYSIS

Collecting and analyzing of data to determine the cause of failure and steps taken to prevent it are combinely called Failure Analysis.

There are several types of tools and methods used in big industries for identification of failure.

While analyzing the failures, types of failures can be grouped in various categories as below:

(i) Quality Deterioration Failure: By these, the equipment gradually deteriorates to the extent that the quality of the processed products are lowered.

(ii) Catastrophic Failure: These type of failure occur when the equipment suddenly breaks down due to partial or total damage of some parts. But the equipment can be restored back by replacement or repairing the particular part.

(iii) Degradation Failure: Due to these types of failure, the equipment gradually losses its performance while in use and causes loss, even though the equipment does not stop or breakdown.

Failure analysis includes defining the failures properly, finding out function of defective units and finding out alternative means to prevent the failures. After failure analysis, different maintenance strategies are adopted to prevent failure.

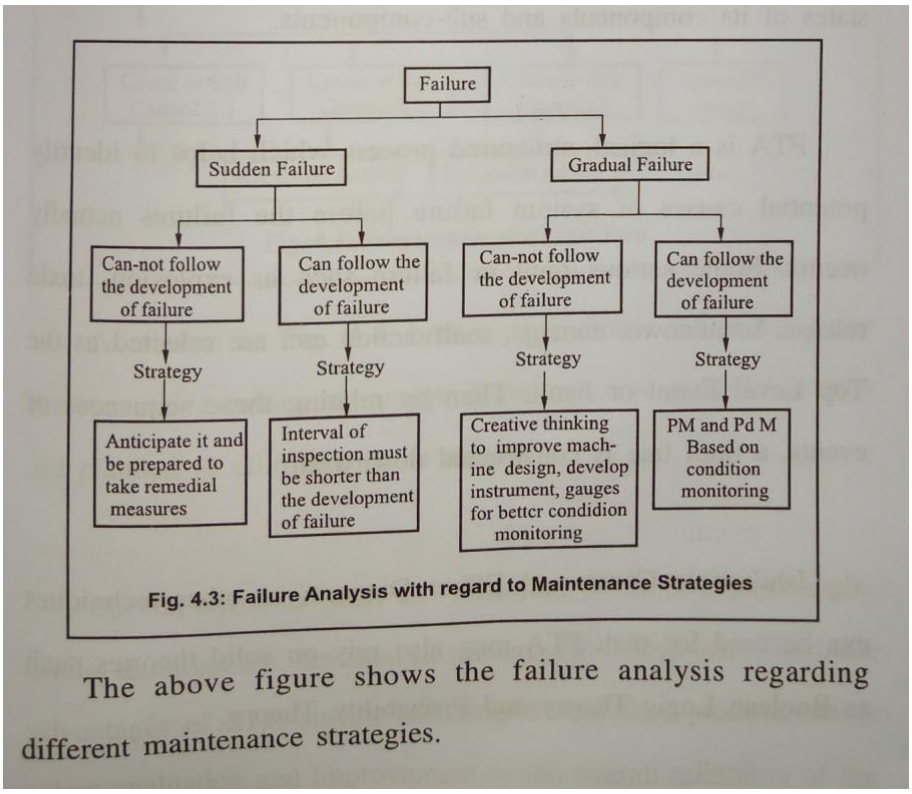


Fig. 4.3: Failure Analysis with regard to Maintenance Strategies

The above figure shows the failure analysis regarding different maintenance strategies.

FAULT TREE ANALYSIS (ETA)

FTA is a technique, which is used for reliability and safety analysis. This concept of FTA was developed in Bell Telephone laboratories in 1962 for the U.S air force for use with the
minutemen system. which was later adopted by many industries.
FTA diagrams or Fault Tree diagrams (FTDs) are logic block diagrams, which display the state of a system in terms of the states of its components and sub-Components.

FTA is a logical, structured process which helps to identify potential causes of system failure before the failures actually occurs. Some serious fault or failure such as explosion, toxic release, breakdown, damage, malfunction etc. are selected as the Top Level Event or Fault. Then by relating these sequences of events, a fault tree is constructed downward.

Ishikawa's Cause and Effect Diagram or other techniques can be used for that. FTA may also rely on solid theories such as Boolean Logic Theory and Probability Theory.

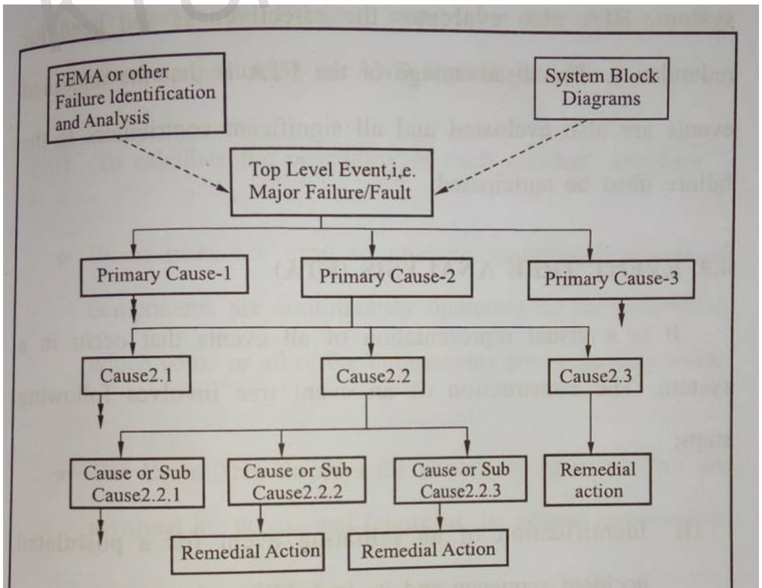


Fig. 4.4: Preparation of a Fault Tree

As shown in Fig. 4.4, both quantitatively and qualitatively the successive causes are analyzed and essential remedial actions are planned to eliminate those causes.

Special symbols such as 'And-Gate', 'Or-Gate', rectangle, circle, diamond etc. are used in modem FTA diagrams. The main advantages of FTA are the meaningful data they produce which allow evaluation and improvement of the overall reliability of the system. FTA also evaluates the effectiveness and need for redundancy. The disadvantage of the FTA is that the undesired events are also evaluated and all significant contributors to the failure must be anticipated.

Failure Modes Effects and Criticality Analysis (FMECA)

FMECA is the inductive process of identifying primary functional failures, their related failure modes or states, the effect of the failure modes on the operation of the system and the associated criticality of the failure mode as a function of impact and likelihood. This valuable analytical tool enables the removal or better management of failure modes through application of advanced maintenance techniques, redesign or redundancy. Table 4.2 explains the methodology in determining the total impact of failure of each subsystem in a plant.

Table 4.2 Typical FMEA table

System details	*Possible effects of failure (X)*	*Criticality of such failure (Y)*	*Inverse of the reliability of detection or control mechanism (Z)*	*Frequency of failure occurrence (n)*	*Total weightage (X+Y+Z)*n*
Compressor					
Lubricating pump					
Dryer					

Based on the total weightage obtained criticality of each equipment or subsystems are decided. The FMEA/ FMECA is generally viewed as an analysis, which should be implemented during the design phase, to have maximum influence and impact on the final design. The FMEA serves to input and support other engineering design activities such as the following:

. Safety engineering: The FMEA would support the safety engineering efforts in analysis such as the fault tree analysis. The failure modes with their assigned criticality would be seen as basic events.

• Maintainability engineering: As part of the maintainability analysis, is the importance that detection and isolation is accurately reflected in the overall mean time to repair calculations.

• Design engineering: The FMEA would support the design engineering effort to ensure that program design requirements are addressed. These could be in the support of requirements such as no single point of failure etc.

The FMEA can be implemented as a functional and or physical analysis. Earlier in a design process a functional analysis approach would be taken. With better definition of the design and as more details are firmed up then this will permit a physical analysis to be implemented. The FMEA is most effective in providing a contribution to the final system configuration, with respect to reliability performance characteristics, during the actual design phase.

Root Cause Failure Analysis (RCFA)

RCFA assesses a failure after the fact with the intent to determine its root cause for occurrence. Once the root cause is ascertained, the engineer can assess the risk of recurrence, the success with which the root cause might be controlled and the cost to control it. With this information, a decision can be made to deploy control.

DIFFERENCE BETWEEN RCM AND RCA (ROOT CAUSE ANALYSIS)

The purpose of RCM is to determine the maintenance requirements of any physical assets (Equipment) in its operating context. This is accomplished by answering seven questions about the equipment in order to determine what type of maintenance strategy to employ for the asset. RCM provides a flow diagram that gives details on what type of maintenance to use. By answering the seven questions all of the potential modes of failure are uncovered and a predictive maintenance strategy is devised to mitigate the consequences of the failure based on the criticality of the failure mode. In RCM, these failure modes are identified as the root cause(s) of the failure. But, the purpose of RCA is to uncover the underlying reasons (root causes) why an event (not just equipment related events, but any type of event) is occurring so that the necessary steps can be taken to eliminate the event in its entirety. This is accomplished by analyzing the modes (the point at which RCM stops). RCA uses a logic tree that stresses verification at every level. The advantage is that the actual root causes are uncovered facts that have been derived from the verification process. The comparison between the two programs is striking — RCM is driven by preventive maintenance strategies while RCA is driven by maintenance prevention strategies.

It should be clear that the difference between RCM and RCA is that RCM treats the symptom while RCA finds and corrects the cause. For example, consider a person who has chronic headaches for some unknown reason. RCM would analyze all the possible reasons or modes (stress, disease, allergies, loud noise, bright light, lack of rest, etc.) that this person was having headaches. RCM would then tell this person to do anything from taking aspirin to performing more complicated forms of treatments, at designated intervals, in order to mitigate the consequences of the headache in its primary state. By comparison, RCA would uncover the reasons why the headache is recurring and provide resolutions for its complete elimination. Both the techniques would solve the immediate problem of headache pain, but only RCA would uncover and eliminate the actual cause of headache.

EVENT TREE ANALYSIS

Event trees are generally used on certain occasions when analysis of sequence of events are to be carried out in addition to human action that can lead to disasters or undesirable events. The activity is sometimes called cause consequence analysis, and is more applicable in safety studies rather than reliability. A simple case study of a fire alarm system is considered where it is assumed that there are three possible sequences by which fire can spread. They are as follows:

- Alarm fails to function and the operator fails to notice and take appropriate action.
- Alarm functions but the sprinkler or the fire extinguisher fails to operate and the operator fails to notice and take action.
- Alarm fails to function and the operator notices but the sprinkler system fails to function and the operator fails to notice the malfunction of the sprinkler.

Various probability figures for failure of the system have been assumed based on historical data or by experience as in the case of human factors and an event tree diagram is formulated as per the figure given below. Such a figure will indicate quantitative figures for fire to spread or to get extinguished in each case (Figure 4.13).

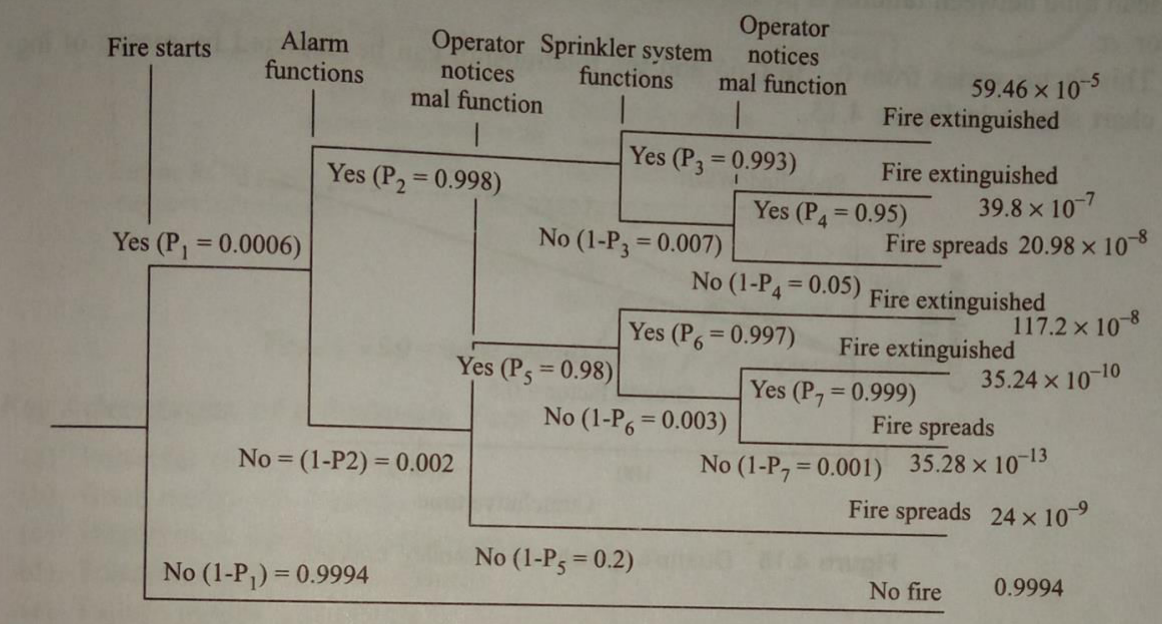


Figure 4.13 Event tree analysis for safety issues (probability figures given are only assumptions and does not reflect any actual data).

MODULE V

TEROTECHNOLOGY

The term terotechnology is another word for resource a life cycle management and it describes a systems; approach for managing physical assets. In other word it is an integrated approach to cost control and encompass all the cost elements starting from design, developmnt of a product up to its final disposal.

Definition

Terotechnology is defined as a combination of management, financial, engineering and other practices applied to physical assets in pursuit of economic life cycle costs and it is concerned with the specification, design for reliability and maintainability of plant, machinery, equipment, building sand structure with their installation,commissioning,maintenance,modification,replacement, feedback of information on design, performance.

Terotechnology system

combination of management systems and communication channels which provide support for maintenance. Typical contributions include the foilowing:

(1) Design: Assets designed for maintainability and reliability.
(iii) Projects: Provision of assets having operability and maintainability features.
(iv) Operations: Introduction of operating techniques which reduce down time and improve care of assets.
(vi) Personnel: Selection and training programmes for operating and maintenance personnel.
(v) Finance: Cost control, cost monitoring and feedback.

A terotechnology system is a set of functions and decisions which controls activities arising from the practice of temtechnology so that proper options can be taken at each stage in the life cycle of physical assets to which the techniques are applied.

A terotechnology system must be designed:

(i) To react rapidly to breakdowns or emergencaes necessary.

(ii) To stimulate examination of fault equipment.

Terotechnology process

At the design stage, the designer puts his effort to design-out maintenance and design in reliability and he will be encouraged to design in maintainability where maintenance cannot be eliminated completely.

The designer receives the feedback of experience with the equipment or product from all five phases

(a) Installation,
(b) Commissioning,
(c) Operation,
(d) Maintenance and
(e) Replacement.

In terotechnology process the procurement fonction plays a very important role. The procurement engineer is fully responsible for securing this suppliers understanding and acceptance of specification. The installation phase of resource management is very important, because incompletely planned installations leave a long legacy of operating problems.

The The terotechnology concept insits on the use of systematic methods of managing the installation project. The terotechnology process separates commissioning from installation and commissioning is seen as both testing new equipment and running it upto full production performance. The operating phase of terotechnology is characterized by the need for close collaboration with the maintenance function. The operation phase will involve the generatibn of detailed cost and performance. records to list terotechnology effectively.In terotechnology process maintenance phase also plays a very important rule. The maintenance manager is involved at the design and other primary stages of the life cycle of equipment and his feedback to design is considered as very important feedback.

Replacement phase is the final phase of terotechnolcgy process. This phase needs both the timing of replacement and the disposal of the equipment. Replacement involves teamwork from the collaborating departments.

Strategies for TerotechnoIOgy

Terotechnology is concerned with the provisioning and subsequent management of physical assets. Assets provisioning can be considered in three phases and they are: Preparation phase, Decision phase and Implementation phase.

Some of the important considerations in these phases in a life cycle are listed in following:

Preparation Phase

Consideration of Feedback, Flaming, Technical forecasting, Wholc Life Planning, Life cycle costing.

Decision Phase

Direct participation by users, preparation for procure check lists, reviews of supplier profile and quality specification of support systems, Review of Life plans and cycle costs.

Implementation Phase

Design, Studies, Project Planning and control, Information systems, Preparation of documentation, Maintenance Planning, Commissioning, Handover.

Utilization Phase

Operation, Maintenance, Condition Monitoring, Technical and cost records, Analysis of records, feedback to operation, maintenance, design and procurement.

Review Phase

Technical & Financial Reviews, Disposal or Raplacement Decisions, Feedback to Benefit Future plans.

TOTAL PRODUCTIVE MAINTENANCE (TPM)

TPM is a maintenance program which involves a newly designed concept of maintaining plants and equipments; (hilosophically TPM resembles Total Quality Management (TQM) in several aspects such as

i) total commitment to the programme by upper level management

(ii) employees to be empowered to initiate corrective action

(iii) a long range outlook must be accepted as TPM (may take a year) (or) more to implement and is an ongoing process.

Features of TPM

Total Productive Maintenance (TPM) has led to better maintenance and upkeep of the equipment and resulted in enhanced quality of products and reliability of equipments. Thus TPM leads towards economic efficiency excellence. Some of the features of TPM are as follows:

(i) Increase of Overall Equipment Effectiveness (GEE).

(ii) Provides training to upgrade operation and maintenance skills.

(iii)Generally promotes small autonomous group concept for better motivation and coordination.

(iv) Establishes a total system of complete maintenance and upkeep of the equipments, generally covering the entire plant life cycle.

(v) Involves all departments such as maintenance, Operation, connected planning groups, material management, quality, finance and administration and utilizes cross functional teamwork.

(vi) Involves the participation of mmbers of all groups from top management level to shop-floor worker level.

(vii) The operator is the best condition monitor

Methodology of TPM

The stages and steps used to implement TPM in any industries are as follows:

1) preparatory phase

This phase is also known as pre-requestier.It include the following steps.

a)Discussion with workers union representatives

b)Announced by management through company's communication channels and news letters,to introduce TPM,highlighting TPM objectives and grains.

c)TPM promotion-Special committees at every level to promote TPM.

d)Establish basic TPM policies and goals.

e) Preparation and formation of master plan

2)TPM Take off phase

TPM take off should take form of a formal presentation by top executive,with all employees attending at specified time.To gain full support of all employees this opportunity can be used.The phase is also known as introduction stage.

3)Implementation phase

1.Development of an equipment management program.
2.Development of a planned maintenance program
3.Development of an autonomous maintenance program.
4.Increase skills of production and maintenance personnel.
5.Early development of equipment management programme.

Benefits Of TPM

some of the benefits of TPM are as follows

(i) Reduced equipment down time.
(ii) Approaching zero equipment caused defects.
(iii) Increased plant capacity
(iv) Lower maintenance and production costs...
(v) Better utilization of work area and employees.
(vi) Reduced inventory levels and inventory coming costs it all part of the supply chain.
(vii) Enhanced job satisfaction.
(viii) Increased equipment productivity.
(ix) Immediate attention of smaller problems to prevent its aggravation.
(x) Increased Return Of Investment (ROI).

TPM and Terotechnology

Although the scope of TeroTechnology is much larger as compared to TPM, the purpose of both TPM and terotechnology is some What similar to pursue economically efficient life cycle cost.

Terotechnology involves designer, manufacturers, erections and other outside agencies, in addition to user plant personnel and it doesnot concentrate much on maintenance, but tpm is connected with only user plant.

Six sigma maintenance

Application of six sigma principle in maintenance is known as six sigma maintenance . It focuses on reducing the vibration in business production process . By reducing vibration a business can achieve higher control over its operational system such as increasing their cost effectiveness and encouraging productivity breakdown .

Six sigma provides a structural approach to solve problems by implementation of five phases ; Define opportunities, measure performance ,Analyze opportunity ,Improve performance, Control Performance (DMCAIC). Six sigma is also known as DMAIC process or methodology .

Six sigma quality level indicates how often defects are likely to occur. The higher the sigma quality level ,lower the possibility that the process produce defects.

There are also number of disadvantages that must be addressed for six sigma to become a sustainable technique , some of them are as follows.

1.The training and solution put forward by six sigma can be prohibitively expensive for many business

2.The correct selection of improvement project is critical etc.

Six sigma process

Although the overall goal of six sigma maintenance differs from RCM process , some of the step of six sigma maintenance process closely resemble RCM process.

Define	Determine Benchmark , Set Base line , Determine Availability and Reliability Requirement , Get customer commitment Map, Process flow
Measure	Develop Defect / Failure measurement Technique and tools , Develop data , Collect data , Create forms , Compile and Display dat

Analyze	Check and verify data , Data conclusion , Determine improvement (Failure elimination etc) opportunities , Find Root causes
Improve	Create improvement and Failure elimination ideas and plans , Create model equipment maintenance process , Create Root problem statements , Create total repair
Control	Monitor Improves Program (maintenance) Monitor Improves Performance Statistically and through Condition Recheck

Lean maintenance

The term lean maintenance is used for organization which endevour for continuous improvement when TPM is strongly routed. Though then concept of lean maintenance is taken from lean manufacturing , it is neither a subset nor a spinoff of lean manufacturing. It is instead a prerequisite for success as a lean manufacturer.

Lean manufacturing is a proactive maintenance operation which employs planned and rescheduled maintenance activities through Total Productive Maintenance (TPM) practices using maintenance strategies develop through application of Reliability Centered Maintenance (RCM) decision logic and practices by empowered action terms using the s5 process.

Challenges of Lean Maintenance

In recent days lean maintenance is becoming more desirable due to these following reasons .

- Declining state of maintenance in industries
- Retiring good employees and shortage of labour and knowledge
- Lack of vocational – technical trainees and programmes
- Competitive pressure etc.

5 Zero concept

i. **Zero Breakdown**

It implies a very high degree of reliability combined with very good maintenance capability . The reliability falls within the competence of manufacturers and maintenance capability to some extent falls within the competence of maintenance and operational practice . Therefore both maintenance personal and manufacturers should associate and aim for zero breakdown

ii. Zero Fault

It actually means that fault should not be allowed to occur but if it occurs then that should be detected much earlier and corrected at initial strategies

iii. Zero Delay

The zero delay concept call for planned and rapid response to equipment outage . No time should be lost for fault diagnosis or repair Zero delay concept also calls for planning and scheduling essential maintenance jobs with available shutdown in such a way that actual delay is almost nil and no separate shutdown is needed exclusively for maintenance

iv. Zero Stock

It means that spares and other materials are obtained in such a way that those are received only when those are actually needed for consumption. Due to this , the materials are not unnecessarily stocked in stores and inventory carrying cost is almost nil.

v. Zero Paper Work

The Zero paper work concept tries to eliminate the paper work or atleast reduce that to barest minimum . It involves extensive use of computers or other devices and integrates the same with system computer with necessary Local Area Network (LAN) and customized software . This concept enables the maintenance personal to immediately know how when and where of thr job and intimate feedback. Therefore , the 5 Zero concept covers all areas with specific aim of high availability and reliability.

5-S Concept In Maintenance

S-1 Sort

It refers to the practice of going through all the tools , materials etc in the area and keeping only essential items.

Sorting can be done as shown in table

Priority	Frequency of use	How to use
Low	Once in year , or may Be once in more than Six months	Throw away . Store away from the workplace
Average	Once per week to Once in six month	Store together but offline
High	Daily to once per week	Located at the workplace

S-2 Set in order

This includes organizing of work area for additional improvement opportunities and looking for ways to reduce sources of waste and error as well as to make the workplace more visual resources to achieve improvement

S-3 Shine

This include three primary activities getting the workpiece clean , maintaining its appearance and using preventive measures to keep it clean . The workplace can be cleaned by eliminating dust , fluid and other debris. Working in clean environment enables workers to notice malfunctions in equipment such as vibration , breakage and misalignment . Equipment that are kept clean perform more efficiently , have less unscheduled downtime and reduce cost to the company.

S-4 Standardize

During this phase of implementation , the team identifies ways to establish the improves workplace as a standard. The main objective of standardization is to create best practice and to get each team member to use the established best practices the same way . Team members should discuss together and decide on standards for keeping the workplace neat and clean . These standards are implemented for whole organization and are inspected randomly .

S-5 sustain

The purpose of this concept is to maintain the momentum generated during the initial event or project . A management auditing process should be put into practice to ensure that employees understand that maintaining the level of workplace organization is a top priority.

Management audits should focus whether the routines and shedules specified in S-4 standards are being properly maintained or not .

Some of the benefits of S-5 concept in maintenance are as follows

a) Improves quality and reduce defects or failures
b) Improves time delivery or time completion
c) Reduce lead time
d) Reduce inventory and storage costs
e) Reduce waste material , space and time
f) Increase safety and profitability
g) Reduce changeover time and equipment down time etc.

Business Centered Maintenance

In 1980, Kelly developed a maintenance approach , which is termed as Business Centered Maintenance (BCM).This approach was developed in response to the need for a most effective method of maintenance with a high priority for safety.BCM is a general approach , which can be applied in most industries or to most manufacturing / production systems or service system , such as power station , chemical process plants etc.BCM emphasise the importance of aligning the maintenance function with corporate objectives and then a thorough understanding of the operation of system is used as input for the top-down bottom – up analysis , in which life plan developed for the component , items and units of the system.

Six Pillars of BCM

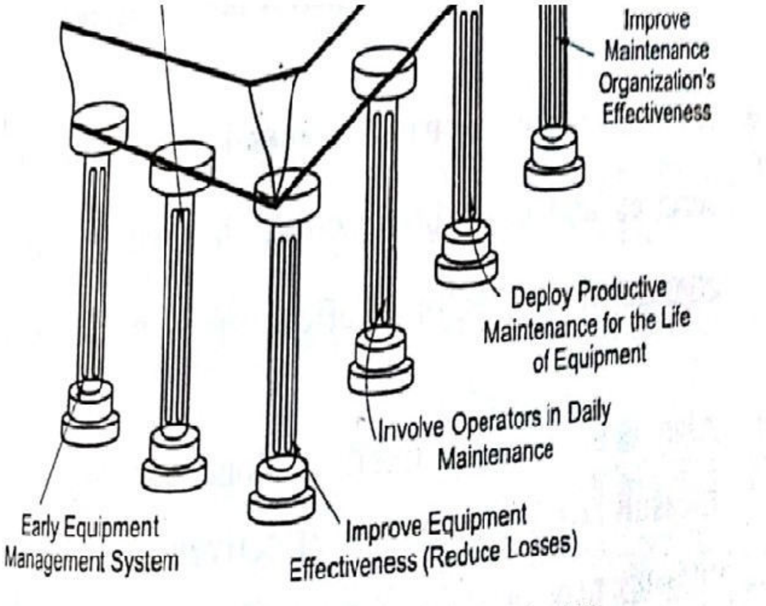


Fig. 5.6: Six Pillars of Business - Centred Maintenance.

QUALITY ASSURED MAINTENANCE

The objective of quality assured maintenance is to ensure that a continuous process of evaluation and improvement is being followed. The main activities of quality assured maintenance cover the systematic monitoring and evaluation of defined quality indicators such as the results of different means of feed back to measure effectiveness of some activity.

There are two types of quality assurance process involved in maintenance phase:

(i) Process that directly related to feedback and review process.
(ii) Process that may be triggered by decision to change or update some activity.

CONTROL CHARTS FOR ATTRIBUTES

It is very difficult to represent many quality characteristics numerically. In such cases, each item inspected is classified as either **conforming** (or) **non-conforming** to the specifications on that quality characteristic. The attributes data assume only two values.

Good (or) Bad

Pass (or) Fail

Defective (or) Non-defective
Attributes cannot be measured but they can be observed and counted. Attributes are useful for many practical solutions as given below.

- When measurements are not possible (e.g) visually inspected items such as colour, scratches, damage and parts.
- Where measurement can be made but are not made because of time, cost (or) need.

For example, although the diameter of a hole can be measured, it is easy to use a "go – no go" gauge to determine whether the product conforms (or) does not conform to specifications.

Need for control charts for attributes

Even though variable control charts are good in controlling quality, they do have limitations.

1. Control charts for variable cannot be used for quality characteristics that are attributes. (example) Non-conformities such as missing parts, incorrect colour, etc., are not measurable and a variable control chart cannot be used.
2. They are many variables in manufacturing unit. Even a small manufacturing plant has 1000 variable quality characteristics. Since Ẍ and R charts are needed for each characteristic, 1000 charts required which may not be possible and also lead to confusion. It is also expensive.

A control chart for attributes can minimize the above limitations by providing overall quality information at a minimize cost.

Two different groups of control charts for attributes.

1. 'p' chart and 'np' chart
2. 'c' chart and 'u' chart

Defects and Defectives

A **defect** is a simple Non-conforming characteristic of an item, while a **defective** is an item that has one (or) more defects. In some situations, quality personnel may be interested not only in whether an item is defective but also in how many defects it has.

1. 'p' chart and 'np' chart are nothing but 'Number of defective chart' i.e for non-conforming units. 'p' chart shows the proportions non conforming in a sample. The proportion can be

expressed as a fraction (or) a percent. ‘np’ chart is used for number of non-conforming.

2. The ‘c’ chart is used to control the total number of defects per unit, when the sub group is constant.

The ‘u’ chart is used to control the average number of defects per unit, when the sub-group sizes are variable.

Types of Control Charts for Attributes

Type	Central line	Control Limits	Comments
p	$\bar{p}$	$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$ $LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$	Use for nonconforming units with constant or variable sample size.
np	$\overline{np}$	$UCL = \overline{np} + 3\sqrt{\overline{np}(1-\bar{p})}$ $LCL = \overline{np} - 3\sqrt{\overline{np}(1-\bar{p})}$	Use for nonconforming units where np is the number non conforming. The sample size must be constant.
c	$\bar{c}$	$UCL = \bar{c} + 3\sqrt{c}$ $LCL = \bar{c} - 3\sqrt{c}$	Use for non-conformities within an unit where c is the count of non-conformities. The sample size is one inspected unit.

'c' chart is for **non-conformities.** 'c' chart shows the count of non-conformities in a inspected unit such as bale of clothe (or) roll of paper.

MODULE VI

Maintenance Planning

Planning is the activity performed to make a time-bound programme for successful completion of any job. To correctly and efficiently perform the planning function, management should provide adequate guidance on the levels of control necessary to ensure consistent quality maintenance of plant/equipment. The basic concepts of the maintenance function as well. planning are applied to Maintenance planning and scheduling should be viewed as the centre of industrial maintenance since other processes such as preventive maintenance, root cause analysis (RCA), spare parts management are dependent on the planning and scheduling processes to work.

All three approaches to planning, namely long-range planning, short-range planning and planning for immediate activity are also applicable to maintenance work. For effective working of any system it is necessary to plan and schedule its activities. The planning approach differs widely depending on the purpose and the work being planned. A long-range planning is done at the higher level. In this approach of planning the goals are set, strategies are developed and operational programmes are devised for a period of five to ten years. Short-range plans are prepared at the departmental level for a period of one to two years. Immediate activity planning is almost a routine procedure and is done at the working level as and when required. The three approaches to planning have very little in common except that they all come under the area of planning and all are necessary to fulfil the objectives of the organization. In any planning, the basic steps required are problem identification, identification of solution, evaluation, selection, and placing of the solution into practice. Maintenance planning also involves a similar decision-making process. The basic objective of any planning, therefore is to convert the concepts into workable actions. In the maintenance context, planning is therefore the task of organizing resources to carry out a job satisfactorily at reasonable cost within a specified period of time.

PLANNING OF MAINTENANCE FUNCTION

Maintenance planning involves the assignment of jobs to the maintenance crew with relevant information of the work to be carried out. Job assignment must be done on the basis of proper job scheduling of the maintenance work. The risk of an emergency maintenance work going unattended must be minimized. At the same time the maintenance workforce must not remain unutilized. The following aspects need to be considered carefully while planning the maintenance work.

Job Distribution

In planning and organizing the maintenance work, the first and foremost consideration should be given to the distribution of the jobs to the personnel for preventive as well as emergency maintenance work. If the same group is used for both the functions, some amount of time must be allowed during scheduling for unforeseen break-downs, which may occur, to avoid underutilization or over-utilization of the available manpower. If separate teams are used for preventive and emergency maintenance, the effective utilization of manpower calls for proper planning of maintenance functions. Such a planning process should incorporate the following components.

Organizational goals

The maintenance planning must be in accordance with the organizational goals, but all aspects of the organization do not necessarily form part of maintenance. Maintenance Needs Analysis (MNA) should therefore be carried out to identify the role of a piece of equipment or asset in achieving the organizational goals. Based on such an analysis, equipment or assets are identified for inclusion in the planned maintenance system. The objectives of maintenance planning at the departmental level must be clear to all the personnel involved in the work and they must also be clear about the objectives of the organization. The planned work should be carried out to improve the performance of the production system.

Policies

The maintenance department must evolve the fault-oriented maintenance policies. Such policies should identify the level of maintenance required for different assets and also formulate the main procedures of conducting the maintenance operations. The policies must be well defined so that the maintenance functions planned can be easily identified for timely implementation. Here also the objectives of the organization must be kept in mind for efficient working of the maintenance functions.

Procedures

The maintenance planning involves determining the methods to carry out each of the maintenance functions. The procedures of the work must be well defined and standardized so that the maintenance personnel do not get into any confusion. The development of procedures includes the design of the inspection form, interval of reporting, issue of maintenance tools, etc. The procedure for organizing men materials or other resources for carrying out any , maintenance work should be well known to the maintenance workforce. This reduces the logistic time during any maintenance operation, without impairing the effective working hours of a machine.

Programme

The objective of any planned preventive maintenance programme is to reduce the system costs for providing services. A maintenance programme is a well-formulated combination of the available skills and resources that ensures optimum utilization to successfully complete the work. The development of such a programme involves

(i) selecting activities for preventive maintenance,
(ii) determining their frequency, and
(iii) deciding which out of the two, whether repair or replacement, is more cost effective.

These three aspects of a maintenance programme are briefly discussed below.

Selection of activities

To select the activities for programme implementation, the following information should be available in respect of each acitvity.

(a) Frequency of failures
(b) Causes of failures
(c) Cost of failures
(d) Cost of preventive maintenance
(e) Impact of failures on the system

The selection of any maintenance activity is dependent upon the, cost of maintenance and the importance attached to it. If the cost of the preventive maintenance is lower than the cost of the breakdon maintenance, then the former will be preferred over the latter. However, the requirements of the equipment/system must be kept in mind before the final decision.

Determination of preventive maintenance frequency

The optimum period or frequency for preventive maintenance can be determined from the failure data. The time period for different types of breakdowns to occur can also be calculated by analyzing such failure information. From this information, the interval of preventive maintenance is determined.

For the efficient planning of preventive maintenance work it is essential to know the cause of actual failures so that such failures can be prevented in future. It is known that a substandard material or workmanship causes frequent failures. This aspect is duly taken care of during planned/scheduled maintenance work.

The comparison of the preventive maintenance cost with the breakdown cost should also be made before selecting a particular policy.

Repair versus replacement

In the case of failures where no repair is possible such as bulbs, electrical goods, electronic goods, the defective parts have to be replaced. Such replacements are carried out during the scheduled inspections as well as on their failures. This type of scheduled replacement is similar to the preventive maintenance programme. Policies followed with regard to scheduled replacement are:

(a) Replace all items (both good and failed components/units) periodically.
(b) Replace only the failed components/units periodically.
(c) Replace the failed components/units as and when required.
(d) Replace the failed components/units as they fail and also replace both good and bad components/units periodically.

The decision regarding the scheduled replacement policy has to be based on the analysis of the past failures data on the same type of projects or products from the same field. Incorrect decisions may, in fact, increase the maintenance cost to a high level.

MAINTENANCE SCHEDULING

The concept of scheduling can be applied to the maintenance function for improving the operational availability of the equipment. To start with the maintenances scheduling, the first step would be to know the number of machines to be maintained. The next step would be, how to maintain them. Then the maintenance schedule is to be prepared for all critical items, which require preventive maintenance. Initially, this exercise can be started with a few selected components of a machine and with experience the knowledge gained can be applied to the complete system.

The main objective of maintenance planning and scheduling is to raise the standards of the maintenance functions and make it cost effective which is possible only through critical analysis of the results obtained. In the case where the number of machines is high and the manual scheduling is difficult, the use of computers is inevitable. For the jobs not completed in time, rescheduling of the same can be done.

Once the process of schedule generation is completed, all assigned works must progress smoothly until something comes up that necessitates an alteration in the predefined process. Sometimes due to the budgetary constraints the rescheduling of work become essential. Backlogging work must be minimized and avoided. Basically, the scheduling is of two types—fixed scheduling and dynamic scheduling.

In the case of fixed scheduling the problem of backlogging is common when the work is not completed as per the schedule and the system can work under ideal situation. However, dynamic scheduling takes care of all practical constraints under all circumstances.

For proper scheduling of the maintenance work, the job must be controlled through the work-order system, which provides the basic paperwork for planning the workforce, the material and the time. The work order is also an authorization to carry out the particular job. The concept of priorities is also essential in case of schedulin.

The priorities must be set to handle the mixture of backlogged and the new pieces of scheduled jobs. The frequency of maintenance and the criticality of the operations are the key factors for establishing the priorities for the jobs. Frequency indicates the relative importance of one procedure over the other. If the equipment becomes over due for a certain number of jobs, it is treated critically important and the priorities must be set accordingly. To minimize such situations the scheduling must be done when it is due. For effective results, under-scheduling and over-scheduling must be avoided.

Scheduling process

The scheduling process consists of the following activities:

- ♦ Prioritizing the maintenance work
- ♦ Dealing with the emergencies
- ♦ Maintenance calendars

- ♦ Scheduling the backlog
- ♦ The allocation of scheduling methods
- ♦ Priority numbering systems
- ♦ Weekly and daily schedules
- ♦ Controlling the backlog

Cost reduction with maintenance planning and scheduling

The cost reduction in maintenance function is possible with proper planning and scheduling of the work. The first step in this direction is to utilize the shutdown time of the equipment occurring due to failures. This will depend upon the following:

- ♦ What type of work is executed during shutdown
- ♦ When is the shutdown work list finalized
- ♦ How well is the shutdown work being planned

Work executed during breakdown

Attempts must be made to minimize the shutdown period of the machine, which ultimately will reduce the maintenance costs. During the shutdown period, jobs of minor nature such as cleaning, repair and preventive maintenance, etc, should be undertaken. When this basic principle is followed, it will result in reduced overtime, lower contractor costs and better documentation.

It is a common belief that during the major shutdown period maximum maintenance related works must be completed. There is also pressure to postpone the scheduled minor repairs by executing this work during the major outage instead. In such an approach, it is likely that additional cost attributable to overtime labour, expedited parts delivery, execution of unplanned work and reduced worker efficiency will exceed the apparent savings. Major shutdowns should therefore never be used for periodic minor repairs.

It is noticed that increasing the Mean Time Between Production Loss (MTBPL) versus Mean Product Loss (MPL) indicates that the efforts of maintenance and operations are resulting in improved productivity. Increasing the time between schedule outages or reducing the time available for repairs during scheduled outages may cause this trend to turn downwards due to increased unscheduled breakdowns.

Shutdown work finalization

In the long-term plan, there should be fairly detailed lists of major works that must be done during each shutdown in the coming years. For example, during boiler inspections, relining of the tile tanks, sewer repairs and electrical power distribution system inspections should be planned and estimated in the long-term plan. Some mandatory provision must be made for minor repairs as inspections often do not get adequate attention until it is too late to properly prepare for their execution.

In order to get a major shutdown accurately budgeted, the scope, the duration and the timing of the outage must be supplied before the budget is approved. The short-term plan can be developed using the long-term plan as a starting point. During the short-term plan, expensive repairs must be identified. When the equipment is nearing its final outage, then the short-term outage is not justified. Jobs added on short notice before a shutdown, are generally the cause of most disruptions to planned and scheduled work. It is important to note that planning the maintenance work is expensive and its cancellation at the last moment is wasteful. Review of repair histories and making of accurate estimates of the time, materials and expenses that commonly occur with each project is essential.

The success of shutdown planning and scheduling depends on key events occurring far in advance. Continuous improvement of the process requires that a detailed critique of each shutdown be performed, with inputs solicited from engineering and supply stream from maintenance operation personnel. A word of caution. Never estimate the budget for shutdowns using the budget figures from the past.

Planning shutdown work:

More work can bed one by less people if it is properly planned. The resulting repair quality will be better with the reduced costs. The unplanned repair works which take 8 hours to complete will take 2 hours when planned. This is due to better instructions and coordination of tools and materials and resources. Each work order should be planned before execution. This includes all the preventive maintenance work as well as repairs. The planning should include the following:

♦ A clear scope of work required
♦ An accurate estimate of the manpower required
♦ A detailed procedure for the work
♦ A list of tools and special equipment required
♦ Schedule of execution of work
♦ Safety and environmental hazard

The comparison of quality shutdown management versus the poor shutdown approach shows the areas where savings in maintenance functions are possible.

Quality shutdown	Poor shutdown
Controlled work list	Unlimited work list
Limited overtime	Unlimited overtime
Routine work done in scheduled time	Routine work done in overtime
Timely availability of spare parts	Untimely availability of spare parts
All work planned in advance	Some work planned, most unplanned
Accurate schedule	Unscheduled work
Add on work is rare	Add on work is common
Planned, scheduled work get priority	Planned scheduled jobs get cancelled
Budget based on reality	Budget based on past information
Better documentation	Poor documentation
Backlog minimum	Backlog maximum
Absenteeism of workers is less	Absenteeism of worker is more
Better acountability of work	Poor acountability of work

OBJECTIVES OF MAINTENANCE ORGANIZATION

Maintenance of modern machinery and industry calls for setting up of a healthy, balanced and rationalized organization to achieve the multi-faceted objectives. This is essential to keep the diverse activities of the maintenance department under control without any problem. An effective maintenance organization can be set up after a careful study of the background of the industry because the nature of machinery deployed would be the key factor. It is seen in practice that some of the equipment need more attention than the others and the effect of environment is also important for the establishment of maintenance department. While setting up the organization, the future trend of the industry should also be assessed so that any modifications required in the set-up can be incorporated in due course of time.

The importance of the maintenance organization grows with the increasing size of the industry and the complexity of the equipment/ system. A small-scale industry may require a simple maintenance organization with a foreman in-charge. Whereas, when the size of the industry increases, the complexities of the maintenance and therefore those of the maintenance operations, also grow in size. And therefore, a highly trained and competent person may be required to head the maintenance organization/department. There has to be a close relationship between the production and maintenance departments for their effective working without problems.

The basic objective of any maintenance department/organization should be to ensure that the maintenance function is carried out effectively and the equipment downtime as well as the loss of production is minimized. High equipment availability can be achieved by proper coordination of maintenance functions with other departments. At the same time the cost of maintenance functions must be kept under control since it is considered a burden on the production.

The head of the maintenance department/organization show, possess the necessary expertise and experience since the succes or failure of the maintenance department would depend upon his abilities and capabilities. He has to look after not only the day-to-day maintenance/repair of equipment but also ensure the lifeline of the production unit or process unit. High availability of the production system can be obtained by continuously monitoring the planned preventive maintenance schedules identified for the machine/equip-ment. In a highly mechanized and sophisticated organization, the chief engineer (Maintenance) should normally head the maintenance department. The structure of the maintenance department/organization depends on the type of the industry as well. For a complex industry, for example, mining, a centralized maintenance unit can be set up since hundreds of mining units operate independently in different areas. In such type of organizations, a maintenance unit can be set up at the headquarters, and several field branches of such a unit can be set up at convenient places near the working areas to cope up with the daily requirements.

The following points should be considered while setting up a maintenance organization or department.

♦ To organizational goals pertaining to the maintenance function must be identified and should match with the overall organizational goals.

♦ Maintenance workload should be determined beforehand to achieve the desired results with proper utilization of manpower and facilities.

♦ Total maintenance work should be properly and uniformly distributed among all the concerned persons to avoid conflicts among the workers.

♦ The important and essential work should be assigned clearly and definitely to various departments of the maintenance organization.

♦ Due consideration and care should begiven for proper qualification of the workers while assigning a particular job.

♦ The maintenance organization should be staffed with the best-qualified and trained people available since the nature of work is unpredictable and time consuming.

♦ The policies and procedures shouldbe clearly designed at an early stage to help maintenance people to achieve the organizational goals.

ORGANIZATIONAL REQUIREMENTS

While setting up a new maintenance organization department, the following parameters must be kept in mind.

Coordination

Success of an organization depends on effective coordination and cooperation of the people in the organization. For a prolific maintenance organization it is essential to have a clearly defined organizational chart indicating job-descriptions and unambiguous definition of authority for each job. It is observed that a group rather than an individual performs most of the maintenance jobs.

Therefore, it is utmost necessary to maintain work harmony. To maintain proper team spirit, the leadership of the group is very important which can bring people together. Thus, success of the maintenance function entirely depends upon the dynamic leadership and coordination Of the departmental head.

Maintenance Engineer

The role of the maintenance engineer is very important and crucial, as his primary job is to minimize the downtime with optimal performance of the equipment/system under his supervision and control. Therefore. the maintenance engineer should be a well qualified, technically competent, knowledgeable and cost conscious person in order to be an effective and efficient leader of the maintenance group. The output of the maintenance department with, respect to time. talent and effort put in by the team is the index of its efficiency. Application of proper management techniques, motivation of workforce, avoidance of conflicts and the inspiring leadership of the maintenance engineer can bring the targets and achievements closer. Accountability of each and every individual of the maintenance group is essential for effective ofutilization of manpower. The authority wrested with the maintenance, should not be abused in the interest of the organization.

Attitude of Personnel

The attitude of the working personnel in many instance, is not always positive towards accepting the modern facilities/techniques available for the maintenance function. Under the existing conditions the maintenance personnel should be apprised of the latest techniques available in the field of maintenance together with their merits and demerits so as to change their mindset and encourage them to adjust to the changing environment: The organizations must correspondingly mould their policy to bring change in the attitude of their personnel towards acceptance and implementation of advanced maintenance concepts and techniques. which can definitely help to improve the performance of maintenance personnel. The persons in the organization must be encouraged and motivated to accept the challenging jobs of maintenance which otherwise is taken as secondary job.

Policy

The policies adopted by the maintenance organization should be such that they can be easily understood and followed by everyone within its framework. These can be either formal or informal. The formal policies are recorded and are subjected to modification from time to time. It is the responsibility of the maintenance boss to frame the policies, in consonance with the company rules, keeping in mind working hours, benefits, safety, security, overtime, and the like. The policies framed should fit in the organization set-up as well. On the other hand, informal policies depend upon the situation of the maintenance requirements and are to be decoded on the spot. This situation normally arises in case of sudden breakdowns and no planning on the spot is possible. And therefore, such decisions may bring criticism from the fellow members as well as production people and require due attention.

Maintenance Work Control

The structure of a maintenance organization should be such that there is always sufficient manpower to supervise the work. Care should also be taken to see that a balance is always struck between the number of supervisors and the number of workers to be supervised. However, there is no fixed rule to maintain the proper ratio of supervisors to workers, although effective monitoring is most essential because, when the number of supervisors is high the work may suffer at the same time their shortage will also yield the same result.

Managerial Functions

It is the duty of the supervisory staff to develop their subordinates to a required level of proficiency. The working personnel should be properly motivated to attain the high levels of proficiency so that they can work freely and fearlessly to fulfill the organizational objectives. However, the attitude of the working personnel is very important for the development of the subordinates. The development of the subordinates can be done keeping the following in mind:

- ♦ Level of education and training
- ♦ Level of skill
- ♦ Level of intelligence
- ♦ Level of motivation
- ♦ Attitude towards the work

It must be pointed out here that the above levels entirely differ from oneperson to another. The jobs to be handled also require different levels of skill, such as unskilled, semi-skilled, and highly skilled however, the importance of experience will have its own weightage. This should also be borne in mind during the development stage of the subordinates. In this regard, the leadership of the super visor plays a very important role to coordinate the work effectively.

Capacity Utilization

The main function of the maintenance organization should be to utilize the full potential of its workers and use of maintenance facilities. During the selection of persons, the values of each individual must be assessed thoroughly, as it is seen that though a person is a very good engineer but lack managerial qualities. However, managerial qualities can be imparted with proper training and incentive and thus a good engineer can become an efficient manager as well. It is also sometimes noticed that individuals move from one organization to another for better career opportunities. This can be taken care of by the top management so that the skilled and efficient persons are retained in the organization. The real leadership calls for an effective utilization of the capacity of the individuals with utmost care. This can be best achieved by properly assigning the jobs to the personnel. The maintenance work should be projected as a challenging job so that the persons, who are competent and dynamic, do not hesitate to take up this assignment.

ORGANIZATIONAL PROBLEMS

The maintenance organizations face various problems due to the nature of the maintenance work as well as its occurrence place. To overcome these problems, the maintenance organizations, with the cooperation of the plant management and the production department, should try to fill up the organizational gaps arising out of the following situations.

Lack of Coordination

The plant management must identify the objectives of the maintenance organization in consonance with the overall production strategy. Sometimes the production department does not allow the maintenance personnel to take up the scheduled maintenance work as this disturbs their production targets. This normally happens during the end of the production month.

The maintenance work is of varied nature; the maintenance organization should understand the difference between the routine and essential work so that the essential work is carried out most expeditiously with the cooperation of the production department and the routine work can be adjusted during other available time period.

A clear distinction between field and shop work should be made so that the traditional attitude does not hamper the maintenance work. The logic will not hold good for the breakdown maintenance work all the times because of the nature of failures. The maintenance organization should try the new concepts for better work control procedures.

Availability of Trained Manpower

As stated earlier, the properly qualified and experienced persons should only man the maintenance organization. Sometimes the persons from other departments are also shifted to the maintenance department either on promotion or due to their unsuitability in their respective departments, which should be avoided as it may create serious problems in the maintenance organization. It should be borne in mind that though policies set up by the top management should act as the guidelines for every activity of maintenance function, the actual procedures are the outgrowth of such policies because of the nature of work involved. It is normally seen that if more than the required number of people are engaged on a job, it ultimately suffers, as nobody owns its responsibility. Sometimes, too many assistants in a particular job create confusion among the workers due to multiple chains of command, which must be avoided to minimize conflicts among the workers.

Improper Planning

During the planning stage of an organizational set-up, it must also be kept in mind that overstaffing needs to be avoided to obviate overlapping of duties and at the same time understaffing will also result in not completing work as per schedule therefore proper balance for all type of activities must be struck. The planning of other activities associated with maintenance functions is also important and crucial and must be cared well in time. This include the facilities required for completion of any maintenance related problems.

TYPES OF MAINTENANCE ORGANIZATIONS

The selection of a particular type of maintenance organization/system will largely depend upon the main structure of an industry as well as the type of product handled. However maintenance organizations in general can be of the following types:

- ♦ Decentralized
- ♦ Centralized
- ♦ Partially decentralized

In the large-sized plants located at different places, inter-unit communication is difficult. Therefore, in such cases the decentralized type of organization is best suited, which means that the maintenance organization works under the direct control of a chief engineer in-charge of production. With this type of organizational structure, a better coordination between the production and maintenance groups is possible since one person heads it only and the communication down the line is direct. The advantages of such type of organization are as under:

♦ Speedy and timely decisions due to better line of communication under single control is possible. ♦ Maintenance and production people understand each other's problems better because of their common goals of meeting the production targets.

♦ Interchangeability of workforce, even at the managerial level, is also possible without any conflict among the staff.

♦ Better training at the workers' level can be arranged.

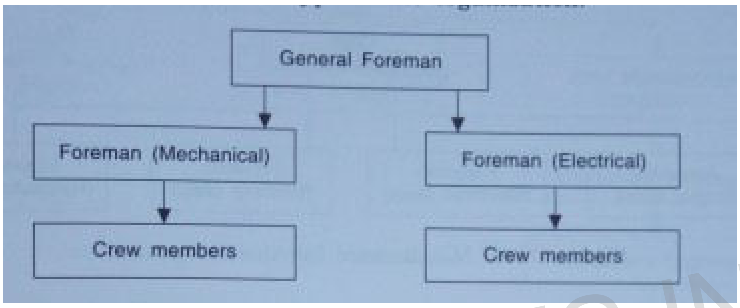
♦ Better coordination with fellow members.

In a small factory where communication between the departments is more free, the centralized type of maintenance organization is preferred, which is placed under a chief maintenance engineer/ manager. The total responsibility of the maintenance function for the entire factory lies with the chief maintenance engineer. Under this type of organization, the responsibilities and accountability of work must be properly specified for production as well as maintenance personnel to successfully meet the project goals. If this is not taken care of, one department may blame the other for any shortfall.

The partially decentralized organization, which is the modified form of a centralized type of organization, is most suitable for projects that have units at far away locations. Under this type of maintenance organization, the maintenance personnel, attached to the production unit, carry out work at unit level and look after day-to-day maintenance. However, important maintenance functions such as over-hauling, planned maintenance work, procurement of spare parts, etc. is kept under the charge of a chief maintenance engineer at the central office. All the centralized work pertaining to maintenance planning and documentation is done at the level of central maintenance workshop.

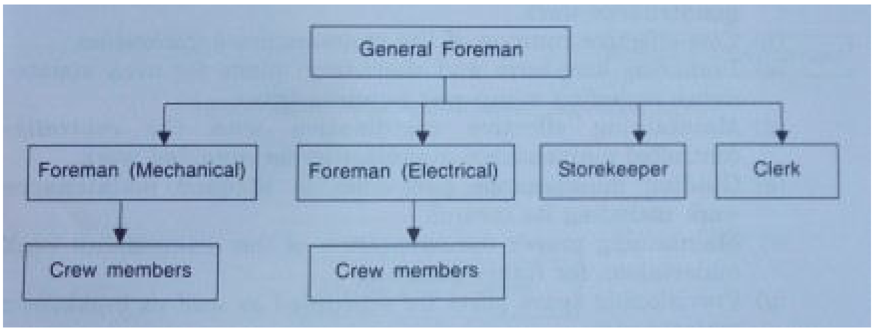
The above three types of maintenance organizations, however, are not strictly exclusive and some adjustments can be made to suit the working environment and the need.

Basically there are two types of organizations that are followed in most of the projects/industries—line organization and staff organization. In the past, the line organization was mostly followed, which consisted of a general foreman and a number of specialist foremen with their own working personnel under them. Here the specialist foreman executed maintenance work in their respect areas while the general foreman supervised the total work under his control. Following shows a typical line organization.



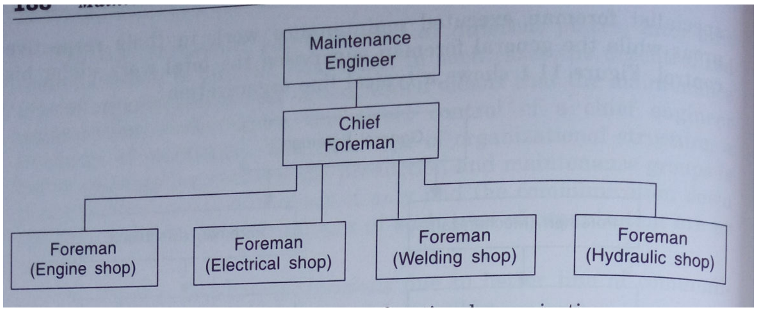
Line organization

Realizing the need of recording the maintenance work, a few staff members when introduced in the line organization form a line-staff organization as shown below.



Line-staff organization

In the recent past, the maintenance organization was based on craft concept. The persons joined the organization as apprentices and rose to the higher positions (foreman) after accumulating sufficient experience in their jobs. However, these persons were never given a formal training of the foreman's job. Such an organization emphasized craft skills and therefore strongly supported the idea of specialization gained through skills. Further growth in the field of maintenance function led to the concept of functional organization that was purely based on craft organization. In this system a few workers are placed under each functional foreman as shown in below.



Maintenance functional organization

MAINTENANCE BUDGETING

A budget is a financial plan, forecast of expenditure and revenues for a specified period of time. In other words, a budget is the some of money allocated for a particular purpose and the summary of intended expenditures along with proposal for how to meet them.

To control maintenance costs, budgeting og maintenance cost is very important because maintenance is a service organization and probably no better way is available to control its cost.

Types of Maintenance Budgeting

Maintenance budget are of two types and they are Revenue and Capital.

If it is further classified, following three types can be observed.

(i) Appropriation budgets: Which sets a lumpsum as the maximum amount that can be spent for a given item.

(ii) Fixed budget: Which specifies the allowable amount of cost for a period of time.

(iii) Flexible budget: Which relates the allowable cost to some measure of activity.

Preparation of Maintenance Budget

In preparation of maintenance budget, usually three basic approaches are used and they are as follows:

(i) Allocate revenue and expenses using top-down/bottom up, (or) Production/maintenance Schedule Approach.

(ii) Labour Allocation Approach.

(iii) Integrated approach.

All these three approaches are self explanatory. Individually the production or maintenance approach and labour allocation approach may not be very precise as working alone. Both approaches may face some uncertainties such as hidden waiting time from one process to another, variation in skill requirements and skill available etc. Due to this, a combination of integrated approach is often used for preparation of the maintenance budget. It includes some cash budget for contingent expenditures which may come up unexpectedly.

Advantages of Maintenance Budgeting

i. It improves the system effectiveness and also increase the efficiency of maintenance organization.

ii. As maintenance personnel know their budget in advance, they can plan their expenditures judiciously and timely so that no job is held Up for shortage of funds.

iii. It is very effective technique for projecting future as well as additional requirements of fund.

MANPOWER PLANNING FOR MAINTENANCE

- The most valuable and unique resource for an industry is the manpower resource. Thus, manpower is the key economic resource which should be paid the same attention as is paid to finance, raw materials, equipment, production, sales, investments, profit and maintenance functions.
- Manpower planning is a process wherein the demand and supply of labour are equated. To maximize the profit of an industry, capital and labour must be managed properly.
- An industry must determine the requirement of manpower for the overall life of the industry based on the price of labour and nature of the work.
- It is necessary to findout what type of manpower will be recruited and what time during the life of the industry.
- The first step in the manpower planning process is to establish the planning horizon ie, the future period for which the manpower will apply.
- The demand for labour services should remain matched the supply of labour services over this period.
- Often the difference between the estimates of demand and supply of labour services is referred to as the manpower gap.
- The main components of manpower strategy is to formulate plans for closing the manpower gap by recruitment and training or by planned redundancy.

Objectives of Manpower Planning

The objectives of manpower planning are as follows:

(i) Optimum Productivity: Skilled and qualified workers, through the manpower planning help an organization to achieve optimum utilization of human potential, which will result in optimum productivity.

(ii) Reduction in Labour cost: Effective use of manpower and optimum productivity will reduce the wastage and thereby reduce the labour cost.

(iii) Effective Requirement and selection: Right person can be placed at the right job and at right time through manpower planning.

(iv) To maximize individua development.

(v) To develop the future training and management development needs.

(vi) To avoid the staff surplus and unnecessary dismissals in the manpower planning.

Stages of Manpower Planning

Maintenance planning involves the following stages.

I. Defining the overall maintenance objectives for the stated period ahead.

II. Conversion of these maintenance objectives into manpower objectives for the same period and allowing for changes in the maintenance system, number of equipment etc.

III. Designing of a manpower information system to obtain and processing of data in the most efficient and economical way.

IV. Undertaking a manpower inventory in terms of composition, deployment and utilization by tabulation and careful analysis of the current manpower resources with in the system.

V. Analysis Of manpower requirements or the demand forecast based on the maintenance objective which requires.

a) A decision concerning as to where the maintenance system or the workshop management should concentrate their effort.

b) An assessment of the overall size of the maintenance system.

c) Estimation of the resources needed by the system.

d) Formation of advance maintenance plans.

e) Detailed targets of each management level.

COMPUTERIZEC MAINTENANCE MANAGEMENT SYSTEM

Computerized maintenance management system (CMMS), also known as computerized maintenance management information system (CMMIS), is a software package that maintains a computer database of information about an organization's maintenance operations.This information is intended to help maintenance workers do their jobs more effectively (for example, determining which machines require maintenance and which storerooms contain the spare parts they need) and to help management make informed decisions (for example, calculating the cost of machine breakdown repair versus preventive maintenance for each machine, possibly leading to better allocation of resources). CMMS data may also be used to verify regulatory compliance.

CMMS packages may be used by any organization that must perform maintenance on equipment, assets and property. Some CMMS products focus on particular industry sectors (e.g. the maintenance of vehicle fleets or health care facilities). Other products aim to be more general.

CMMS packages can produce status reports and documents giving details or summaries of maintenance activities. The more sophisticated the package, the more analysis facilities are available.

Many CMMS packages can be either web-based, meaning they are hosted by the company selling the product on an outside server, or LAN based, meaning that the company buying the software hosts the product on its own server.

- A computer-aided maintenance management system (CMMS) is a type of management software that performs functions in support of management and tracking of operations and maintenance activities.
- The main objective of CMMS can be said to move ‘to a planned environment and allow for further progression along the maintenance evolutionary path.
- In recent days, CMMS encompasses alla aspects of maintenance including preventive and predictive maintenance tracking, inventory usage tracking, failure tracking, RCM, TPM, EAM, vendor management, documentation analysis and system integration etc.

- Work orders are generated by CMMS automatically according to a schedule or manually from service request.
- A properly used and set up CMMS is considered as a powerful tool forlenhancing reliability efforts and improving Return On Investment (ROI). On the other hand, an improperly setup or improperly used CMMS can have an equally negative impact on reliability and ROI.

Functions of CMMS

A computer aided maintenance management system carries out the following functions.

(i) To build a plant asset information database

To obtain maximum value of a CMMS, a core foundation of trusted data must be available each and every time the system is used. System administrations strive to have high data integrity from the outside of its CMMS implementation. From a well implemented maintenance management system, improved overall maintenance efficiency, compliance, safety and plant availability can be achieved.

(ii) Fault Prediction

CMMS is also used to carry-out proactive failure prediction through continuous monitoring of systems. Based on board equipment or within the data collection stream, it sends notifications about potential problems that could lead to failure or other undesirable operating conditions. By integrating with current system monitoring allows to identify needed maintenance based on machine behaviour and to recognize potential problems before they occur. It also provides solutions by comparing new information with historical records to make intelligent recommendations based on past performance.

(iii) Expert System Diagnostic Methodology

CMMS also enables diagnostics through expert system.

Factors Affecting Selection of CMMS

Some of the basic points that need to be considered for selection of CMMS in any kind of industry are as follows:

(i) Compatibility with existing hardware or operating system.

(ii) Compatibility with previous CMMS or other maintenance software.

(iii) General reputation of software and its vendor.

(iv) Integration with other commercial and technical software.

(v) Cost of implementation, including cost of purchase and consultants.

(vi) Availability in local language version.

(vii) Ease of implementation and ease of use.

(viii) Availability of local support and training facility.

(ix) Multiple system interface, consistency between multiple sites.

(x) Extensive Management reporting capabilities.

(xi) Support regulatory compliance.

Advantages of CMMS

Some of the benefits of CMMS are as follows:

1. Reduction in other costs and improved cost control.
2. Improved equipment availability and reliability.
3. Enhanced transparency and accountability.
4. Longer asset or machine life cycle.
5. Conformity with health and safety Standard.
6. Quicker access to Plant maintenance.
7. Compliance with industry and statutory regulatory standards. etc.

MAINTENANCE INTEGRATION

In recent days, the outlook for manufacturing appears relatively bright. However, some of the challenges are expensive investments in new facilities, increase in international competitions etc. Due to this reason, manufacturers look for holding the processes by improving their efficiencies. One of such attempts is integration of maintenance functions with engineering, procurement and overall supply chain management.

Various Steps in Integration

There are several steps involved in maintenance integration and they are

i. Aligning of the engineering and maintenance functions under production umbrella.
ii. Involvement of maintenance staff early in the concept and design phase itself.
iii. Awareness to production or machine specification.
iv. Third Party consultancy assistance.
v. Integration of e-business software with enterpricse resourse planning packages, like SAP.
vi. Integration of CMMS with process control data.
vii. Periodical meetings, once in a weak or months between various departments in the organization.

Some of these are discussed as follows:

Aligning of the Engineering and Maintenance Functions under Production Umbrella

Increasing efficiencies in maintenance and engineering functions is a first step toward improvement, which can be achieved by more closely aligning the maintenance and engineering activities with engineering activities within production operation. Most manufacturers facilitate collaboration between maintenance function and engineering, although companies have traditionally managed each seperately.

Involvement of Maintenance Staff Early Concept and Design Phase itself

By involving engineering and maintenance support engineeers during the product design, development, manufacture installation, operation phases at any project, the long-standing problems can be overcome. For designing and optimally maintaining production equipment, active participation from both the groups is very effective.

Awareness to Production/Machine Specification

When any problem occurs in any machine or equipment in an industry, maintenance team often repairs the equipment to its most recent production levels but not to the machine’s optimal design capacity. Thus, maintenance teams should compare their equipment’s actual productivity with the project engineer’s original design specifications to maximize its operating potential.

Third Party Consultancy Assistance

To help the maintenance and engineering staffs collaborate more effectively, third party consultants are used by many manufacturers to prov1de the 1ns1ght into opportunities for process improvements and synergies.

Integration of e-business software with Enterprise Resource Planning Packages like SAP

- ➔ Integration of e-business plant maintenance solutions with SAP systems provides the suppu chain functionality neeeded by large maintenance driven organizations while providing all of the transaction details required for complte financial control.
- ➔ Various industries use third party software integrator to develop an integration solution, that connects software to SAP to pull together the key elements. of work management and supply chain.
- ➔ This best-of-breed solution ensures that all requirements for procurement life cycle data and static data sharing between systems are met.
- ➔ With the e-business plant maintenance software SAP integration solution, business achieves the critical business benefits including:

1. Maximizing returns on asset.
2. Improving throughput.
3. Creating workforce efficiencies.
4. Satisfying regulatory compliance while assuring proper financial accounting.

Scheme of integration of maintenance function with other functions

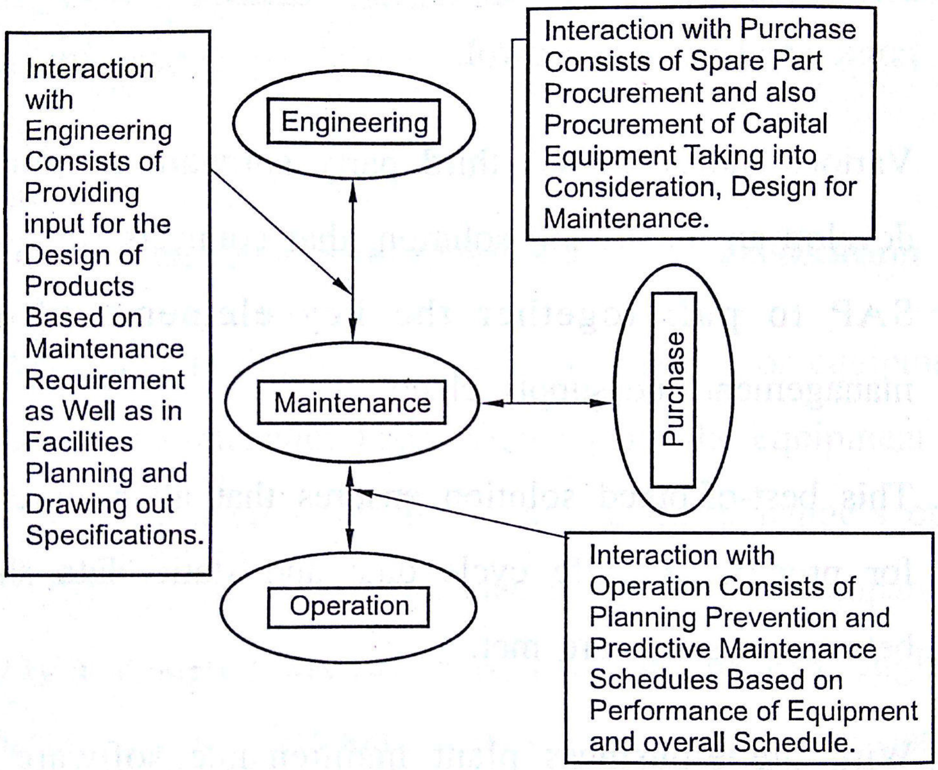


Fig. 6.4: Scheme for Integration of Maintenance Function with other Functions.