A Course Material on

Maintenance Engineering

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TEXT BOOKS

1. **Srivastava, S.K., "Industrial Maintenance Management", S. Chand and Co., 1981.**
2. **Bhattacharya, S.N., "Installation, Servicing and Maintenance", S. Chand and Co., 1995.**

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1. **Garg, M.R., "Industrial Maintenance", S. Chand and Co., 1986.**
2. **Higgins, L.R., "Maintenance Engineering Handbook", 5th Edition, McGraw Hill, 1988.**
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UNIT-1

PRINCIPLES AND PRACTICES OF MAINTENANCE PLANNING

1.1.Maintenance Engineering

1.1.1.Introduction

- Maintenance Engineering is the discipline and profession of applying engineering concepts to the optimization of equipment, procedures, and departmental budgets to achieve better maintainability, reliability, and availability of equipment.

- Maintenance engineering is the occupation that uses engineering theories and practices to plan and implement routine maintenance of equipment and machinery.
- This must be done in conjunction with optimizing operating procedures and budgets to attain and sustain the highest levels of reliability and profit.
- Maintenance engineers are often required to have knowledge of many types of equipment and machinery.
- A person working in the field of maintenance engineering must have in-depth knowledge of or experience in basic equipment operation, logistics, probability, and statistics.
- Experience in the operation and maintenance of machinery specific to a company's particular business is also frequently required.
- Since the position normally requires oral and written communications with various levels of personnel, excellent interpersonal communication and participatory management skills are also desirable.
- Maintenance engineering positions require planning and implementing routine and preventive maintenance programs.
- In addition, regular monitoring of equipment is required to visually detect faults and impending equipment or production failures before they occur.
- These positions may also require observing and overseeing repairs and maintenance performed by outside vendors and contractors.
- In a production or manufacturing environment, good maintenance engineering is necessary for smooth and safe daily plant operations.
- Maintenance engineers not only monitor the existing systems and equipment, they also recommend improved systems and help decide when systems are outdated and in need of replacement.
- Such a position often involves exchanging ideas and information with other maintenance engineers, production managers, and manufacturing systems engineers.
- Maintenance engineering not only requires engineers to monitor large production machine operations and heavy duty equipment, but also often requires involvement with computer operations.
- Maintenance engineers may have to deal with everything from PCs, routers, servers, and software to more complex issues like local and off-site networks, configuration systems, end user support, and scheduled upgrades. Supervision of technical personnel may also be required.
- Good maintenance engineering is vital to the success of any manufacturing or processing operation, regardless of size.
- The maintenance engineer is responsible for the efficiency of daily operations and for discovering and solving any operational problems in the plant.
- A company's success may depend on a **quality maintenance engineering department** that can be depended upon to discover systematic flaws and recommend solid, practical solutions.

1.1.2. Maintenance Manager

- If you choose to take an entry-level position in order to become a facilities **maintenancemanager**, you can expect to spend several years working **maintenance** positions as you learn the skills necessary to become a **manager**.
- Larger employers with greater **maintenance** needs generally look for a facilities **maintenancemanager** who can perform these tasks when needed, but is more focused on managing an in-house staff responsible for the majority of the actual work.

1.1.3.Maintenance Engineering Jobs

- Typically, **maintenance** engineers need to possess knowledge of the principles of building or mechanical **engineering**. **Maintenance** engineer **jobs** generally require the person to maintain the plant or manage a crew who maintains it.
- They also set schedules, hand out paychecks, assign **job** duties, and monitor daily progress. Most construction **engineeringjobs** require at least a bachelor's degree in civil **engineering** or project management.

1.1.4.Definition of Maintenance

- Maintenance is the routine and recurring process of keeping a particular machine or asset in its normal operating conditions.So that it can deliver the expected performance or service without any loss or damage. Or

Maintenance is defined as

- All actions necessary for retaining an item, or restoring to it, a serviceable condition, include servicing, repair, modification, overhaul, inspection and condition verification
- Increase availability of a system
- Keep system's equipment in working order

1.1.5.Purpose of Maintenance

- Attempt to maximize performance of production equipment efficiently and regularly
- Prevent breakdown or failures
- Minimize production loss from failures
- Increase reliability of the operating systems

1.1.6.Principle Objectives in Maintenance

- To achieve product quality and customer satisfaction through adjusted and serviced equipment
- Maximize useful life of equipment
- Keep equipment safe and prevent safety hazards
- Minimize frequency and severity of interruptions
- Maximize production capacity – through high utilization of facility

1.1.7.Problems in Maintenance

- Lack of management attention to maintenance
- Little participation by accounting in analyzing and reporting costs
- Difficulties in applying quantitative analysis
- Difficulties in obtaining time and cost estimates for maintenance works
- Difficulties in measuring performance

Problems Exist Due To:

- Failure to develop written objectives and policy
- Inadequate budgetary control
- Inadequate control procedures for work order, service requests etc.
- Infrequent use of standards
- To control maintenance work
- Absence of cost reports to aid maintenance planning and control system

Maintenance Costs

- Cost to replace or repair
- Losses of output
- Delayed shipment
- Scrap and rework

1.2. Basic Principles of maintenance planning

1.2.1.Maintenance Planning

Effective planning and scheduling contribute significantly to the following:

- Reduced maintenance cost.
- Improved utilization of the maintenance workforce by reducing delays and interruptions.
- Improved quality of maintenance work by adopting the best methods and procedures and assigning the most qualified workers for the job.

1.2.2. Planning Objectives

- Minimizing the idle time of maintenance workers.
- Maximizing the efficient use of work time, material, and equipment.
- Maintaining the operating equipment at a responsive level to the need of production in terms of delivery schedule and quality.
-

Classification of Maintenance Work According to Planning Purposes

- Routine maintenance: are maintenance operations of a periodic nature. They are planned and scheduled and in advance. They are covered by blanket orders.
- Emergency or breakdown maintenance: interrupt maintenance schedules in order to be performed. They are planned and scheduled as they happened.
- Design modifications: are planned and scheduled and they depend on eliminating the cause of repeated breakdowns.
- Scheduled overhaul and shutdowns of the plant: planned and scheduled in advanced.
- Overhaul, general repairs, and replacement: planned and scheduled in advanced.
- Preventive maintenance: planned and scheduled in advanced.
- An essential part of planning and scheduling is to forecast future work and to balance the workload between these categories.
- The maintenance management system should aim to have over 90% of the maintenance work planned and scheduled.

1.2.3. Planning Procedures

- Determine the job content.
- Develop work plan. This entails the sequence of the activities in the job and establishing the best methods and procedures to accomplish the job.

- Establish crew size for the job.
- Plan and order parts and material.
- Check if special tools and equipment are needed and obtain them.
- Assign workers with appropriate skills.
- Review safety procedures.
- Set priorities for all maintenance work.
- Assign cost accounts.
- Complete the work order.
- Review the backlog and develop plans for controlling it.
- Predict the maintenance load using effective forecasting technique.
-

1.2.4.Basic Levels of Planning Process (Depend on The Planning Horizon)

1. Long-rang planning: it covers a period of 3 to 5 years and sets plans for future activities and long-range improvement.
2. Medium-range planning: it covers a period of 1 month to 1 year.
3. Short-rang planning: it covers a period of 1 day to 1 week. It focuses on the determination of all the elements required to perform maintenance tasks in advance.

1.2.4.1.Long Range Planning

Needs to utilize the following:

1. Sound forecasting techniques to estimate the maintenance load.
2. Reliable job standards times to estimate staffing requirements.
3. Aggregate planning tools such as linear programming to determine resource requirements.

sets plans for future activities and long-range improvement.

1.2.4.2. Medium-Range Planning

- Specify how the maintenance workers will operate.
- Provide details of major overhauls, construction jobs, preventive maintenance plans, and plant shutdowns.
- Balances the need for staffing over the period covered.
- Estimates required spare parts and material acquisition.

1.2.4.3. Short-Range Planning

It focuses on the determination of all the elements required to perform maintenance tasks in advance.

1.3. Objectives and Principles of Planned Maintenance Activity

Analysis of repetitive equipment failures.

Estimation of maintenance costs and evaluation of alternatives.

Forecasting of spare parts.

Assessing the needs for equipment replacements and establish replacement programs when due application of scheduling and project management principles to replacement programs.

Assessing required maintenance tools and skills required for efficient maintenance of equipment.

Assessing required skills required for maintenance personnel.

Reviewing personnel transfers to and from maintenance organizations assessing and reporting safety hazards associated with maintenance of equipment.

1.4. Importance and benefits of sound Maintenance systems

Minimization of down time
Life of equipment
Safety and smooth operation
Backup Supply
Reliability
Working environment
profit

1.5.1.Maintenance organization

- Organizing is the process of arranging resources (people, materials, technologyetc.) together to achieve the organization's strategies and goals.
- The way in which the various parts of an organization are formally arranged is referred to as the organization structure.
- It is a system involving the interaction of inputs and outputs.

- However, there is no universally accepted methodology for designingmaintenance systems, *i.e.*, no fully structured approach leading to an optimalmaintenance system (*i.e.*, organizational structure with a defined hierarchy ofauthority and span of control; defined maintenance procedures and policies, *etc.*).Identical product organizations, but different in technology advancement andproduction size, may apply different maintenance systems and the differentsystems may run successfully.
- So, maintenance systems are designed usingexperience and judgment supported by a number of formal decision tools andtechniques.
- Maintenance managers must have the capabilities to create a division of laborfor maintenance tasks to be performed and then coordinate results to achieve acommon purpose.
- Solving performance problems and capitalizing on opportunitiescould be attained through selection of the right persons, with the appropriatecapabilities, supported by continuous training and good incentive schemes, in orderto achieve organization success in terms of performance effectiveness andefficiency..

1.5.2.Maintenance Organization Objectives and Responsibility

A maintenance organization and its position in the plant/whole organization is heavily impacted by the following elements or factors:

- Type of business, *e.g.*, whether it is high tech, labor intensive, production or service;
- Objectives: may include profit maximization, increasing market share and other social objectives;
- Size and structure of the organization;
- Culture of the organization; and
- Range of responsibility assigned to maintenance.

Organizations seek one or several of the following objectives: profit maximization, specific quality level of service or products, minimizing costs, safe and clean environment, or human resource development. It is clear that all of these objectives are heavily impacted by maintenance and therefore the objectives of maintenance must be aligned with the objectives of the organization.

The principal responsibility of maintenance is to provide a service to enable an organization to achieve its objectives. The specific responsibilities vary from one organization to another; however they generally include the following according to Duffuaa *et al.* (1998):

1. Keeping assets and equipment in good condition, well configured and safe to perform their intended functions;
2. Perform all maintenance activities including preventive, predictive; corrective, overhauls, design modification and emergency maintenance in an efficient and effective manner;
3. Conserve and control the use of spare parts and material;
4. Commission new plants and plant expansions; and
5. Operate utilities and conserve energy.

The above responsibilities and objectives impact the organization structure for maintenance as will be shown in the coming sections.

1.5.3.Determinants of a Maintenance Organization

The maintenance organization's structure is determined after planning the maintenance capacity. The maintenance capacity is heavily influenced by the level of centralization or decentralization adopted. In this section the main issues that must be addressed when forming the maintenance organization's structure are presented. The issues are: capacity planning, centralization *vs* decentralization and in-house *vs* outsourcing.

1.5.4.Maintenance Capacity Planning

Maintenance capacity planning determines the required resources for maintenance including the required crafts, administration, equipment, tools and space to execute the maintenance load efficiently and meet the objectives of the maintenance department. Critical aspects of maintenance capacity are the numbers and skills of craftsmen required to execute the maintenance load. It is difficult to determine the exact number of various types of craftsmen, since the maintenance load is uncertain. Therefore accurate forecasts for the future maintenance work demand are essential for determining the maintenance capacity. In order to have better utilization of manpower, organizations tend to reduce the number of available craftsmen below their expected need. This is likely to result in a backlog of uncompleted maintenance work. Maintenance Organization 7

1.5.5. Centralization *vs* Decentralization

The decision to organize maintenance in a centralized, decentralized or a hybrid form depends to a greater extent on the organization is philosophy, maintenance load, size of the plant and skills of craftsmen. The advantages of centralization are:

1. Provides more flexibility and improves utilization of resources such highly skilled crafts and special equipment and therefore results in more efficiency;
2. Allows more efficient line supervision;
3. Allows more effective on the job training; and
4. Permits the purchasing of modern equipment.

disadvantages:

1. Less utilization of crafts since more time is required for getting to and from jobs;
2. Supervision of crafts becomes more difficult and as such less maintenance control is achieved;
3. Less specialization on complex hardware is achieved since different persons work on the same hardware; and
4. More costs of transportation are incurred due to remoteness of some of the maintenance work.

In a decentralized maintenance organization, departments are assigned to specific areas or units. This tends to reduce the flexibility of the maintenance system as a whole. The range of skills available becomes reduced and manpower utilization is usually less efficient than in a centralized maintenance. In some cases a compromise solution that combines centralization and decentralization is better. This type of hybrid is called a cascade system. The cascade system organizes maintenance in areas and whatever exceeds the capacity of each area is challenged to a centralized unit. In this fashion the advantages of both systems may be reaped. For more on the advantages and disadvantages of centralization and de- centralization see Duffuaa *et al.* (1998) and Niebel (1994).

1.5.6 In-house *vs* Outsourcing

At this level management considers the sources for building the maintenance capacity. The main sources or options available are in-house by direct hiring, outsourcing, or a combination of in-house and outsourcing. The criteria for selecting sources for building and maintaining maintenance capacity include strategic considerations, technological and economic factors. The following are criteria that can be employed to select among sources for maintenance capacity:

1. Availability and dependability of the source on a long term basis;
2. Capability of the source to achieve the objectives set for maintenance by the organization and its ability to carry out the maintenance tasks;
3. Short term and long term costs;
4. Organizational secrecy in some cases may be subjected to leakage;
5. Long term impact on maintenance personnel expertise; and
6. Special agreement by manufacturer or regulatory bodies that set certain specifications for maintenance and environmental emissions.

Examples of maintenance tasks which could be outsourced are:

1. Work for which the skill of specialists is required on a routine basis and which is readily available in the market on a competitive basis, *e.g.,*:
   - Installation and periodic inspection and repair of automatic fire sprinkler systems;
   - Inspection and repair of air conditioning systems;
   - Inspection and repair of heating systems; and
   - Inspection and repair of main frame computers *etc.*
2. When it is cheaper than recruiting your own staff and accessible at a short notice of time.

The issues and criteria presented in the above section may help organizations in designing or re-designing their maintenance organization.

1.5.7.Design of the Maintenance Organization

A maintenance organization is subjected to frequent changes due to uncertainty and desire for excellence in maintenance. Maintenance and plant managers are always swinging from supporters of centralized maintenance to decentralized ones, and back again. The result of this frequent change is the creation of responsibility channels and direction of the new organization’s accomplishments *vs* the accomplishments of the former structure. So, the craftsmen have to adjust to the new roles. To establish a maintenance organization an objective method that caters for factors that influence the effectiveness of the organization is needed. Competencies and continuous improvement should be the driving considerations behind an organization’s design and re-design.

1.5.8 Current Criteria for Organizational Change

Many organizations were re-designed to fix a perceived problem. This approach in many cases may raise more issues than solve the specific problem (Bradley, 2002). Among the reasons to change a specific maintenance organization's design are:

1. Dissatisfaction with maintenance performance by the organization or plant management;
2. A desire for increased accountability;

4. A desire to minimize manufacturing costs, so maintenance

resources are moved to report to a production supervisor, thereby eliminating the (perceived) need for the maintenance supervisor;

4. Many plant managers are frustrated that maintenance seems slow paced, that is, every job requires excessive time to get done. Maintenance people fail to understand the business of manufacturing, and don't seem to be part of the team. This failure results in decentralization or distribution of maintenance resources between production units; and
5. Maintenance costs seem to rise remarkably, so more and more contractors are brought in for larger jobs that used to get done in-house.

1.5.9 Criteria to Assess Organizational Effectiveness

Rather than designing the organization to solve a specific problem, it is more important to establish a set of criteria to identify an effective organization. The following could be considered as the most important criteria:

1. Roles and responsibilities are clearly defined and assigned;
2. The organization puts maintenance in the right place in the organization;
3. Flow of information is both from top-down and bottom-up;
4. Span of control is effective and supported with well trained personal;
5. Maintenance work is effectively controlled;
6. Continuous improvement is built in the structure;
7. Maintenance costs are minimized; and
8. Motivation and organization culture.

1.5.10. Basic Types of Organizational Models

To provide consistently the capabilities listed above we have to consider three types of organizational designs.

- Entralized maintenance. All crafts and related maintenance functions report to a central maintenance manager as depicted in Figure 1.2. The strengths of this structure are: allows economies of scale; enables in-depth skill development; and enables departments (*i.e.*, a maintenance department) to accomplish their functional goals (not the overall organizational goals). This structure is best suited for small to medium- size organizations. The weaknesses of this structure are: it has slow response time to environmental changes; may cause delays in decision making and hence longer response time; leads to poor horizontal coordination among departments and involves a restricted view of organizational goals.
- Decentralized maintenance. All crafts and maintenance craft support staff report to operations or area maintenance as described in Figure 1.3. The strengths of this structure are that it allows the organization to achieve adaptability and coordination in production units and efficiency in a

  centralized overhaul group and it facilitates effective coordination both within and between maintenance and other departments. The weaknesses of this structure are that it has potential for excessive administrative overheads and may lead to conflict between departments.
- Matrix structure, a form of a hybrid structure. Crafts are allocated in some proportion to

production units or area maintenance and to a central maintenance function that supports the whole plant or organization. The strengths of this matrix structure are: it allows the organization to achieve coordination necessary to meet dual demands from the environment and flexible sharing of human resources. The weaknesses of this structure are: it causes maintenance employees to experience dual authority which can be frustrating and confusing; it is time consuming and requires frequent meetings and conflict resolution sessions. To remedy the weaknesses of this structure a management with good interpersonal skills and extensive training is required.

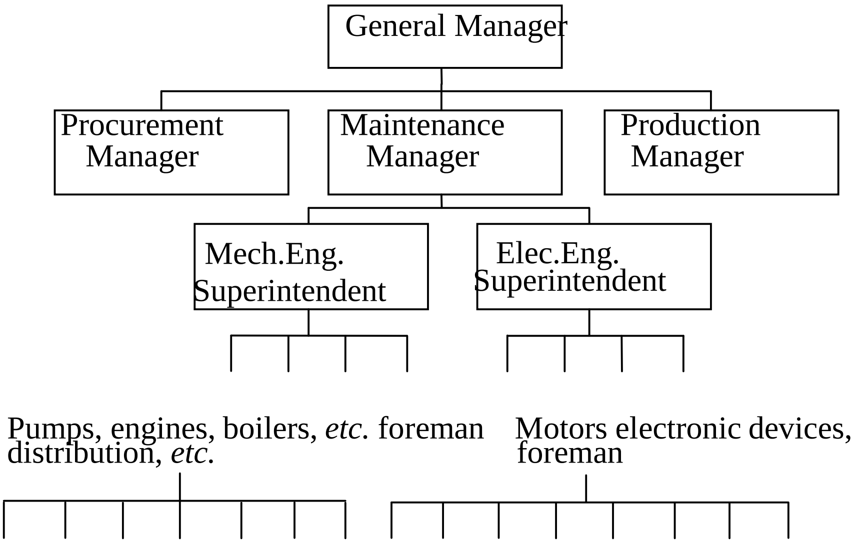


Figure 1.2. Centralized (functional) organizational structure

1.5.11. Material and Spare Parts Management

The responsibility of this unit is to ensure the availability of material and spare parts in the right quality and quantity at the right time at the minimum cost. In large or medium size organizations this unit may be independent of the maintenance organization; however in many circumstances it is part of maintenance. It is a service that supports the maintenance programs. Its effectiveness depends to a large extent on the standards maintained within the stores system. The duties of a material and spare parts unit include:

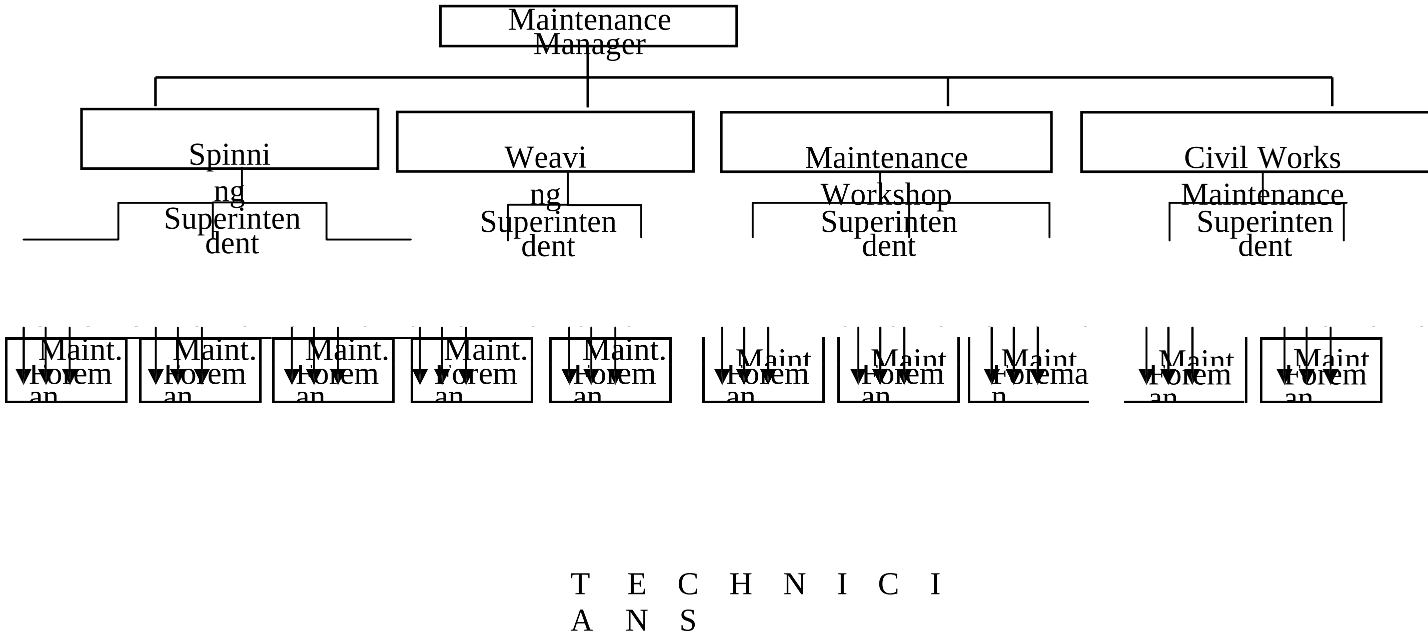


Figure 1.3. Functionally de-centralized organizational structure of maintenance in a textile factory

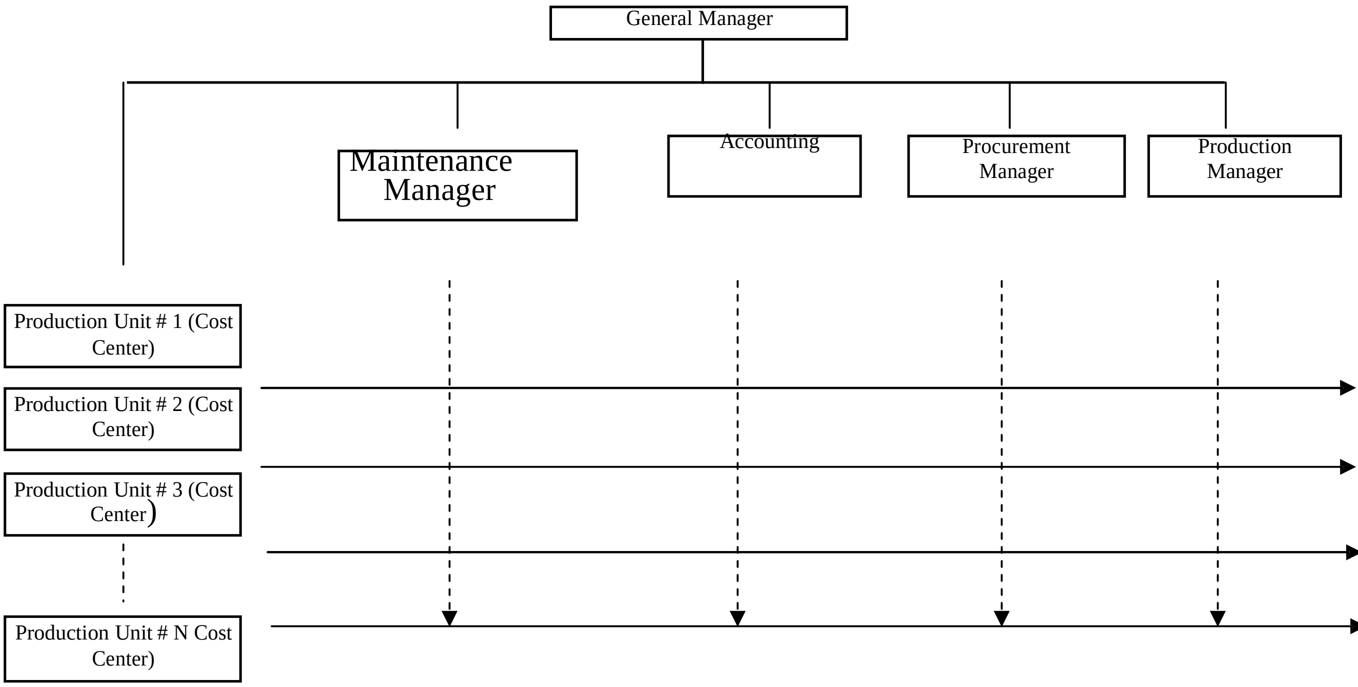


Figure 1.4. Matrix (de-centralized) organizational Structures

1. Develop in coordination with maintenance effective stocking polices to minimize ordering, holding and shortages costs;
2. Coordinate effectively with suppliers to maximize organization benefits;
3. Keep good inward, receiving, and safe keeping of all supplies;
4. Issue materials and supplies;
5. Maintain and update records; and
6. Keep the stores orderly and clean.

1.5.12. Establishment of Authority and Reporting

Overall administrative control usually rests with the maintenance department, with its head reporting to top management. This responsibility may be delegated within the maintenance establishment. The relationships and responsibility of each maintenance division/section must be clearly specified together with the reporting channels. Each job title must have a job description prescribing the qualifications and the experience needed for the job, in addition to the reporting channels for the job.

1.5.13. Quality of Leadership and Supervision

The organization, procedures, and practices instituted to regulate the maintenance activities and demands in an industrial undertaking are not in themselves a guarantee of satisfactory results. The senior executive and his staff must influence the whole functional activity. Maintenance performance can never rise above the quality of its leadership and supervision. From good leadership stems the team- work which is the essence of success in any enterprise. Talent and ability must be recognized and fostered; good work must be noticed and commended; and carelessness must be exposed and addressed.

1.5.14. Incentives

The varied nature of the maintenance tasks, and differing needs and conditions arising, together with the influence of production activity, are not attuned to the adoption of incentive systems of payment. There are, however, some directions in which incentives applications can be usefully considered. One obvious case is that of repetitive work. The forward planning of maintenance work can sometimes lead to an incentive payment arrangement, based on the completion of known tasks in a given period, but care must be taken to ensure that the required standards of work are not compromised. In some case, maintenance incentives can be included in output bonus schemes, by arranging that continuity of production, and attainment of targets, provides rewards to both production and maintenance personnel.

1.5.15. Education and Training

Nowadays it is also recognized that the employers should not only select and place personnel, but should promote schemes and provide facilities for their further education and training, so as to increase individual proficiency, and provide recruits for the supervisory and senior grades. For senior staff, refresher courses comprise lectures on specific aspects of their work; they also encourage the interchange of ideas and discussion.

The further education of technical grades, craft workers, and apprentices is usually achieved through joint schemes, sponsored by employers in conjunction with the local education authority. Employees should be encouraged to take advantage of these schemes, to improve proficiency and promotion prospects.

A normal trade background is often inadequate to cope with the continuing developments in technology. The increasing complexity and importance of maintenance engineering warrants a marked increase in training of machine operators and maintenance craftsmen through formal school courses, reinforced by informed instruction by experienced supervisors.

The organization must have a well defined training program for each employee. The following provides guidelines for developing and assessing the effectiveness of the training program:

- Evaluate current personnel performance;
- Assess training need analysis;
- Design the training program;
- Implement the program; and
- Evaluate the program effectiveness.

The evaluation is done either through a certification program or by assessing the ability to achieve desired performance by persons who have taken a particular training program.

The implementation of the above five steps provides the organization with a framework to motivate personnel and improve performance.

1.5.16. Management and Labor Relations

The success of an undertaking depends significantly on the care taken to form a community of well-informed, keen, and lively people working harmoniously together. Participation creates satisfaction and the necessary team spirit. In modern industry, quality of work life (QWL) programs have been applied with considerable success, in the form of management conferences, work councils, quality circles, and joint conferences identified with the activities. The joint activities help the organization more fully achieve its purposes.

1.5.17. Summary

This chapter considered organizing as one of the four functions of management. It is the process of arranging resources (people, materials, technology, *etc.*) together to achieve the organization’s strategies and goals. Maintenance organization structure is the way various part of the maintenance organization is formed including defining responsibilities and roles of units and individuals. A set of criteria are provided to assess and design organization structures and the main issues to be addressed are outlined. The issues include centralization, decentralization and outsourcing. The chapter describes three types of organization structures. In addition, several functions that could support maintenance organization such as material and spare management, training and the management of labor relations are presented.

1.6.Maintenance economics.

Life cycle cost analysis

Life-cycle cost analysis (LCCA) is a tool to determine the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or process, when each is equally appropriate to be implemented on technical grounds. For example, for a highway pavement, in addition to the initial construction cost, LCCA takes into account all the user costs, (e.g., reduced capacity at work zones), and agency costs related to future activities, including future periodic maintenance and rehabilitation. All the costs are usually discounted and total to a present day value known as net present value (NPV). This example can be generalized on any type of material, product, or system.

In order to perform a LCCA scoping is critical - what aspects are to be included and what not? If the scope becomes too large the tool may become impractical to use and of limited ability to help in decision-making and consideration of alternatives; if the scope is too small then the results may be skewed by the choice of factors considered such that the output becomes unreliable or partisan. Usually the LCCA term implies that energy and environmental costs are included, whereas the similar Whole Life Costing generally has a reduced scope.

Estimation of economic life of equipment

Consider an investment in a machine with an initial purchase price of $1000. The yearly operating costs and salvage value of the machine depend on its age as shown in the table below. We anticipate requiring the use of the machine far into the future. Given that the salvage value is decreasing and operating costs are increasing, there must be some optimal time to replace it. The optimal replacement time is called the economic life of the machine.
Investment analysis recognizes that money spent or earned in the future has less value when viewed from the present. This is called the time value of money principle. We compute the present value of an amount c_n received n years from now as

$P = c_n/(1 + i)^n$

The quantity i is a percentage expressed as a decimal, and is variously called the interest rate, discount rate, or minimum acceptable rate of return. The term $1/(1 + i)^n$, is the discount factor. When i is a positive

quantity the discount factor is less than 1.

"Maintenance costs"

One universal measurement of maintenance performance, and perhaps the measure that matters most in the end, is the cost of maintenance. Unfortunately maintenance costs are often used to compare maintenance performance between companies or between plants within the same company.

Equally unfortunately, there is no standard for measuring maintenance costs. Each company, usually each plant within a company and often each department within a plant develop their own definition of "maintenance costs."

For this reason, maintenance cost comparisons should always be accompanied by a clear definition of what is included and excluded for each plant included in the comparison.

If you are in the process of defining maintenance costs, or believe that your definition needs updating, the following table may be of help.

Type of cost (materials and labor)	**Recommended cost category**
Preventive maintenance	Maintenance

Type of cost (materials and labor)	Recommended cost category
Corrective maintenance (repair or replacement of failed components)	Maintenance (unless its a capital replacement)
Lubrication (a specific PM task)	Maintenance (In some plants this is a Production cost)
Contracted preventive and corrective maintenance	Maintenance
"Maintenance" work done by Production employees. This can included cleaning, inspections, replacement of "production" components (e.g. filter media, etc) and perhaps some lubrication.	Production - but remember to take these costs into account when making comparisons
"Non-working" maintenance labor (e.g. maintenance safety meetings, waiting time, etc)	Maintenance
Maintenance supervision, planning and administration	Maintenance
Non-capital plant improvements. This includes both process and reliability improvements	Probably maintenance, however its a good idea to include an "improvement" category in Work Order codes to allow improvement costs to be identified
Capital improvements and replacements	Capital (but remember that the definition of "capital" also varies widely)
Disposal of obsolete and surplus stock and inventory adjustments (where inventory is working capital)	A special expense account, separate from other costs and not in the maintenance budget

There are other specific activities that may be performed by Maintenance people and these should be considered and defined, such as snow removal, reading utility meters, etc.

A clear definition is important so that cost trends can be identified, which is the "comparison" that is of the greatest value. The definition becomes critical if costs are used as part of an incentive, for example, where maintenance is contracted to an outside company

MAINTENANCE BUDGETING

The need for a maintenance budget arises from the overall budgeting need of corporate management and involves estimation of the cost of the resources (labour, spares etc.) that will be needed in the next financial year to meet the expected maintenance workload. The maintenance life plans and schedule have been laid down to achieve the maintenance objective (which incorporates the production needs, e.g. operating pattern and availability) and in turn generates the maintenance workload.

1.7.RELIABILITY

Reliability may be defined in several ways:

The idea that an item is fit for a purpose with respect to time.

In the most discrete and practical sense: "Items that do not fail in use are reliable" and "Items that do fail in use are not reliable".

The capacity of a designed, produced or maintained item to perform as required over time.

The capacity of a population of designed, produced or maintained items to perform as required over time.

The resistance to failure of an item over time.

The probability of an item to perform a required function under stated conditions for a specified period of time.

In line with the creation of safety cases for safety, the goal is to provide a robust set of qualitative and quantitative evidence that an item or system will not contain unacceptable risk.

The basic sorts of steps to take are to:

First thoroughly identify as many as possible reliability hazards (e.g. relevant System Failure Scenarios item Failure modes, the basic Failure mechanisms and root causes) by specific analysis or tests.

Assess the Risk associated with them by analysis and testing.

Propose mitigations by which the risks may be lowered and controlled to an acceptable level.

Select the best mitigations and get agreement on final (accepted) Risk Levels, possible based on cost-benefit analysis.

AVAILABILITY

A Reliability Program Plan may also be used to evaluate and improve Availability of a system by the strategy on focusing on increasing testability & maintainability and not on reliability.

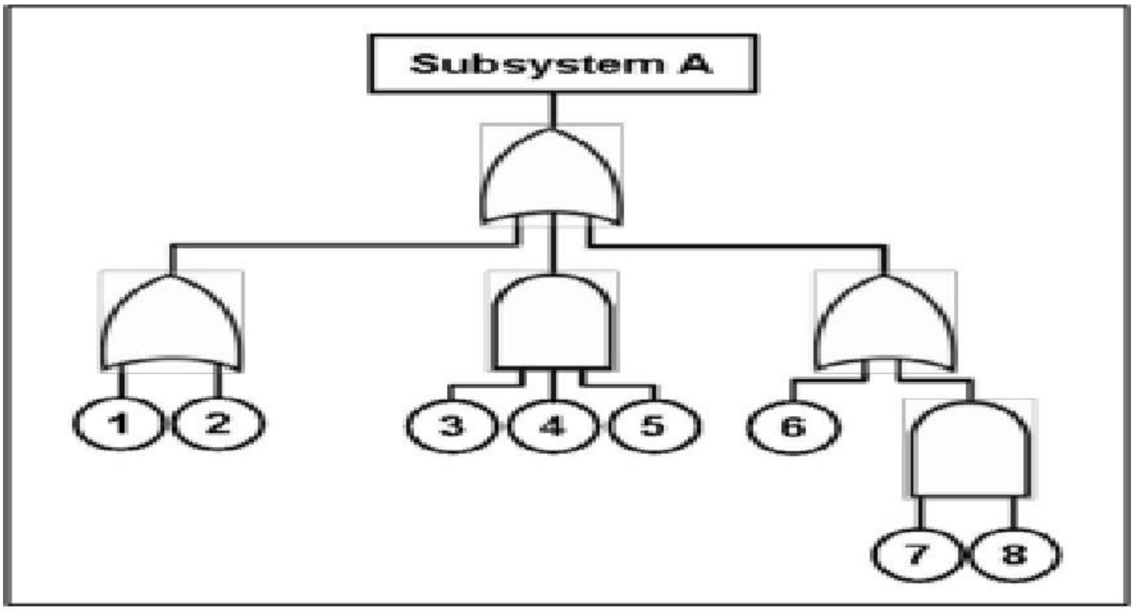
Improving maintainability is generally easier than reliability. Maintainability estimates (Repair rates) are also generally more accurate.

However, because the uncertainties in the reliability estimates are in most cases very large, it is likely to dominate the availability (prediction uncertainty) problem; even in the case maintainability levels are very high.

When reliability is not under control more complicated issues may arise, like manpower (maintainers / customer service capability) shortage, spare part availability, logistic delays, lack of repair facilities, extensive retro-fit and complex configuration management costs and others.

The problem of unreliability may be increased also due to the "**Domino effect**" of maintenance induced failures after repairs.

Only focusing on maintainability is therefore not enough. If failures are prevented, none of the others are of any importance and therefore reliability is generally regarded as the most important part of availability



A Fault Tree Diagram

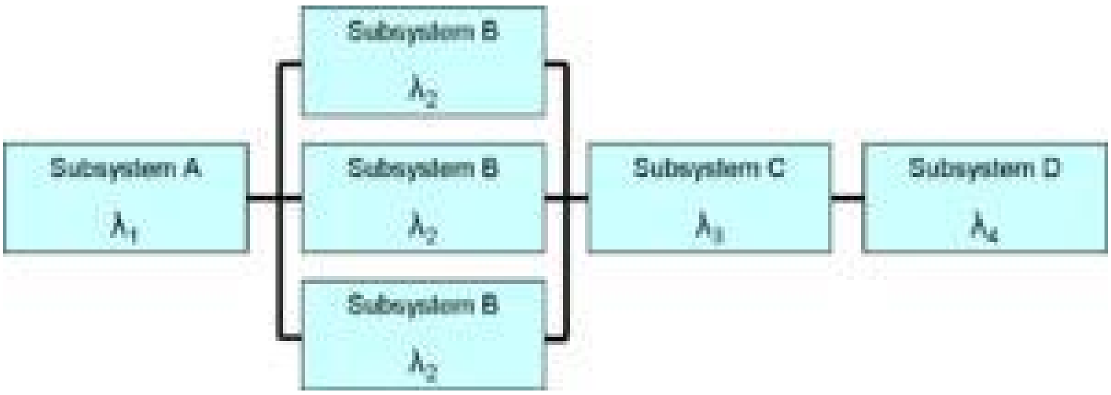
One of the most important design techniques is redundancy.

RELIABILITY THEORY

Reliability is defined as the probability that a device will perform its intended function during a specified period of time under stated conditions. Mathematically, this may be expressed as,

$$R(t) = Pr\{T > t\} = \int_t^{\infty} f(x)\, dx,$$

where $f(x)$ is the failure probability density function and t is the length of the period of time (which is assumed to start from time zero).



ACCELERATED TESTING:

The purpose of accelerated life testing is to induce field failure in the laboratory at a much faster rate by providing a harsher, but nonetheless representative, environment.

In such a test, the product is expected to fail in the lab just as it would have failed in the field—but in much less time.

The main objective of an accelerated test is either of the following:

To discover failure modes.

To predict the normal field life from the high stress lab life.

An Accelerated testing program can be broken down into the following steps:

Software reliability is a special aspect of reliability engineering. System reliability, by definition, includes all parts of the system, including hardware, software, supporting infrastructure (including critical external interfaces), operators and procedures. Traditionally, reliability engineering focuses on critical hardware parts of the system. Since the widespread use of digital integrated circuit technology, software has become an increasingly critical part of most electronics and, hence, nearly all present day systems.

Despite this difference in the source of failure between software and hardware, several software reliability models based on statistics have been proposed to quantify what we experience with software: the longer software is run, the higher the probability that it will eventually be used in an untested manner and exhibit a latent defect that results in a failure (Shooman 1987), (Musa 2005), (Denney 2005).

As with hardware, software reliability depends on good requirements, design and implementation. Software reliability engineering relies heavily on a disciplined software engineering process to anticipate and design against unintended consequences. There is more overlap between software quality engineering and software reliability engineering than between hardware quality and reliability. A good software development plan is a key aspect of the software reliability program. The software development plan describes the design and coding standards, peer reviews, unit tests, configuration management, software metrics and software models to be used during software development.

Define objective and scope of the test

Collect required information about the product

Identify the stress(es)

Determine level of stress(es)

Conduct the accelerated test and analyze the collected data.

MEAN TIME BETWEEN FAILURES

Mean time between failures (MTBF) is the predicted elapsed time between inherent failures of a system during operation. [1] MTBF can be calculated as the arithmetic mean (average) time between failures of a system.

FORMAL DEFINITION OF MTBF

By referring to the figure above, the MTBF is the sum of the operational periods divided by the number of observed failures.

If the "Down time" (with space) refers to the start of "downtime" (without space) and "up time" (with space) refers to the start of "uptime" (without spMean time betMean time between failuresween failuresace), the formula will be:

$$\text{Mean time between failures} = \text{MTBF} = \frac{\sum(\text{start of downtime} - \text{start of uptime})}{\text{number of failures}}.$$

The MTBF is often denoted by the Greek letter θ, or

$$\text{MTBF} = \theta.$$

The MTBF can be defined in terms of the expected value of the density function f(t)

$$\text{MTBF} = \int_0^\infty t f(t)\, dt$$

where f is the density function of time until failure – satisfying the standard requirement of density functions –

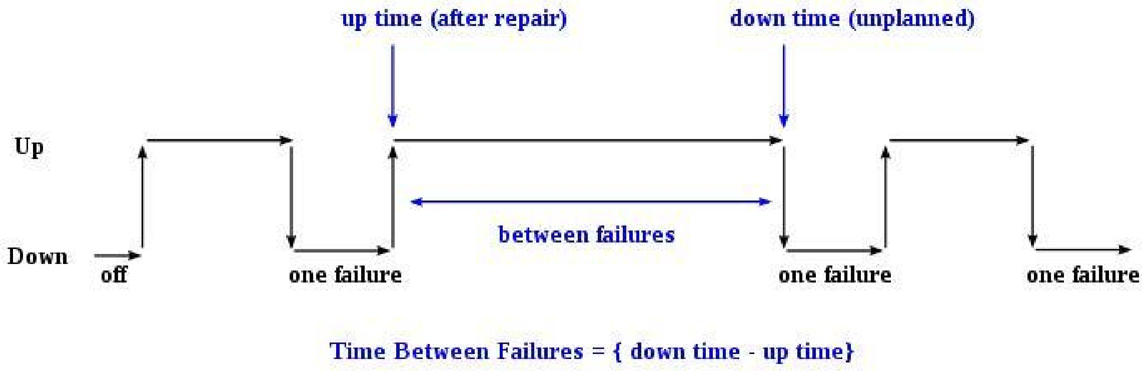
$$\int_0^\infty f(t)\, dt = 1.$$

The Overview

For each observation, downtime is the instantaneous time it went down, which is after (i.e. greater than) the moment it went up, uptime. The difference (downtime minus uptime) is the amount of time it was operating between these two events.

MTBF value prediction is an important element in the development of products. Reliability engineers / design engineers, often utilize Reliability Software to calculate products' MTBF according to various methods/standards (MIL-HDBK-217F, Telcordia SR332, Siemens Norm, FIDES,UTE 80-810 (RDF2000), etc.).

However, these "prediction" methods are not intended to reflect fielded MTBF as is commonly believed. The intent of these tools is to focus design efforts on the weak links in the design



MTTR

MTTR is an abbreviation that has several different expansions, with greatly differing meanings.

It is wise to spell out exactly what is meant by the use of this abbreviation, rather than assuming the reader will know which is being assumed.

The M can stand for any of minimum, mean or maximum, and the R can stand for any of recovery, repair, respond, or restore.

The most common, mean, is also subject to interpretation, as there are many different ways in which a mean can be calculated.

Mean time to repair

Mean time to recovery/Mean time to restore

Mean time to respond

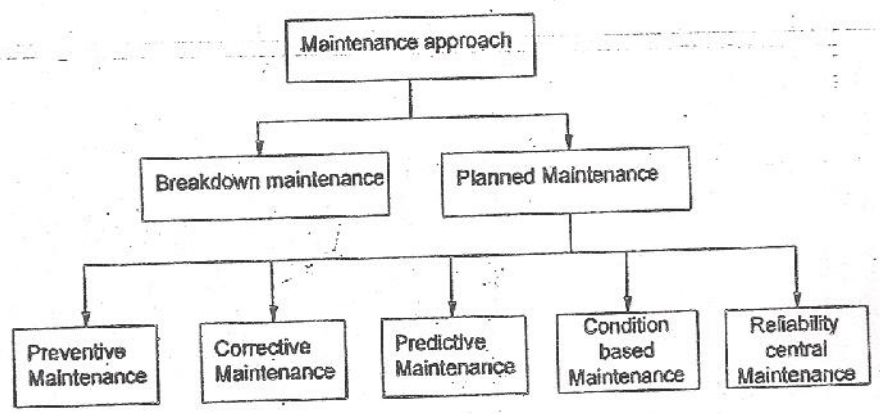
Mean time to replace

In an engineering context with no explicit definition, the engineering figure of merit, mean time to repair would be the most probable intent by virtue of seniority of usage.

It is also similar in meaning to the others above (more in the case of recovery, less in the case of respond, the latter being more properly styled mean "response time").

UNIT II
MAINTENANCE POLICIES – PREVENTIVE MAINTENANCE

2.1 MAINTENANCE CATAGORIES



Basically there are two types of maintenance tasks they are

Breakdown maintenance
Planned maintenance

Planned maintenance may further be classified into

Preventive maintenance
Corrective maintenance
Predictive maintenance
Condition based maintenance
Reliability centered maintenance

Corrective maintenance

The main objectives of this program are to

Eliminate breakdowns
Eliminate deviations from optimum operating conditions
Eliminate unnecessary repairs
Optimize all critical plant systems

Preventive maintenance

It is a maintenance program which is committed to the elimination or prevention of corrective and break down maintenance.

Benefits of preventive maintenance

It maintains the equipment in good condition to preventin them from bigger problems.
Prolongs the effective life of the equipments.
Detects the problem at earlier stages.
Minimize/eliminates the rework/scrap and helps in reducing the process variability.
Significantly reduces unplanned downtime.

Predictive Maintenance

Predictive maintenance is a management technique that uses regular evaluation of the actual operating conditions of the plant equipment.

Benefits of preventive maintenance

Reduced breakdown losses.

Reduction of quality defects.
Increased net operating profit
Reduced maintenance costs

Condition based maintenance techniques

Vibration Monitoring

Determines the actual conditions of equipments/machines by studying the noise or vibration produced during functioning.

Thermography

Determines the condition of plant machinery, systems etc. by studying the emissions of infra red energy i.e. temperature

Reliability Centered maintenance

The rough process of RCM is as follows

1. Target products or systems of maintenance should be clearly identified and necessary data should be collected
2. All possible failures and their effect on target products or systems are systematically analyzed

Application of RCM

When designing, selecting and installing new systems in a plant.

When setting up preventive maintenance for complex equipment and systems for which we are not clear on how they work.

When teaching people the basics of reliability it helps to explain the matters in a detailed fashion using RCM.

2.2.TOTAL PRODUCTIVE MAINTENANCE

TPM is a maintenance program which involves a newly defined concept of maintaining plants and equipments. The goal of TPM program is to significantly increases the production, at the same time increasing employee morale and job satisfaction. TPM philosophically resembles TQM in many aspect such as

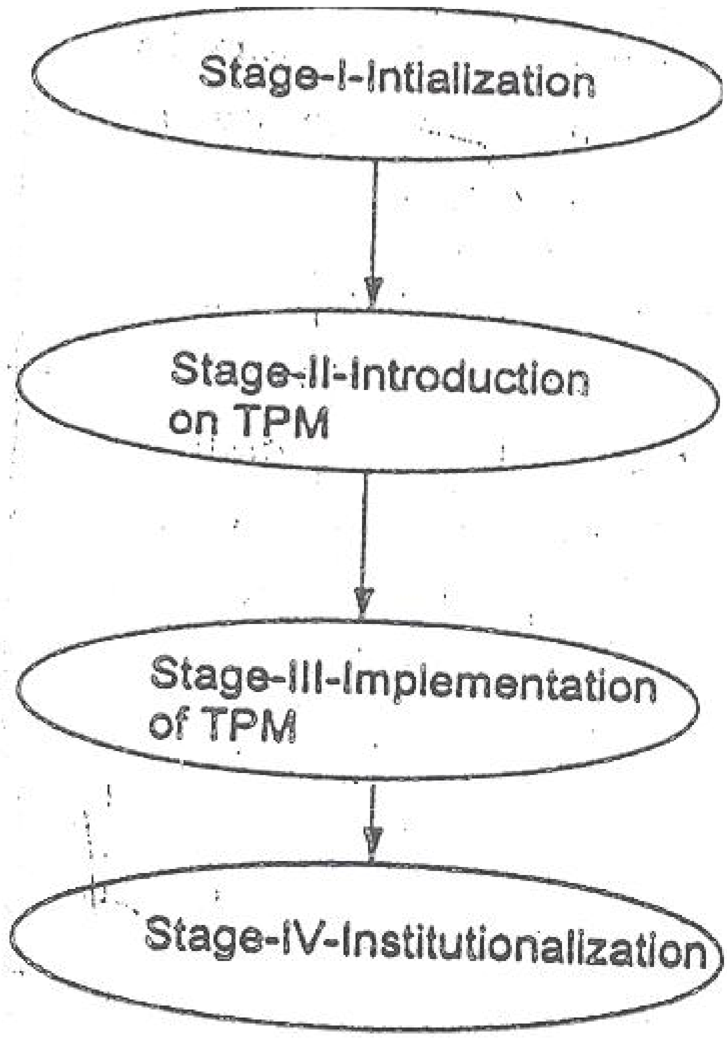
Requirements of commitment by top level management
Requirement of empowering employees to initiate corrective action
Accepting long range plan on any on goin process. The five S principles used for implementations of TPM.

- SEIRI – Sort out
- SEITON –Organize
- SEISO – Shine workplace
- SEIKETSU – Standardization
- SHITSUKE – Self discipline

various pillars of TPM

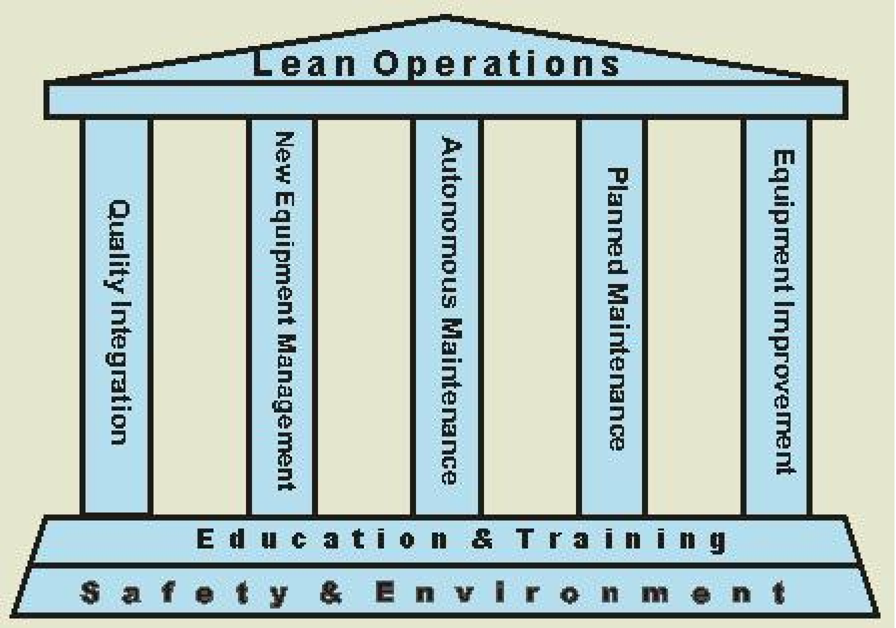
- 5,S Principle
- jishu hozen(JH)
- Kaizen
- planned maintenance
- Quality maintenance.
- training
- office TPM
- Safety, health and environment

Implementation of TPM:



The main objectives of TPM are

- to achieve zero defects
- achieve zero accidents and zero break downs in all functional areas of an organization
- to create different team of people to have active participation.
- To aim at minimization of defects and
- To inculcate autonomous policy.



2.3.STAKEHOLDERS

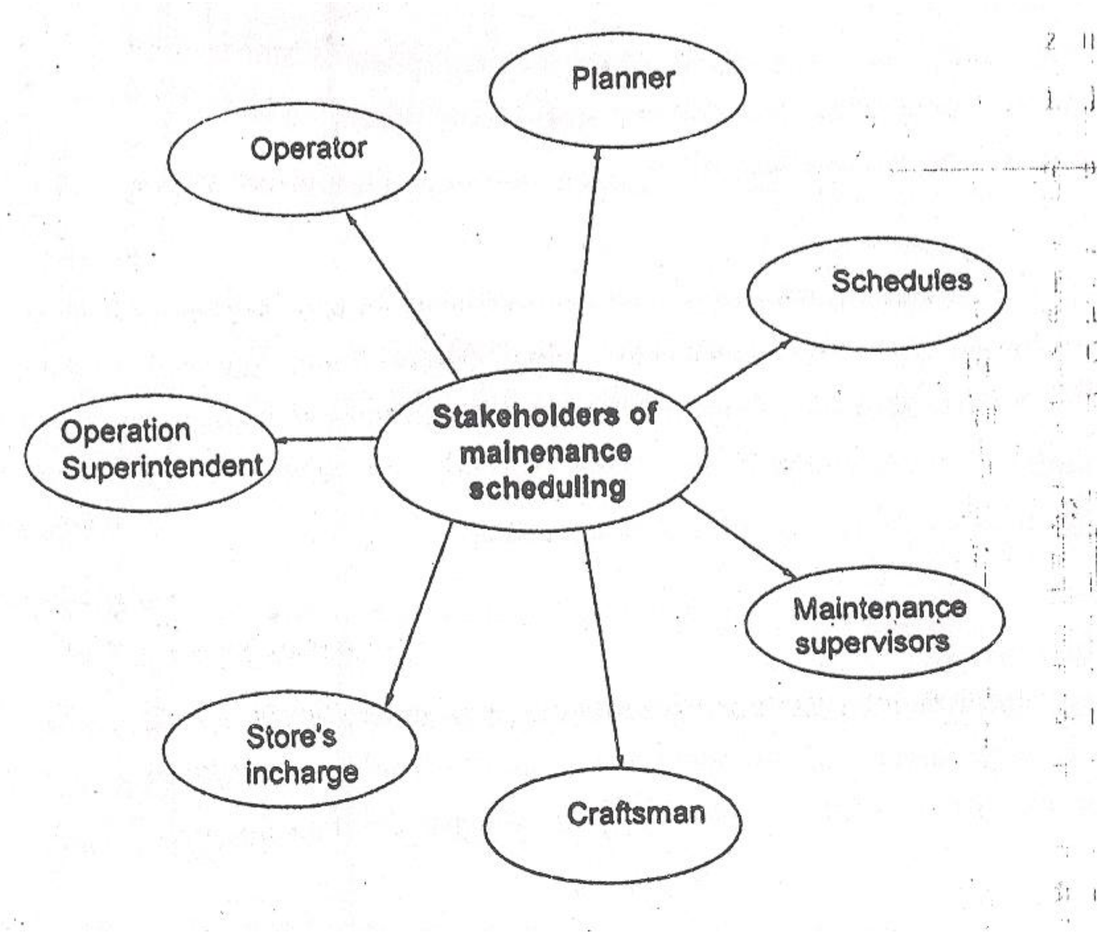
Maintenance scheduling is a joint maintenance operations activity in which maintenance agrees to make the recourses available at a specific time when the unit can also be made available by operations

various stakeholders of maintenance scheduling.

Operators
Planners
Schedulers
Maintenance supervisors
craftsman
Store's in charge
operation superintendent

Planner:

He/She should ensure that the work is properly planned with respect to customer requirements, stores material, directly purchased material and special service mentioned on work order. Also the work to be carried out with the line of safety requirements should be described.



Scheduler:

He/She should ensure that

Trades are available to conduct the work during the schedule duration

Materials and/or service availability

Communicating the details of the above to person involved in maintenance and operations

Maintenance supervisor:

He/She will be the responsible for the day-to-day activities comprised in weekly schedule and also determines the business availability. They attend to specify such as to who-what-where-when.

Craftsman:

He/She executes the assigned task and keep informing the maintenance team, the outcome as well as any practical difficulty in their part, for any further analysis

Storeroom Personnel:

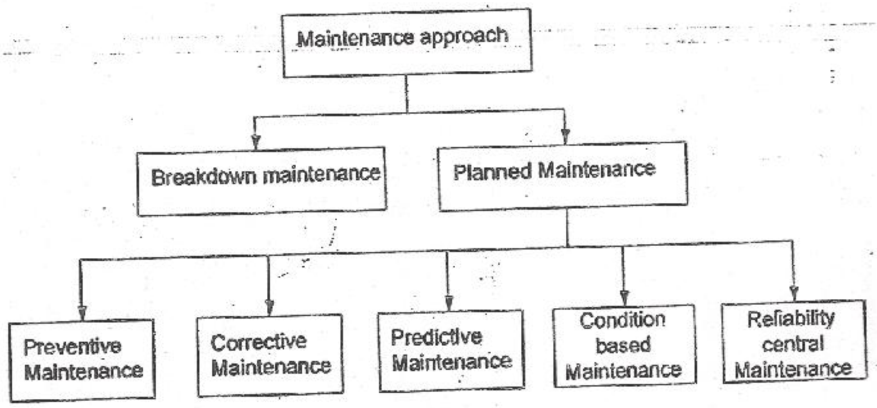
They maintain the records of the receipt of goods and notify if any damages exists.

Operations Superintendent:

He must be kept informed in advance about the equipment condition. Since he is well aware of production schedule, should determine the opportune time with maintenance to release the equipment.

Operator:

He is the person responsible for securing the equipment and report back to the maintenance personnel if any deviation is observed.



JISHU HOZEN Target:

1.Reduce oil consumptionby50%
2.Reduce process time by 50%
3.Increase use of JH by 50%

.

Steps in JISHU HOZEN:

1. Training employees.
2. Initial cleanup of machines.
3. Taking counter measures
4. Fixing tentative JH standards
5. General inspection
6. Autonomous inspection
7. Standardization and
8. Autonomous management.

Training Employees :

The employees should be educated

About TPM, its advantages,

JH advantages and Steps in JH. Also

About the abnormalities in equipments.

Initial cleanup of machines :

Dust, stains, oils and grease are to be removed.

Oil leakage, loose wires, unfastened nits and bolts and worn out parts are the things that have to be taken care while cleaning.

After clean up problems are categorized and suitably tagged. White tags are place where problems can be solved by operators. Pink tag is placed where the aid of maintenance department is needed.

Supervisor and technician should discuss and set a date for implementing step1

Arrange all items needed for cleaning

On the arranged date, employees should clean the equipment completely with the help of maintenance department.

Contents of tag should be transferred to a register.

Area which were inaccessible to be noted down.

Finally, close the open parts of the machine and run the machine.

Counter Measures :

Inaccessible regions had to be reached easily. e.g. If there are many screw to open a fly wheel door, hinge door can be used. Instead of opening a door for inspecting the machine, acrylic sheets can be used.

To prevent work out of machine parts necessary action must be taken.

Machine parts should be modified to prevent accumulation of dirt and dust.

Tentative Standard :

JH schedule has to be made and followed strictly.

Schedule should be made regarding cleaning, inspection and lubrication and it also should include details like when, what and how.

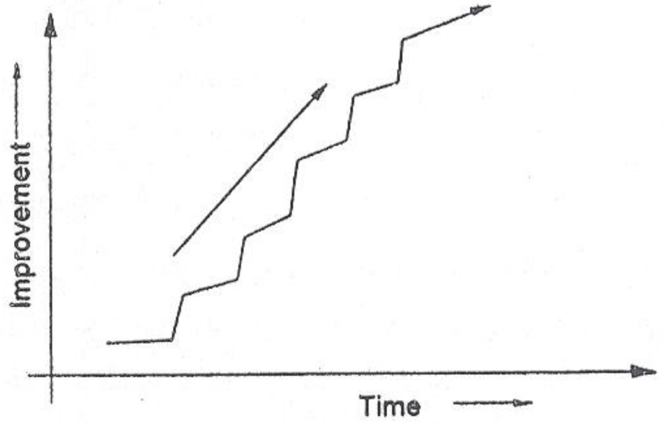
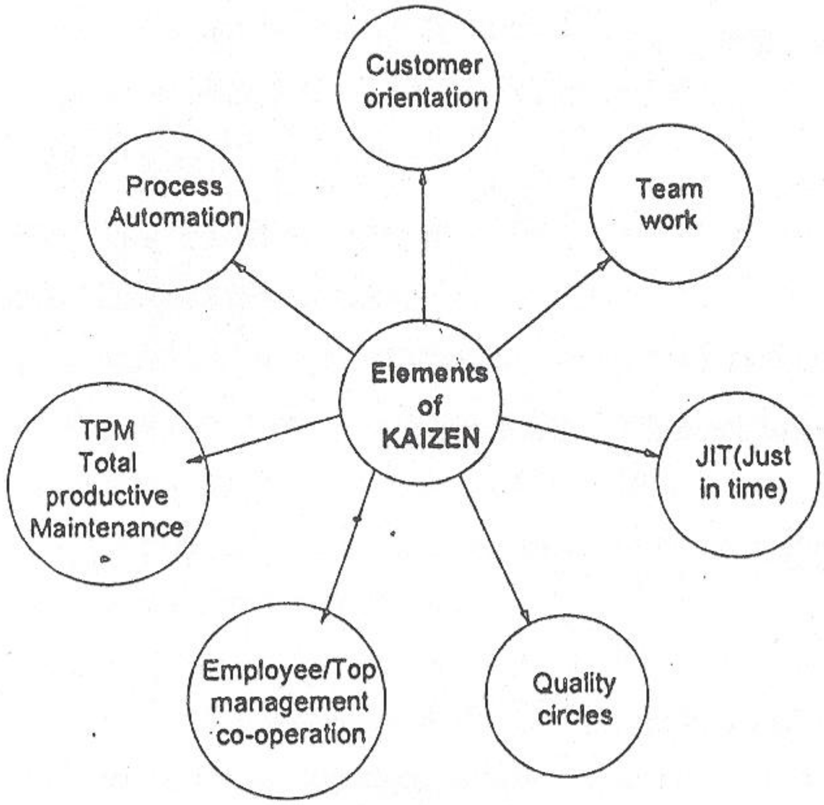


Figure 2.5 Continuous and step-by step improvement



2.4.Maintenance Scheduling

Maintenance scheduling is the process by which jobs are matched with resources (crafts) and sequenced to be executed at certain points in time. The maintenance schedule can be prepared in three levels depending on the horizon of the schedule. The levels are: (1) medium range or master schedule to cover a period of 3 months to 1 year; (2) weekly schedule, it is the maintenance work that covers a week; and (3) the daily schedule covering the work to be completed each day.

		Filled			Date..................	
Equipment		Approval			Priority	
No	Completion	Work Order	Unit	Work description	Crafts	Estimated
.....	....	....	....	....	....	....
.....	....	....	....	....	....	....
.....	....	....	....	....	....	....
.....	....	....	....	....	....	....
.....	....	....	....	....	....	....
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.....	....	....	....	....	....	....
.....	....	....	....	....	....	....

Figure 11.4. An example of a maintenance planning sheet

The medium range schedule is based on existing maintenance work orders including blanket work orders, backlog, preventive maintenance, and anticipated emergency maintenance. It should balance long term demand for maintenance work with available manpower. Based on the long-term schedule, requirements for spare parts and material could be identified and ordered in advance. The long- range schedule is usually subjected to revisions and updating to reflect changes in plans and realized maintenance work.

The weekly maintenance schedule is generated from the medium range schedule and takes account of current operations schedules and economic consideration. The weekly schedule should allow for about 10–15% of the workforce to be available for emergency work. The planner should provide the schedule for the current week and the following one, taking into consideration the available backlog. The work orders that are scheduled for the current week are sequenced based on priority. Critical path analysis and integer programming are techniques that can be used to generate a schedule. In most small and medium sized companies, scheduling is performed based on heuristic rules and experience.

The daily schedule is generated from the weekly schedule and is usually prepared the day before. This schedule is frequently interrupted to perform emergency maintenance. The established priorities are used to schedule the jobs. In some organizations the schedule is handed to the area foreman and he is given the freedom to assign the work to his crafts with the condition that he has to accomplish jobs according to the established priority.

2.5. Elements of Sound Scheduling

Planning maintenance work is a prerequisite for sound scheduling. In all types of maintenance work the following are necessary requirements for effective scheduling:

1. Written work orders that are derived from a well conceived planning process. The work orders should explain precisely the work to be done, the methods to be followed, the crafts needed, spare parts needed and priority.
2. Time standards that are based on work measurement techniques;
3. Information about craft availability for each shift.
4. Stocks of spare parts and information on restocking.
5. Information on the availability of special equipment and tools necessary for maintenance work.
6. Access to the plant production schedule and knowledge about when the facilities may be available for service without interrupting the production schedule.
7. Well-defined priorities for the maintenance work. These priorities must be developed through close coordination between maintenance and production.
8. Information about jobs already scheduled that are behind schedule (backlogs).

The scheduling procedure should include the following steps as outlined by Hartman:

1. Sort backlog work orders by crafts;
2. Arrange orders by priority;
3. Compile a list of completed and carry-over jobs;
4. Consider job duration, location, travel distance, and possibility of combining jobs in the same area;
5. Schedule multi-craft jobs to start at the beginning of every shift;
6. Issue a daily schedule (except for project and construction work); and
7. Have a supervisor make work assignments (perform dispatching).

The above elements provide the scheduler with the requirements and the procedure for developing a maintenance schedule. Next, the role of priority in maintenance scheduling is presented together with a methodology for developing the jobs priorities.

2.6. Maintenance Job Priority System

The maintenance job priority system has a tremendous impact on maintenance scheduling. Priorities are established to ensure that the most critical and needed work is scheduled first. The development of a priority system should be well coordinated with operations staffs who commonly assign a higher priority to

maintenance work than warranted. This tendency puts stress on the maintenance resources and might lead to less than optimal utilization of resources. Also, the priority system should be dynamic and must be updated periodically to reflect changes in operation or maintenance strategies. Priority systems typically include three to ten levels of priority. Most organizations adopt four or three level priorities. Table 11.1 provides classification of the priority level and candidate jobs to be in each class as identified by Duffuaa *et al.* (1999).

Table 11.1. Priorities of maintenance work

Code	Name	Time frame work	Type of work
1	Emergency	Work should start	Work that has an immediate effect on safety, environment, quality,
2	Urgent	Work should start within	Work that is likely to have an impact on safety,
3	Normal	Work should start within	Work that is likely to impact the
4	Scheduled	As scheduled	Preventive maintenance and
5	Postponable	Work should start when resources are	Work that does not have an immediate impact on

2.7. Scheduling Techniques

Scheduling is one of the areas that received considerable attention from researchers as well as practitioners in all types of applications including operations scheduling and project scheduling. Techniques are developed to develop optimum or near optimal schedules with respect to different possible performance measures. This chapter highlights some of these techniques and their application in maintenance scheduling.

2.7.1 Gantt Charts and Scheduling Theory

One of the oldest techniques available for sequencing and scheduling operations is the Gantt chart developed by Henry L. Gantt during World War II. The Gantt chart is a bar chart that specifies the start and finish time for each activity on a horizontal time scale. It is very useful for showing planned work activities *vs* accomplishments on the same time scale. It can also be used to show the inter- dependencies among jobs, and the critical jobs that need special attention and effective monitoring. There are large variations of the Gantt chart. To demonstrate the use of the Gantt chart several examples are given below. The example in Figure

11.5 shows the simplest form of the Gantt chart in which activities are scheduled at specified dates within the month.

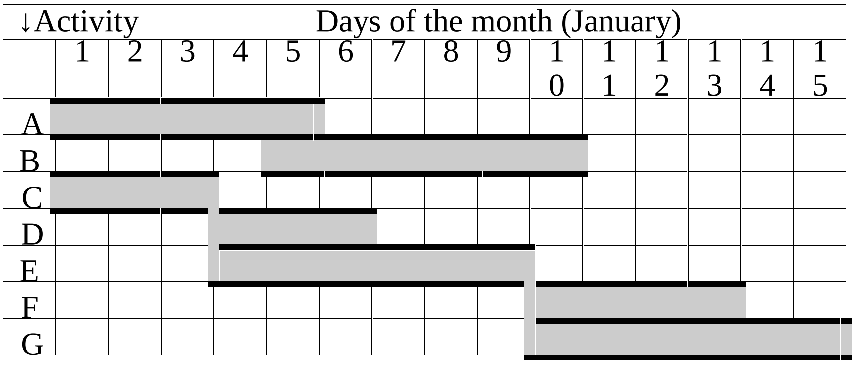
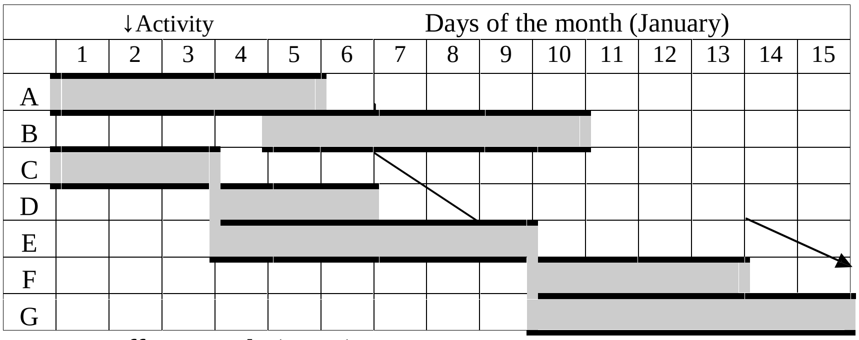


Figure 11.5. A Gantt chart representing a schedule of seven activities



Source: Duffuaa et al. (1999)

Figure 11.6. A Gantt chart with milestones

The example in Figure 11.5 modified to show interdependencies by noting milestones on each job timeline is shown in Figure 11.6. The milestones indicate key time periods in the duration of each job. Solid lines connect interrelationships among milestones.The milestones thus indicate the interdependencies between jobs. Obvious milestones for any job are the starting time for the job and the required completion point. Other important milestones are significant points within a job, such as the point at which the start of other jobs is possible.

Gantt charts can also be used to show the schedule for multiple teams or equipment simultaneously. A case in which three heavy pieces of equipment are scheduled for different jobs throughout the day is shown in Figure 11.7. The actual progression indicated in the chart shows any deviation from the scheduled timing. The chart indicates that jobs 25A and 15D are completed on schedule, job 25C is behind schedule by about a full day while job 25B is ahead of schedule by about a day, and job 41E is in progress exactly on schedule. Jobs 33C and 44E scheduled but have not started yet.

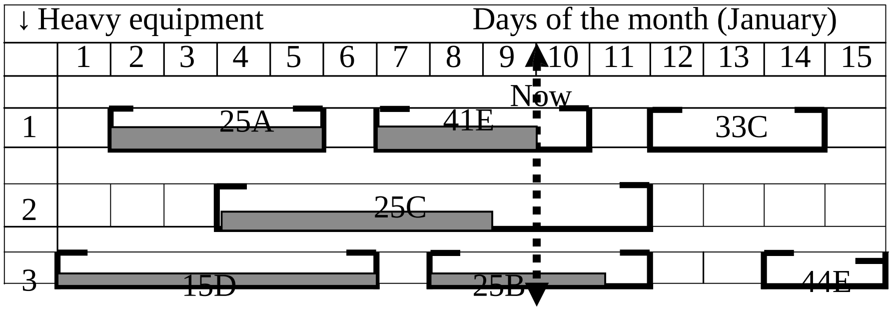


Figure 11.7. Gantt chart with progression

Color codes are sometimes used to reflect certain conditions such as shortage of material or machine breakdowns. Several scheduling packages, such as Primavera, are available to construct Gantt charts for more complicated schedules involving multiple resources and large number of activities. In general, Gantt chart does not build a schedule but helps in presenting the schedule in a simple visible manner that might help in monitoring, controlling and may be adjusting schedules. Scheduling (adding new jobs to the Gantt chart) itself is done following a certain rule that is developed with experience for the schedule to perform in the desired way. An example of such a rule is loading the heaviest job to the least loaded equipment as early as possible for maximizing the utilization of the equipment. This rule is known from scheduling theory to produce a good schedule for minimizing idle time.

Optimization techniques are available in the literature for such cases and for other cases with multiple or single resource. In general, scheduling theory has developed to handle short term production scheduling in different shop structures including job shop, flow shop, open shop and parallel machine structures See Pinedo (2002) for one of the recent books in scheduling theory. Integer programming is commonly used for developing optimum schedules for various scheduling requirements under various problem structures. However, they turn out to be large scale models that are quite complicated for real life situations. Another line of research in scheduling theory is developing heuristic methods, some of which are quite simple and practical, that result in good schedules with respect to certain performance measures. Computer simulation is heavily used in testing the performance of different competing heuristics and dispatching rules under stochastic system behavior including machine breakdowns, and stochastically dynamic job arrivals.

Some of the simple rules that can be utilized in maintenance scheduling are:

- For minimizing the average job waiting time, select jobs with high priority and short time requirements to be scheduled first. More specifically jobs should be ordered in increasing order of the ratio of processing time to weighted job priority (assuming high priority jobs have high weights). This rule is known as the weighted shortest processing time (WSPT) rule in scheduling theory.

- For minimizing the average job waiting time having more than one team (crew) of the same capabilities, construct the schedule by assigning the job with the least time requirement to the fastest team.
- Having teams of different capabilities serving for different tasks for interrelated jobs (job shop environment), each team should select the task belonging to the job with the most remaining time requirement. This will maximize the utilization of maintenance crew (or equipment).

In spite of the developments in scheduling theory, its use in maintenance scheduling is limited due to the different nature of maintenance activities compared to production activities in many aspects including:

- Mai ntenance activities are highly uncertain in terms of duration and resource requirements;
- Maintenance activities are highly related in terms of precedence relations or relative priority;
- Tasks can be divided into subtasks each with different requirements; and
- Tas ks can be interrupted or canceled due to changes in production conditions or maintenance requirements.

Recent advances in scheduling theory tended to tackle problems that are more stochastic in nature and some research is devoted to maintenance scheduling applications. Another recent trend in scheduling theory is the integration of maintenance scheduling and production scheduling which are traditionally done independently.

2.7.2 Project Scheduling

Maintenance activities commonly take the form of a project with many dependent operations forming a network of connected operations. In such cases, project management techniques can be utilized for scheduling the maintenance operations. The two primary network programming techniques used in project scheduling are the critical path method (CPM) and program evaluation and review technique (PERT). Each was developed independently during the late 1950s. The main difference between the two is that CPM uses a single estimate of activity time duration while PERT uses three estimates of time for each activity. Hence, CPM is considered to be a deterministic network method while PERT is a probabilistic method. Both networks consist of nodes representing activities and arrows indicating precedence between the activities. Alternatively, arrows may represent activities and nodes represent milestone. Both conventions are used in practice. Here we are going to use the former.

The objective in both CPM and PERT is to schedule the sequence of work activities in the project and determine the total time needed to complete the project. The total time duration is the longest sequence of activities in the network (the longest path through the network diagram) and is called the critical path. Before we proceed by explaining the two methods it is worth noting that PERT and CPM are not well suited for day-to-day independent small jobs scheduling in a maintenance department. However, they are very useful in planning and scheduling large jobs (20 man hours or more) that consist of many activities such as machine overhauls, plant shut downs, and turnaround maintenance activities. Furthermore, a prerequisite for the application of both methods is the representation of the project as a network diagram, which shows the interdependencies and precedence relationships among the activities of the project.

Formulating the maintenance project as a network diagram helps in viewing the whole project as an integrated system. Interaction and precedence relationships can be seen easily and be evaluated in terms of their impact on other jobs. The project network representation will be demonstrated by an example from maintenance. Table 11.2 shows the data for overhauling a bearing in a train cargo carriage. The data shows the normal, crash duration, their corresponding costs, and precedence relationships for each activity. The term crash time refers to the minimum time the job can be accomplished in (by committing more resources), beyond which no further reduction in the job duration can be achieved. At this duration any increase in the resources for this job will increase the cost without reducing the duration.

Table 11.2. Normal and crash data for bearing overhaul

Activit y	Description	Time (Min.)		Costs($)		Immedia te precede
A	Dismantling	50	30	100	150	0
B	Repair of bolster pockets	67	50	120	150	A
C	Repair side frame	90	60	150	200	A
D	Check friction blocks	35	25	50	75	A
E	Repair bolster rotation stop	35	25	140	170	B
F	Repair side frame	55	40	100	130	C
G	Repair bolster	210	150	250	300	E
H	Assemble	65	45	120	150	D, F and
I	Painting	40	30	80	100	H

Source: Duffuaa et al. (1999)

Figure 11.8 shows the network corresponding to the data in the table. It starts with node A with no predecessor activity and it is represented by a circle nearby a number indicating the time. A itself is a predecessor for three activities B, C, and D drawn as three circles connected to A by arrows to indicate the precedence relation with A. Other activities (nodes) are traced back similarly. The resulting network is terminated by node I that has no successor.

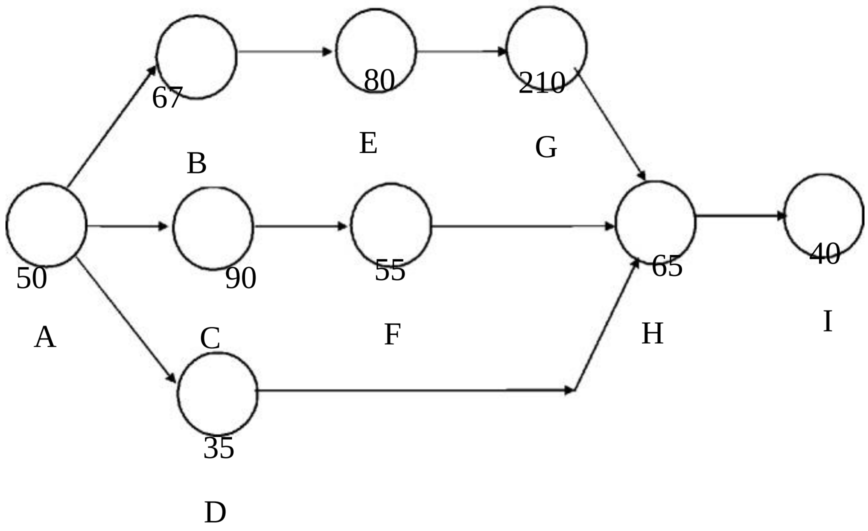


Figure 11.8. Network diagram for bearing overhaul data

There are many paths through the network in Figure 11.8 starting from the first node to the last node. The longest one is called the critical path and the summation of the activity times along that path is the total project duration. Jobs in the critical path are called critical in the sense that any delay in these jobs would cause a delay in the whole project. All other paths include slack times (sometimes called floats), *i.e.,* the amount of extra time that activities in the path can be delayed without delaying the completion time of the whole project. Activities that are not in the critical path may have some slack times, *i.e.*, delaying this activity for one reason or another will not delay the whole project. In this example there are three possible paths shown in Table 11.3. Critical activities must be monitored carefully and adhere to their specified schedules; however, non-critical activities can be used for leveling the resources due to the available slacks.

Table 11.3. Possible paths for completing bearing overhaul

Path	Path activities	Project duration	Sum
1	A-B-E-G-H-I	50+67+35+210+65+40	467
2	A-C-F-H-I	50+90+55+65+40	300
3	A-D-H-I	50+35+65+40	190

Clearly the project duration is 467 min and the critical path is the first path (A- B-E-G-H-I). Paths 2 and 3 have slacks of 167 and 277 min respectively. In this example, it was easy to go through all possible paths to find the one with the longest time; however, it would be extremely difficult to do the same for larger projects having a large number of activities and more complicated relationships

between them. A systematic approach for identifying the critical path is known as the critical path method (CPM).

2.7.3 Critical Path Method

To identify the critical path using the CPM method we need to follow the following steps:

1. Develop the project network diagram as shown in the previous section;
2. Perform the CPM calculation to identify the critical jobs (there are jobs on the critical paths and non-critical jobs (which are jobs with float);
3. Perform project crashing to (determine minimum times for each job) reduce project duration and investigate the cost tradeoffs; and
4. Level the resources in order to have uniform manpower requirements to minimize hiring, firing, or overtime requirements.

The critical path calculation includes two phases. The first phase is the forward pass (starting with the first node and proceeding to the last node). In this phase, the earliest start time, ES, and earliest finish time, EF, are determined for each activity. The earliest start time ES_i for a given activity, i, is the earliest possible time in the schedule that activity i can be started. Its value is determined by summing up the activity times of the activities lying on the longest path leading to it. The earliest finish time EF_i for a given activity i, is its earliest start time plus its activity time T_{ai}. The calculations for the bearing overhaul example are shown in Table 11.4.

Table 11.4. Earliest start times and finish times for the example

Activity	Longest forward	ES_i	Ta_i	EF_i
A	-	0	50	50
B	A	50	67	11
C		50	90	7
D	A	50	35	14
		11	35	0
		7	55	85
E	A	14	21	15
F	A-B	0	0	2
G	A	15	65	19

The second phase is the backward pass (starting with the last node and proceeding back to the first node). We start this phase by assuming that the total project time T_{cp}, is the earliest finish time, EF, of the last activity found in the forward pass. In this phase, the latest finish time, LF, and latest start time, LS, are determined for each activity. The latest finish time LF_i for a given activity, i, is the latest possible time that activity i must be completed in order to finish the whole project on schedule. Its value is determined by subtracting from T_{cp} the activity time along the longest path leading backward from the last node. For the last activity of the schedule, LF is set to be the total time duration of the project, T_{cp}. The latest finish time, LF_i , for a given activity, i, is its latest finish time minus its activity time T_{ai}. The calculations for the bearing overhaul example are shown in Table 11.5.

Table 11.5. Latest finish times and start times for the example

Activity i	Longe st	Length of the	LF i	Ta i	LS i
I	-	0	46	40	42
H	I	40	7	65	7
	I-	10	42	21	36
G	H		7		2
F	I-	5	36	0	15
E	H	10		55	
D	I-H-	5	2	35	2
C	G	31	36	35	30
B	I-	5	2	90	7

The last step in the analysis of the network is to determine the slack time for each activity S_i. It can be determined by the difference between the latest and the earliest start time of the activity. The calculations are shown in Table 11.6 below.

Table 11.6. Slack times for the example

Activity i	LS_i	ES_i	LF_i	EF_i	S_i
A	0	0	50	50	0
B	50	50	117	117	0
C	372	50	362	140	322
D	327	50	362	85	277
	117	117	152	152	0
	307	140	362	195	167
E	152	152	362	262	0
F	362	362	427	427	0

Note that the activities along the critical path (A-B-E-G-H-I) have zero slack times. Activities not lying on the critical path have positive slacks, meaning that they could be delayed by an amount of time equal to their slack without delaying the project completion time.

The construction of the time chart should be made taking into consideration the available resources, and must take full advantage of the CPM calculation. In some circumstances it might not be possible to schedule many activities simultaneously because of personnel and equipment limitations. The total float for non-critical activities can be used to level the resources and minimize the maximum resource requirement. These activities can be shifted backward and forward between maximum allowable limits and scheduled at an appropriate time that levels the resources and keeps a steady workforce and equipment.

In addition to resource leveling, CPM involves project crashing. In project crashing, the duration of one or more critical activities are shortened in an optimal fashion and a curve is prepared to show the trade off between time and cost. This will enable management to evaluate project duration with the resulting cost. Network programming can be used to perform crashing in an optimal fashion. For more on project scheduling, see Taha (1992).

2.7.4 Program Evaluation Review Techniques (PERT)

Maintenance activities are usually unique and commonly involve unexpected needs that make their time duration highly uncertain. CPM uses a single estimate of the time duration based on the judgment of a person. PERT, on the other hand, incorporates the uncertainty by three time estimates of the same activity to form a probabilistic description of their time requirement. Even though the three time estimates are judgmental they provide more information about the activity that can be used for probabilistic modeling. The three values are represented as follows:

> O_i = optimistic time, which is the time required if execution goes extremely well;
> P_i = pessimistic time, which is the time required under the worst conditions;
> and
> m_i = most likely time, which is the time required under normal condition.

The activity duration is modeled using a beta distribution with mean ( ) and variance ( ) for each activity i estimated from the three points as follows:

$$\hat{}_i \quad \frac{O_i \; . \; P_i \; . \; 4m_i}{6}$$

$$\hat{}^2_i \quad \left(\frac{P_i - O_i}{6} \right)^2$$

Estimated means are then used to find the critical path in the same way of the CPM method. In PERT, the total time of the critical path is a random variable with a value that is unknown in advance. However, additional probabilistic analysis can be conducted regarding possible project durations based on the assumption that the total time of the project may be approximated by a normal probability distribution with mean and variance ^{2} estimated as

$$\hat{} \quad \hat{}_i$$

$$\hat{}^2 \quad \hat{}^2_i$$

where i is an activity in the critical path

Using the above approximation we can calculate the probability with which a project can be completed in any time duration, T, using the normal distribution as follows:

$$\Pr(T_{cp} \le T) = \Pr\left(Z \le \frac{T-\mu}{\sqrt{\sigma^2}}\right) = \Phi(z)$$

Where Φ is the distribution function of the standard normal distribution.

Tables exist for evaluating any probability under the standard normal distribution. To illustrate the PERT analysis, consider the previous example with additional time estimates shown in Table 11.7 below.

Table 11.7. The PERT calculation for the bearing overhaul example

Activity	Description	Time (min)			Estimates	
A	Dismantling	40	50	60	50	11.09
B	Repair of bolster	60	67	74	67	5.43
C	Repair side frame rotation stop legs	85	90	95	90	2.79
D	Check friction blocks and all springs	32	35	38	35	4.00
E	Repair bolster rotation stop gibs	30	35	40	35	2.79
F	Repair side frame column wear plates	50	55	60	55	2.79
G	Repair bolster pivot	170	210		210	177.69
H	Assemble	59	65	71	65	4.00
I	Painting	35	40	45	40	2.79
Total					467	213.37

The critical path calculations lead to the same critical path obtained in the previous CPM calculations. The total project time is expected to be 467 min. The estimated variance is 213.37 min. The probability that the project will complete in 467 min can be calculated from the standard normal distribution to be 0.5, or the project has a 50% chance of completing in 467 min. The probability that the project may finish in 500 min can be calculated as:

$$\Phi\left(\frac{500-467}{\sqrt{213.37}}\right) = \Phi(2.26) = 0.9881$$

meaning that, the chance of completing the project in 500 min is almost 99%.

2.8. Scheduling Using Computers

It is always desirable to have a scheduling system that matches required maintenance work to available personnel and necessary equipment. The system should help maintain information of all necessary data and make them available with high reliability to build working schedules that optimizes the utilization of human resources and heavy equipment. A large number of software packages are available for optimum scheduling of personnel for planned maintenance activities and that takes into account the possibility of unplanned maintenance activities. Project scheduling packages are available to perform various functions related to project management. One of the leading packages is Microsoft Project that has the capability of maintaining data and generating Gantt charts for the projects. The critical path through the network diagram is highlighted in color to allow schedule monitoring and test alternatives.

Enterprise Resource Planning (ERP) is increasingly adopted by large enterprises as a global information and data management system to integrate the information flow through various functions within, and sometimes, outside the enterprise. The maintenance function is highly influenced by other functions in the enterprise through information flow as well as strategic directions. ERP is therefore extremely useful for integrating maintenance with production, spare part inventory, and engineering and purchasing. For more details about maintenance strategy integration in ERP see Nikolopoulos *et al.* (2003).

2.9. Summary

Maintenance planning and scheduling must serve the global objectives in the enterprise; hence it must be based on clear vision of its role in its success. Maintenance strategic planning is the process that assures matching between the maintenance objectives and objectives of the whole enterprise as well the objectives of other functional objectives. It selects the appropriate strategies regarding service delivery mode and type of contracts for outsourcing if needed as well as the organization and work structure and maintenance management methodology. In view of the selected strategies, long, medium and short range plans are constructed for time spans ranging from one year in the long term to weekly plans in the short term. The plans are then translated to schedules for implementing the plans at all levels. Master schedules are developed for long range plans and short range schedules are developed for days or hours within a day. Techniques exist in the literature to assist the planner and the scheduler in constructing good plans and schedules that achieve the objectives in the most efficient way. Gantt charts are usually used to monitor and control schedules. Methods like CPM and PERT are used to schedule maintenance activities forming a single large size project.

2.10.Lubrication

- ### A Necessary Function

All material surfaces, no matter how smooth they are, show many irregularities in the form of peaks and valleys, which are large when considered on a molecular scale.

When these two solid surfaces are pressed over or slide over each other, a real contact between these surfaces occurs that will cause friction and consequently the production of heat. During the motion of the sliding surfaces, a considerable amount of frictional heat is evolved at the rubbing surface. This results in high local temperature even under relatively light loads and speeds. This friction also causes a lot of wear and tear of the surfaces of the moving parts.

Even under small load, the local pressure at the peaks of the metals may be sufficiently great to cause appreciable deformation in ductile metals. If two materials of different hardness slide over one another, the peaks of the softer metal get broken more easily than the peaks of the harder metals.

Lubrication reduces friction between the moving surfaces or rolling pairs. The lubricant also acts as a coolant carrying heat away from the sliding surfaces, so proper lubrication of all the moving parts is an important function in machinery or engine operation. By lubrication we keep the moving surfaces separated by a fluid of some defined property

- ### Types of Lubrication

Considering the nature of motion between moving or sliding surfaces, there are different types of mechanisms by which the lubrication is done. They are:

- Hydrodynamic lubrication or thick film lubrication
- Hydrostatic lubrication
- Boundary lubrication or thin film lubrication
- Extreme pressure lubrication

Hydrodynamic Lubrication or Thick Film Lubrication

Hydrodynamic lubrication is said to exist when the moving surfaces are separated by the pressure of a continuous unbroken film or layer of lubrication. In this type of lubrication, the load is taken completely by the oil film.

The basis of hydrodynamic lubrication is the formation of an oil wedge. When the journal rotates, it creates an oil taper or wedge between the two surfaces, and the pressure build up with the oil film supports the load.

Hydrodynamic lubrication depends on the relative speed between the surfaces, oil viscosity, load, and clearance between the moving or sliding surfaces.

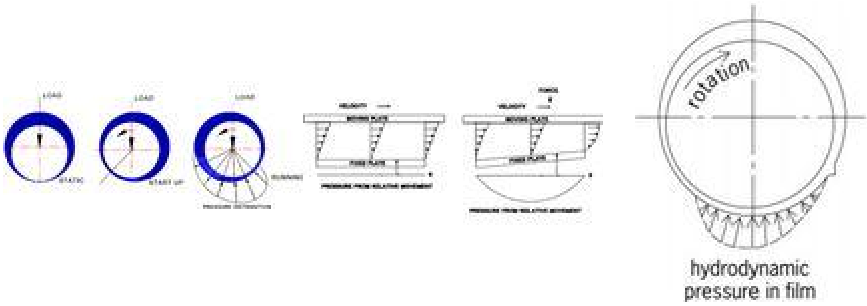
In hydrodynamic lubrication the lube oil film thickness is greater than outlet, pressure at the inlet increases quickly, remains fairly steady having a maximum value a little to the outside of the bearing center line, and then decreases quickly to zero at the outlet.

Application of hydrodynamic lubrication

- Delicate instruments.
- Light machines like watches, clocks, guns, sewing machines.
- Scientific instruments.
- Large plain bearings like pedestal bearings, main bearing of diesel engines.

Hydrocarbon oils are considered to be satisfactory lubrication for fluid film lubrication. In order to maintain the viscosity of the oil in all seasons of the year, ordinary hydrocarbon lubricants are blended with selected long chain polymers.

Hydrodynamic Lubrication



Next Page: Hydrostatic, Boundary, and Extreme Pressure Lubrication

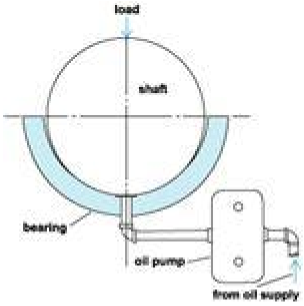
lubrication system is very important in diesel engines.Lubrication reduces friction between the moving surfaces or rolling pairs. various types of lubrication like hydrodynamic lubrication, hydrostatic lubrication, boundary lubrication which are used in diesel engines are explained in this article .

Hydrostatic Lubrication

Hydrostatic lubrication is essentially a form of hydrodynamic lubrication in which the metal surfaces are separated by a complete film of oil, but instead of being self-generated, the separating pressure is supplied by an external oil pump. Hydrostatic lubrication depends on the inlet pressure of lube oil and clearance between the metal surfaces, whereas in hydrodynamic lubrication it depends on the relative speed between the surfaces, oil viscosity, load on the surfaces, and clearance between the moving surfaces.

Example: the cross head pin bearing or gudgeon pin bearing in two stroke engines employs this hydrostatic lubrication mechanism. In the cross head bearing, the load is very high and the motion is not continuous as the bearing oscillation is fairly short. Thus hydrodynamic lubrication cannot be achieved. Under such conditions, hydrostatic lubrication offers the advantage. The oil is supplied under pressure at the bottom of bearing. The lube oil pump pressure is related to the load, bearing clearance, and thickness of the oil film required, but is usually in the order of 35-140 kg/cm^2 .

Hydrostatic Lubrication



Boundary Lubrication or Thin Film Lubrication

Boundary lubrication exists when the operating condition are such that it is not possible to establish a full fluid condition, particularly at low relative speeds between the moving or sliding surfaces.

The oil film thickness may be reduced to such a degree that metal to metal contact occurs between the moving surfaces. The oil film thickness is so small that oiliness becomes predominant for boundary lubrication.

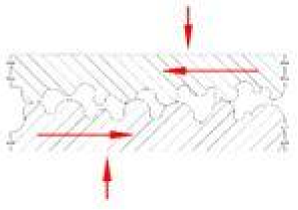
Boundary lubrication happens when

- A shaft starts moving from rest.
- The speed is very low.
- The load is very high.
- Viscosity of the lubricant is too low.

Examples for boundary lubrication:

- Guide and guide shoe in two stroke engine.
- Lubrication of the journal bearing in diesel engines (mainly during starting and stopping of engine).
- Piston rings and when cylinder liner is at TDC and BDC position when the piston direction changes and if the relative speed is very slow.

Boundary Lubrication



Extreme Pressure Lubrication

When the moving or sliding surfaces are under very high pressure and speed, a high local temperature is attained. Under such condition, liquid lubricant fails to stick to the moving parts and may decompose and even vaporize. To meet this extreme pressure condition, special additives are added to the minerals oils. These are called "extreme pressure lubrication." These additives form on the metal surfaces more durable films capable of withstanding high loads and high temperature. Additives are organic compounds like chlorine (as in chlorinated esters), sulphur (as in sulphurized oils), and phosphorus.

UNIT III
CONDITION MONITORING

3.1.Condition Monitoring

Condition monitoring is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure.

It is a major component of predictive maintenance. The use of conditional monitoring allows maintenance to be scheduled, or other actions to be taken to avoid the consequences of failure, before the failure occurs.

Nevertheless, a deviation from a reference value (e.g. temperature or vibration behavior) must occur to identify impeding damages

Predictive Maintenance does not predict failure.

Machines with defects are more at risk of failure than defect free machines. Once a defect has been identified, the failure process has already commenced and CM systems can only measure the deterioration of the condition.

Intervention in the early stages of deterioration is usually much more cost effective than allowing the machinery to fail. Condition monitoring has a unique benefit in that the actual load, and subsequent heat dissipation that represents normal service can be seen and conditions that would shorten normal lifespan can be addressed before repeated failures occur.

Serviceable machinery includes rotating equipment and stationary plant such as boilers and heat exchangers.

3.2.Methods Of Cm

1. Screen monitoring records video or static images detailing the contents, or screen capture, of the entire [video display] or the content of the screen activity within a particular program or computer application. Monitoring tools may collect real time video, accelerated or [time-lapse] video or screen shots, or may take video or still image captures at regular intervals (e.g., once every 4 minutes). They may collect images constantly or only collect information while the user is interacting with the equipment (e.g., capturing screens when the mouse or keyboard is active).
2. Data monitoring tracks the content of and changes to files stored on the local [hard drive] or in the user's "private" network share.
3. Keystroke monitoring (e.g., number of keystrokes per minute) may track the performance of keyboard-intensive work such as word processing or data entry. Keystroke logging captures all keyboard input to enable the employer to monitor anything typed into the monitored machine.
4. Idle time monitoring keeps track of time when the employee is away from the computer or the computer is not being actively used.

3.3.Benefits

- Screen monitoring records video or static images detailing the contents, or screen capture, of the entire [video display] or the content of the screen activity within a particular program or computer application.
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3.4.Load Testing

- Load testing is the process of putting demand on a system or device and measuring its response.
- Load testing is performed to determine a system’s behavior under both normal and anticipated peak load conditions.
- It helps to identify the maximum operating capacity of an application as well as any bottlenecks and determine which element is causing degradation.
- When the load placed on the system is raised beyond normal usage patterns, in order to test the system's response at unusually high or peak loads, it is known as stress testing.
- The load is usually so great that error conditions are the expected result, although no clear boundary exists when an activity ceases to be a load test and becomes a stress test.
- There is little agreement on what the specific goals of load testing are.
- The term is often used synonymously with concurrency testing, software performance testing, reliability testing, and volume testing.

- Load testing is a type of non-functional testing.

3.5.Types Of Condition Monitoring Systems

- Condition monitoring systems are of two types: periodic and permanent. In a *periodic*
- *monitoring system* (also called an *off-line condition monitoring system*),
- machinery vibration is measured (or recorded and later analyzed) at selected time

- intervals in the field; then an analysis is made either in the field or in the laboratory.
- Advanced analysis techniques usually are required for fault diagnosis and trend
- analysis. Intermittent monitoring provides information at a very early stage about
- incipient failure and usually is used where (1) very early warning of faults is
- required, (2) advanced diagnostics are required, (3) measurements must be made at
- many locations on a machine, and (4) machines are complex.
- In a *permanent monitoring system* (also called an *on-line condition monitoring*
- *system*), machinery vibration is measured continuously at selected points of the
- machine and is constantly compared with acceptable levels of vibration.The principal
- function of a permanent condition monitoring system is to protect one or more
- machines by providing a warning that the machine is operating improperly and/or
- to shut the machine down when a preset safety limit is exceeded, thereby avoiding
- catastrophic failure and destruction. The measurement system may be permanent
- (as in parallel acquisition systems where one transducer and one measurement
- chain are used for each measurement point), or it may be quasi-permanent (as in
- multiplexed systems where one transducer is used for each measurement point but
- the rest of the measurement chain is shared between a few points with a multiplexing
- interval of a few seconds).
- In a permanent monitoring system, transducers are mounted permanently at
- each selected measurement point. For this reason, such a system can be very costly,
- so it is usually used only in critical applications where: (1) no personnel are available
- to perform measurements (offshore, remote pumping stations, etc.), (2) it is necessary
- to stop the machine before a breakdown occurs in order to avoid a catastrophic
- accident, (3) an instantaneous fault may occur that requires machine shutdown, and
- (4) the environment (explosive, toxic, or high-temperature) does not permit the

- human involvement required by intermittent measurements.
- Before a permanent monitoring system is selected, preliminary measurements
- should be made periodically over a period of time to become acquainted with the
- vibration characteristics of the machine. This procedure will make it possible to
- select the most appropriate vibration measurement parameter, frequency range, and
- normal alarm and trip levels.

3.6.Establishing A Condition Monitoring Program

- A condition monitoring program may be established to check the satisfactory operation
- of a single machine or, more usually, it is established to check the operation of
- a number of machines, perhaps all the machines in an entire plant. The following
- steps are usually considered in the establishment of such a program, depending on
- the type of machine and impact of failure of operation machines might have.
- **Step 1.** *Determine the type of condition monitoring system,* described in the preceding
- section, that best meets the needs of the plant.
- **Step 2.** *Make a list of all of the machines to be monitored* (see, for example,Table
- 16.1), based on the importance of these machines in the production line.
- **Step 3.** *Tabulate the characteristics of the machines* that are important in conducting
- vibration analyses of the machines of step 2.These characteristics are associated
- with machine construction such as the natural frequencies of shafts, casings, and
- pedestals, and operational and defect responses.A tabulation of machine frequencies
- is important because fault analysis is conducted (Table 16.2) by matching
- machine frequencies to measured frequencies appearing in a spectrum.The following
- machine characteristics provide the necessary information for fault analysis.
- _ Shaft rotational speeds, bearing defect frequencies, number of teeth in gears, number
- of vanes and blades in pumps and fans, number of motor poles, and number of
- stator slots and rotor bars.

- _ Vibratory forces such as misalignment, mass unbalance, and reciprocating masses.
- _ Vibration responses due to process changes, such as temperature and pressure.
- _ Fault responses associated with specific machine types, such as motors, pumps, and
- fans.
- _ Sensitivity to instability in components, such as fluid film bearings and seals due to
- wear and clearance.
- _ Loads or changes in operating conditions.
- _ Effects of mass unbalance, misalignment, distortion, and other malfunction/defect
- excitations on vibration response.

3.7.Condition Monitoring Of Machinery

-
- **TABLE 16.1** Machinery Classification for Monitoring
- Machinery classification Result of failure
- Critical Unexpected shutdown or failure causes significant
- production loss.
- Interrupts production Unexpected shutdown or failure causes minor
- interruptions in production.
- Causes inconvenience Inconvenience in operation, but no interruption
- in production.
- Noncritical Production is not affected by failure.
- **Step 4.** *Select the most appropriate vibration measurement parameter.* When an
- accelerometer is employed as the sensing device in a condition monitoring system,
- the resulting *acceleration* signal can be electronically integrated to obtain *velocity* or
- *displacement*, so any one of these three parameters may be used in measurements.
- The appropriate parameter may be selected by application of the following simple
- rule: *Use the parameter which provides the "flattest" spectrum.* The flattest spectrum
- requires the least dynamic range from the instrumentation which follows the transducer.
- For example,Fig. 16.1 shows a velocity spectrum and a displacement spectrum
- obtained under identical conditions. The dynamic range (i.e., the range from the
- highest to the lowest signal level) required to measure the displacement spectrum is

- much larger than the range for the velocity spectrum; it may even exceed the available
- dynamic range of the instrumentation.Therefore, according to this rule, velocity
- measurements should be selected.
- The *flattest spectrum* rule applies only to the frequency range of interest. Therefore,
- the parameter selection, to some extent, depends on the type of machine and
- the type of faults considered.
- **Step 5.** *Select one of the following vibration pickups that will best meet the requirements*
- *of step 4.*
- ***Displacement Transducer.*** A displacement transducer is a transducer that converts
- an input mechanical displacement into an electrical output that is proportional
- to the input displacement. Displacement transducer of the eddy-current type
- (described in Chap. 12), which have noncontacting probes, are commonly used to
- measure the relative motion between a shaft and its bearings. This information can
- be related directly to physical values such as mechanical clearance or oil-film thickness,
- e.g., it can give an indication of incipient rubbing. Shaft vibration provides
- information about the current condition of a machine and is principally used in permanent
- monitoring systems, which immediately shut the machine down in the event
- of trouble. The use of displacement transducers is essential in machinery having
- journal bearings. However, proximity probe transducers (1) usually are difficult to
- calibrate absolutely, (2) have limited dynamic range because of the influence of electrical
- and mechanical runout on the shaft, and (3) have a limited high-frequency
- range.
- ***Accelerometers and Velocity Pickup.*** Pickups of this type, described in Chap.
- 12, are usually lightweight and rugged. They are always used for detecting faults
- which occur at high frequencies (say, above 1000 Hz), for example, to detect rollingelement
- bearing deterioration or gearbox wear. Acceleration measurements of
- bearing vibration will provide very early warning of incipient faults in a machine.

- **Figure 16.1** Displacement and velocity spectra
- obtained under identical conditions. The velocity spectrum
- requires a smaller dynamic range of the equipment
- which follows the transducer.Therefore, it is preferable.
- **Step 6**. *Select the measurement locations.* When a periodic (off-line) monitoring
- system is employed, the number of points at which measurements are made is limited
- only by the requirement for keeping measurement time to a minimum. As a
- general rule, bearing vibration measurements are made in the radial direction on
- each accessible bearing, and in the axial direction on thrust bearings. It is not usually
- necessary to measure bearing vibration in both the horizontal *and* the vertical direction,
- since both measurements give the same information regarding the forces
- within the machine; this information is merely transmitted through two different
- transmission paths. This applies for *detecting* developing faults. It will later be seen,
- however, that in order subsequently to *diagnose* the origin of the impending fault,
- measurements in both the horizontal and the vertical direction may give valuable
- information.When measuring shaft vibrations with permanently mounted proximity
- transducers, it is convenient to use two probes on each bearing, located at 90 . from
- each other, thereby providing an indication of the orbit of the shaft within the bearing.
- Axial displacement transducers, programmed to shut the machine down on preset
- levels, are mounted where a thrust measurement will protect the machine
- rotating parts, such as blades, from rubbing the stationary casing due to faultinduced
- axial forces.
- When a permanent (on-line) monitoring system is employed using a seismic
- pickup, the number of measurement points usually is minimized for reasons of
- economy. Selection must be made following a study of the vibration spectra of different
- bearings in order to locate those points where all significant components

- related to the different expected faults are transmitted at measurable vibration
- levels if full spectrum comparison is performed. If only broadband measurements
- are monitored, then a further requirement is that all frequency components
- related to the expected faults must be of approximately the same level within the
- selected frequency range. Otherwise, measurements must be made in selected frequency
- bands.
- **Step 7.** *Select the time interval between measurements.* The selection of the time
- interval between measurements requires knowledge of the specific machine. Some
- machines develop faults quickly, and others run trouble-free for years. A compromise
- must be found between the safety of the system and the time taken for measurements
- and analysis. Measurements should be made frequently in the initial stages
- of a condition monitoring program to ensure that the vibration levels measured are
- stable and that no fault is already developing.When a significant change is detected,
- the time interval between measurements should be reduced sufficiently so as not to
- risk a breakdown before the next measurement.The trend curve will help in determining
- when the next measurement should be performed.
- **Step 8.** *Establish an optimum sequence of data acquisition.* The sequence in which
- data acquired in a condition monitoring program must be planned so that the data
- are acquired efficiently. For example, the data collection may be planned on the
- basis of plant layout, on the type of data required, or on the sequence of components
- in the machine train, from driver to driven components.

3.8.Principles And Methods

As a starting point for any discussion on condition monitoring it is useful to define what is meant by the term, and to describe how it relates to other techniques used in the operation and maintenance of machines, such

as alarm and shut down systems or methods for failure and problem investigation.
The crudest method for operating machines is to run them until they fail, and then to try and repair them in order to make them fit for further service. This method of operation can be very expensive in terms of lost output and machine destruction, and in addition can involve hazards to personnel. It is now well recognised that, particularly in the case of large and expensive plant, it is more economical and operationally satisfactory to carry out regular
maintenance. This involves the maintenance of the machine or its various components at regular intervals, to reduce the likelihood of failure during a time when the machine is required to be available for use.

The problem in planning this type of maintenance lies in the choice of an appropriate maintenance interval for the machine, because the actual running
time before maintenance is really needed is not constant, but varies from one occasion to another, due to differences in the operation of the machine in the behaviour of its components.

Fig. 1 shows how the running time to failure of a typical machine would be likely to vary if no preventive maintenance were carried out. The vertical line in this diagram represents the safe time interval between preventive maintenance work which could catch all the failures before they occurred. If this safe overhaul interval is chosen, however, there will be
many occasions when the machinery will be overhauled long before it is really necessary,such as in those cases at the right hand side of the curve where it could have run on for much longer without failing.
This situation wastes production time, and by increasing the frequency of maintenance operations increases the incidence of human errors on reassembly of the machine.

A more satisfactory compromise in terms of maintenance strategy is to carry out preventive maintenance at what may be irregular intervals, but to determine these intervals by the actual condition of the machine at the time. For such condition-based maintenance to be possible,it is essential to have knowledge of the machine condition and its rate of change with time. The main function of condition monitoring is to provide this knowledge.

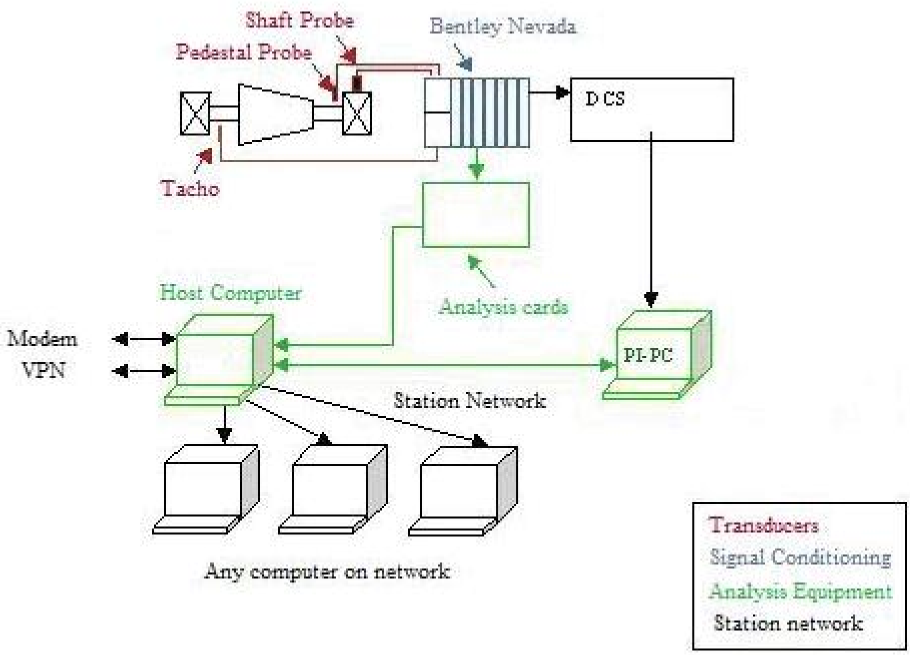
There are two main methods used for condition monitoring, and these are trend monitoring and condition checking. Trend monitoring is the continuous or regular measurement and interpretation of data, collected during machine operation, to indicate variations in the condition of the machine or its components, in the interests of safe and economical operation.

This involves the selection of some suitable and measurable indication of machine or component deterioration, such as one of those listed in Fig.2, and the study of the trend in this measurement with running time to indicate when deterioration is exceeding a critical rate.

The principle involved is illustrated in Fig.3, which shows the way in which such trend monitoring can give a lead time before the deterioration reaches a level at which the machine would have to be shut down.
This lead time is one of the main advantages of using trend monitoring rather than simple alarms or automatic shut down devices.

3.9.Vibration Monitoring System (VMS) Specification

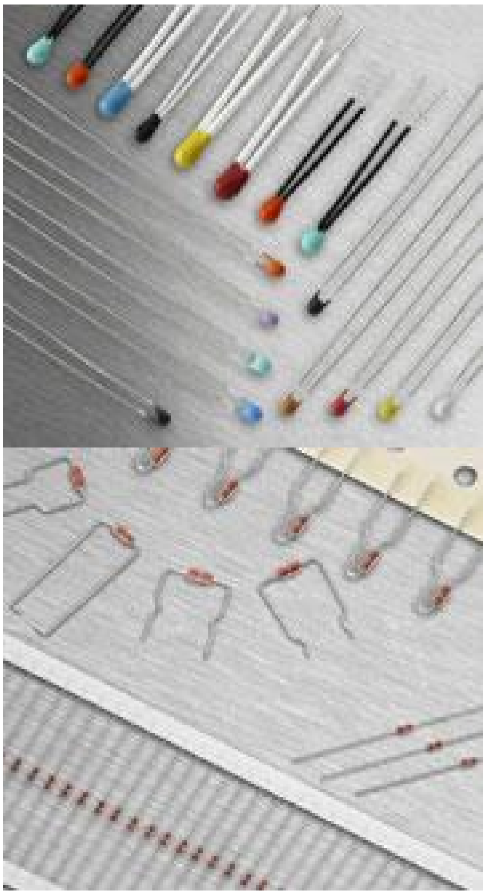
To identify potential turbine generator fault mechanisms and so enable informed operational decisions, sophisticated vibration data analysis is required. To do this a modern dedicated vibration monitoring system (VMS) is required. Vibration Diagnostics can provide vibration specification and commissioning services.



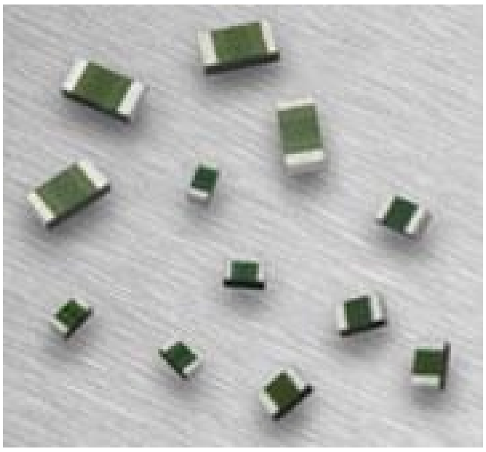
3.10.Thermistors

THERMal resISTORS

A thermistor is a type of resistor used to measure temperature changes, relying on the change in its resistance with changing temperature. Thermistor is a combination of the words thermal and resistor. The Thermistor was invented by Samuel Ruben in 1930, and has U.S. Patent #2,021,491.



Leads, coated Glass encased



Surface mount

Assume a simple linear relationship between resistance and temperature for the following discussion:

$\Delta R = \mathbf{k}\,\Delta T$

where

ΔR = change in resistance

ΔT = change in temperature

k = first-order temperature coefficient of resistance

Source: http://en.wikipedia.org/wiki/Thermistor

Thermistors can be classified into two types depending on the sign of k.

If k is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (**PTC**) thermistor, **Posistor**.

If k is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (**NTC**) **thermistor**.

Source: http://en.wikipedia.org/wiki/Thermistor

Resistors that are not thermistors are designed to have the smallest possible k, so that their resistance remains almost constant over a wide temperature range.

Thermistor Specifications

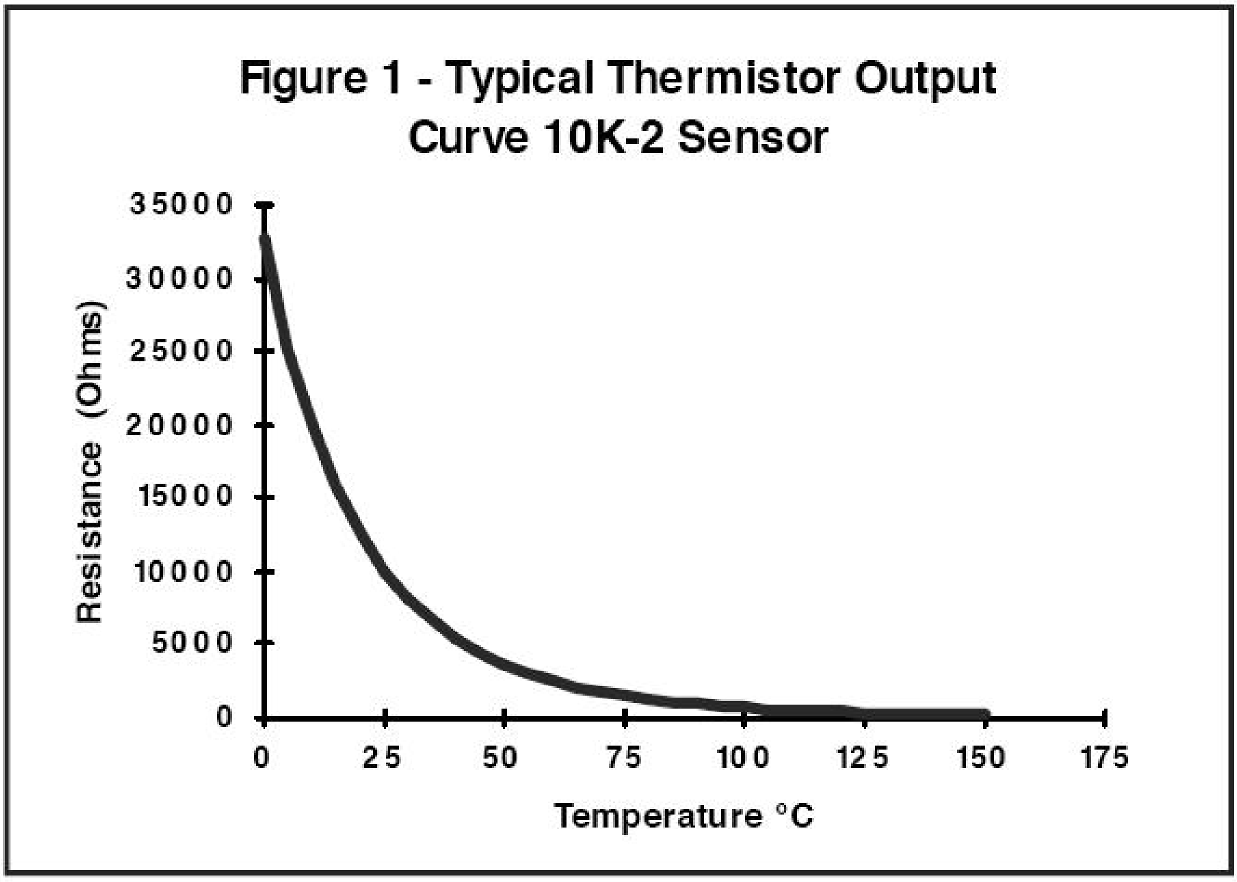
Interchangeability Tolerance (Accuracy):
± 0.2 °C (0 to 70 °C) Standard
± 0.1 °C (0 to 70 °C) XP Option

Dissipation Constant: 2.7 mW/°C

Stability (drift): Less than 0.02 °C / year

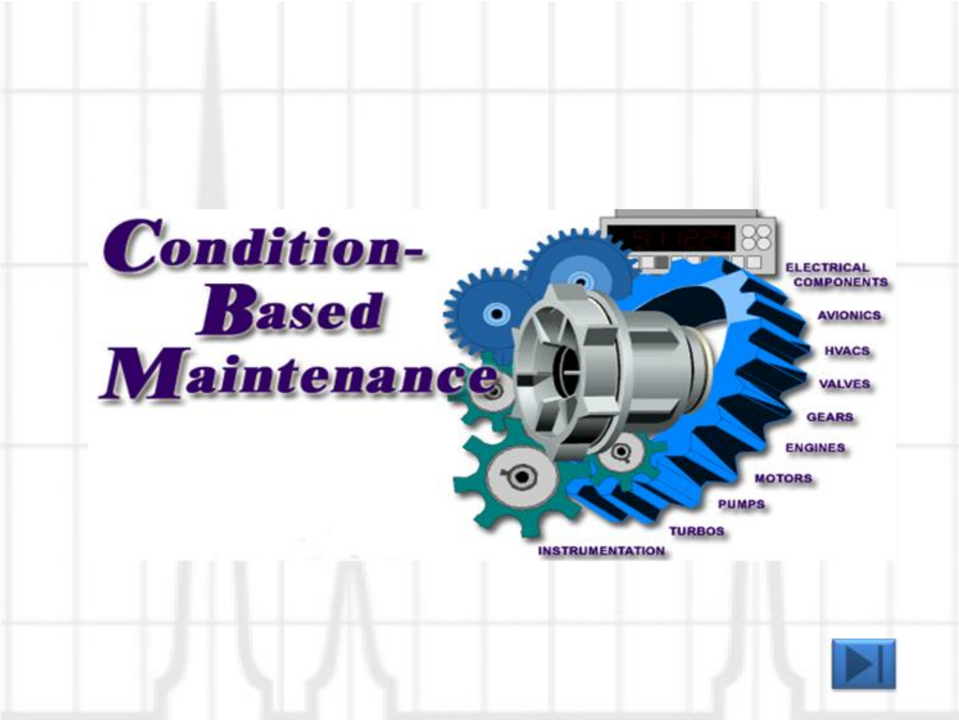
Sensor Type	Reference Resistance	Operating Range
1.8K	1.8 KΩ @ 25 °C	-55 to 150 °C
2.2K	2,252 KΩ @ 25 °C	-55 to 150 °C
3K	3 KΩ @ 25 °C	-55 to 150 °C
3.3K	3.3 KΩ @ 25 °C	-55 to 150 °C
10K-2	10 KΩ @ 25 °C	-55 to 150 °C
10K-3	10 KΩ @ 25 °C	-80 to 150 °C
10K-3(11K)	5.2 KΩ @ 25 °C	-80 to 150 °C
20K	20 KΩ @ 25 °C	-80 to 150 °C
47K	47 KΩ @ 25 °C	-80 to 150 °C
50K	50 KΩ @ 25 °C	-80 to 150 °C
100K	100 KΩ @ 25 °C	-80 to 150 °C

Thermistor-choice is based on the nominal resistance you want at the operating temperature range, on the size, and on the time constant.
Time constants are about 5 - 10 seconds. (Check this out with your thermistor).



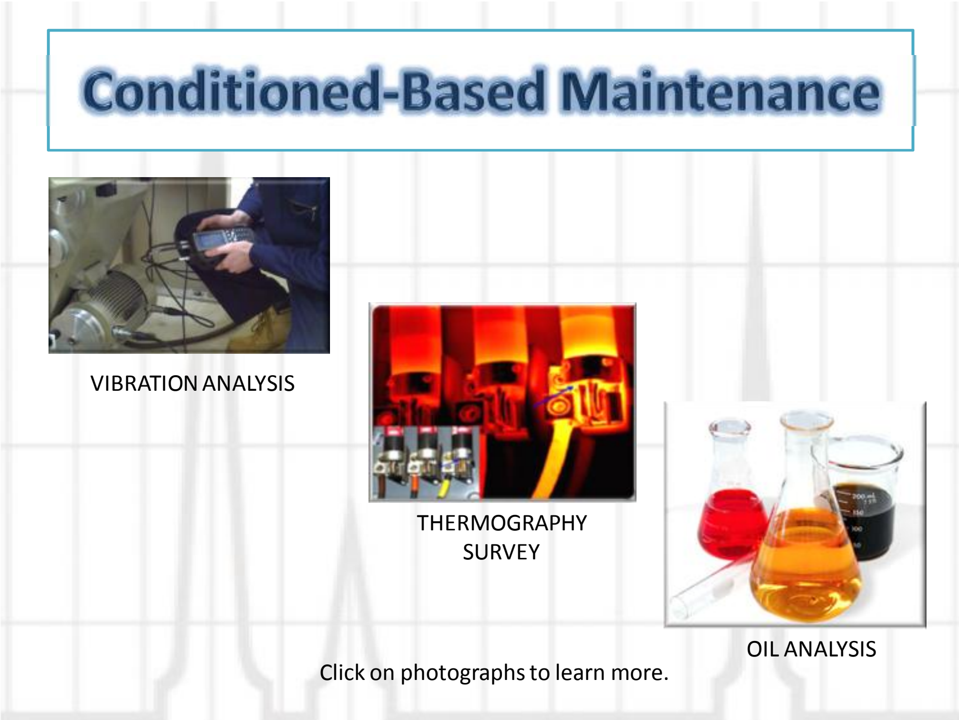
Example Applications:

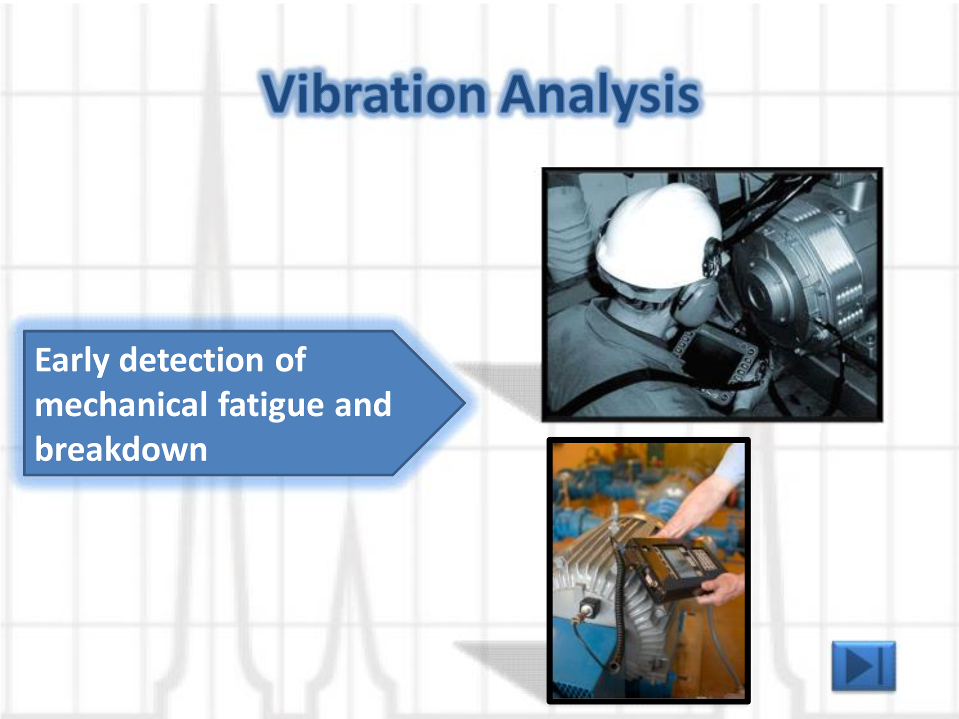
1. Temperature measurement.
2. Time delay (self heating from large current ‘opens’ the thermistor so it can be used as a slow switch). Heating = i^2 R where R is the resistance and i is the current.
3. Surge suppression when a circuit is first energized. Current needs to flow through the thermistor for awhile to heat it so that it ‘opens’, and acts again as a switch.

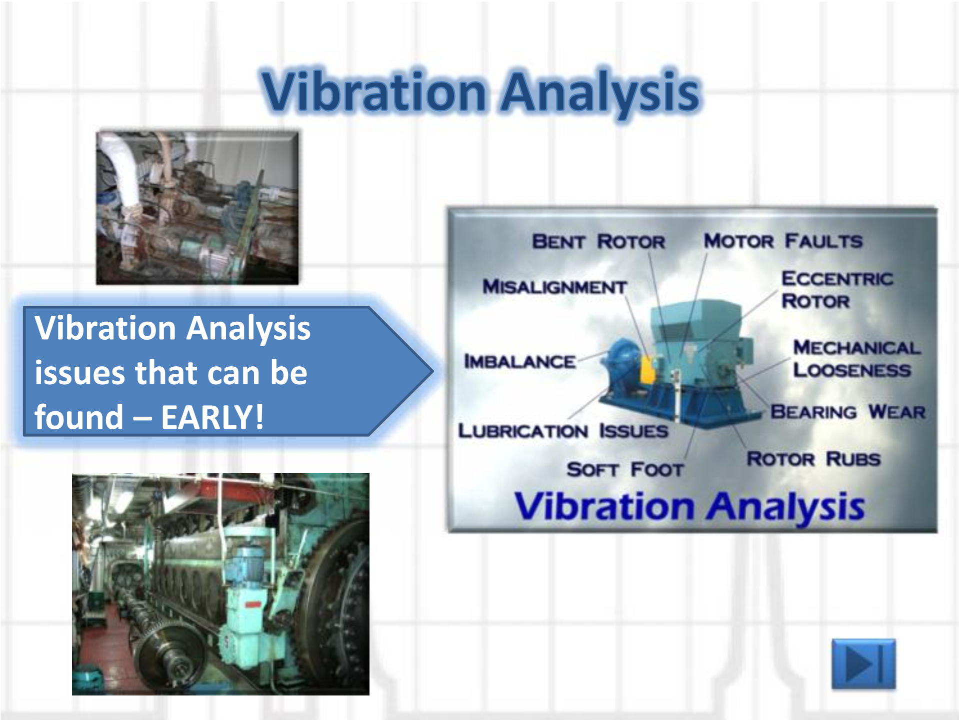


Conditioned-Based Maintenance

- **Condition Based Maintenance** (**CBM**) is the future maintenance practice for equipment that is here today.
- **CBM** is a strategy aimed at extending machine life, increasing productivity, and taking machine health to the next level for the lifetime of the equipment
- Unlike preventative maintenance, which is based on servicing a machine at scheduled intervals, **CBM** is based on specific equipment conditions including operating environment and application.


Conditioned-Based Maintenance
VIBRATION ANALYSIS
THERMOGRAPHY SURVEY
OIL ANALYSIS
Click on photographs to learn more.

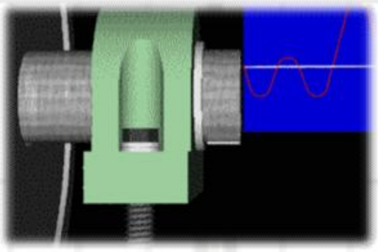

Vibration Analysis
Early detection of mechanical fatigue and breakdown


Vibration Analysis
Vibration Analysis issues that can be found – EARLY!
Bent Rotor
Motor Faults
Misalignment
Eccentric Rotor
Imbalance
Mechanical Looseness
Bearing Wear
Lubrication Issues
Rotor Rubs
Soft Foot
Vibration Analysis


Vibration Analysis
Sample Platforms

Vibration Analysis

Vibration Analysis will find defects …



Avoiding disassembly and averting unplanned downtime

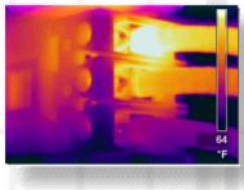
THERMOGRAPHY SURVEY

- A widely used tool in all facets of industry to measure anywhere a fault can be predicted by a temperature differential.
- Non-destructive tool in the analysis and evaluation of electrical distribution equipment.
- Reference point of equipment temperature under normal operating conditions.

THERMOGRAPHY SURVEY

What can Thermography find?

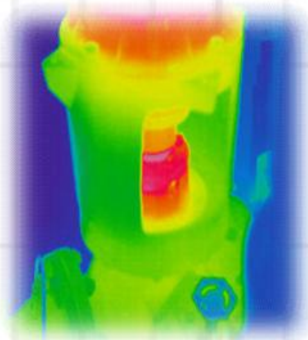
What you see



What thermography sees

Overheating electrical connection indicates a serious fire hazard.

THERMOGRAPHY SURVEY



Indication of bearing overheating, will eventually cause failure

THERMOGRAPHY SURVEY

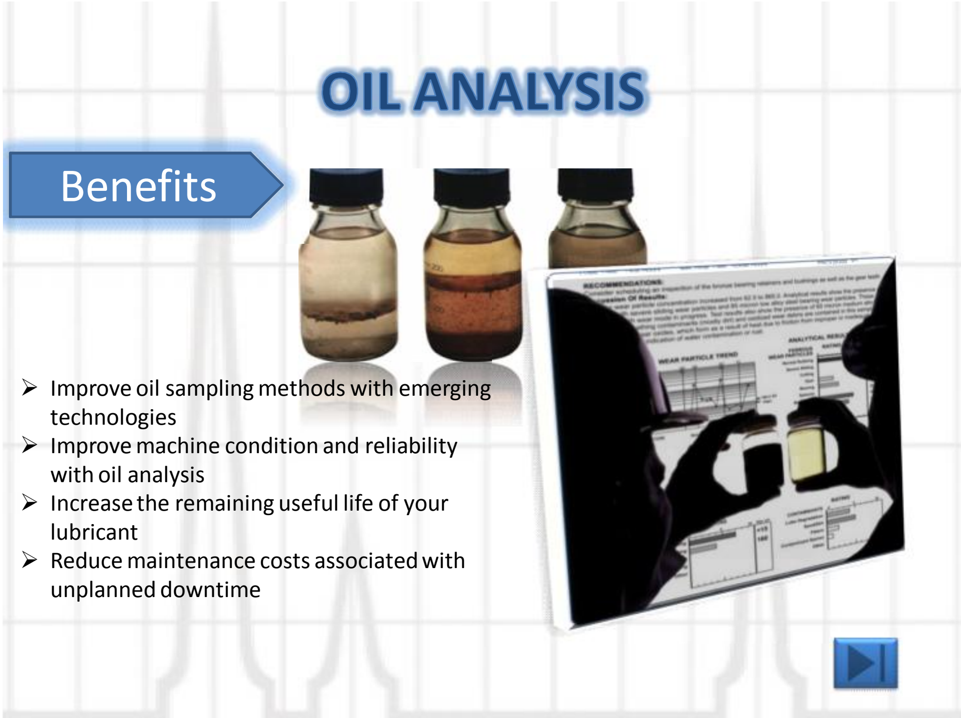
Can you afford not to have a Thermography Survey?

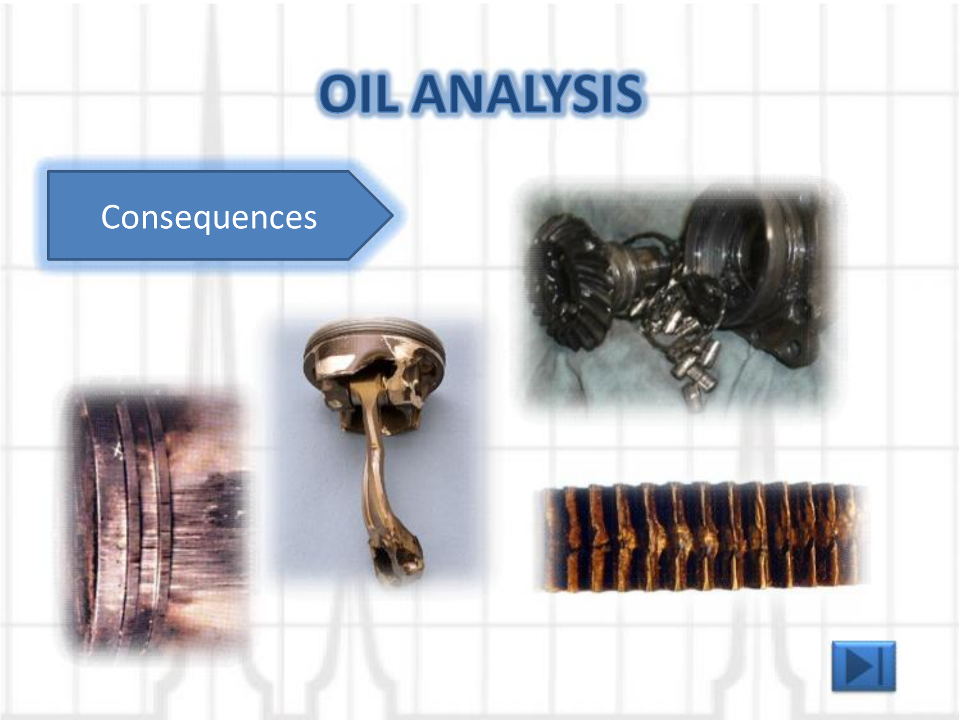
Fire damaged electrical system

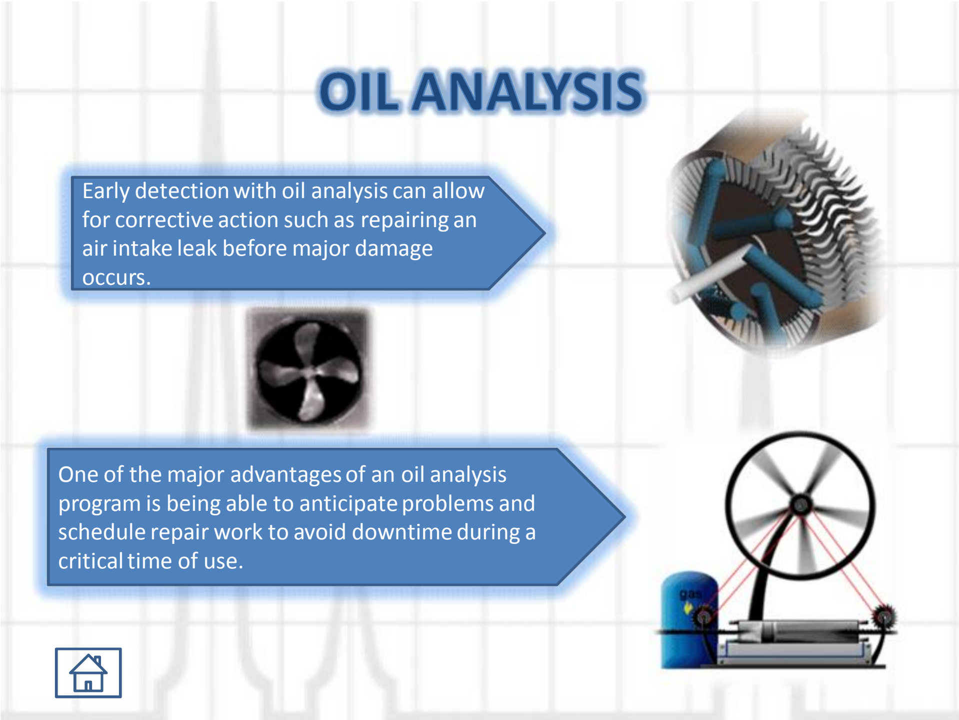
Cruise Ship Fire Damage

OIL ANALYSIS

- Oil Analysis is a non-destructive test used to assess the condition of lubricants and determine the type and amount of contamination present.
- Criticality of lubrication to most industrial equipment, oil analysis trending over time is one of the most powerful predictive tools for identifying potential failures.
- 3 basic categories of elements affecting the lubrication effectiveness: wear metals, contaminants, and additives.


OIL ANALYSIS
Benefits
Improve oil sampling methods with emerging technologies
Improve machine condition and reliability with oil analysis
Increase the remaining useful life of your lubricant
Reduce maintenance costs associated with unplanned downtime


OIL ANALYSIS
Consequences



3.11.Wear Debris Analysis

Using a Scanning Electron Microscope of a carefully taken sample of debris suspended in lubricating oil (taken from filters or magnetic chip detectors).

Instruments then reveal the elements contained, their proportions, size and morphology.

Using this method, the site, the mechanical failure mechanism and the time to eventual failure may be determined. This is called WDA - Wear Debris Analysis

UNIT IV
REPAIR METHODS FOR BASIC MACHINE ELEMENTS

4.1.Repair Methods For Beds

M ANY READERS must be in possession of lathes and other machinery that have slide wear con-centrated in sections of most use. 1 expect that some have heard of, if not come in contact with, the old craftsman held in awe because his mach-ine is in such a bad condition that he is the only one able to produce good work from it. How much better he could perform on a good machine where full concentration could be given to the w o r k p i e c e r a t h e r t h a n t h e e c c e n t r i c i t i e s a n d shortcomings of his machine tool.

An accurate machine is a joy to use. but wear
creeps in insidiously, one foun impos
day it is d s-
ible to adjust gibs to ful trave and
the give l l yet
b tigh enoug accurat wor in sectio
e t h for e k the n
mos use. this arise it
of t When situation s does
not necessarily mean an expensive regrind for your lathe bed for example, my aim is to show
how small machine tool slides may be restored
by the amateur with a minimum of equipment. In
this age of enormous labour costs few reasonably
priced machines have hand-finished slides, so
owne of machines may profit from
rs new a little
of work
the I shall attempt to describe.

Rather than describe the overhaul of a par-ticular make and type of machine 1 shall give a procedure for a 3-1/2 in. lathe, I am sure readers will be able to apply the principles and methods
involved to their own make and size of lathe,
also millers, shapers etc.

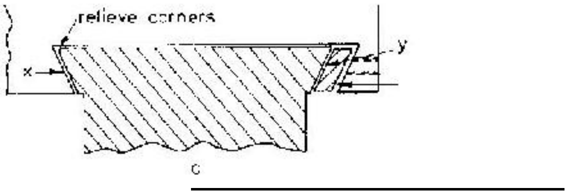
S o me of the methods I use may not be theo-retically correct and there may be better ways given sophisticated equipment but if they are employed intelligently and dextrously they work; I don't want to be jumped by the "Talk in half thou's, work in half yards" brigade.

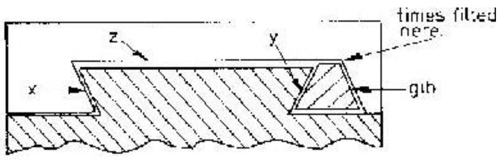
Before stripping, overhaul the headstock man-drel and bearings. I do not intend to enlarge on this, volumes have been written on the subject, adjustment is usually built in anyway. Good bear-
ings are essential for up the lat
letting slides er
an the lathe is still new hav
d intact if bearings e
to be machined.

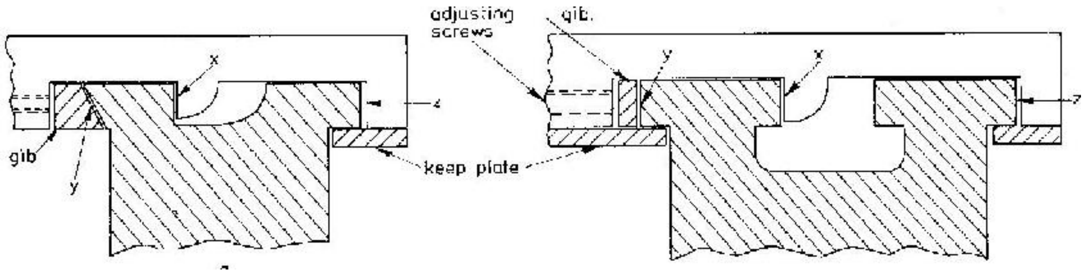
Strip the lathe right down th
to e bed, now
check the mounting onto stan
bench or d that
the bed is not twisted by dow
the holding n
bolts, this can be checked with a sensitive spirit level across headstock seating and unworn sec-tions of bed, readings should be exactly the
same, if not shim adjust bolt
or the jacking s
to correct. Much care be
more must taken with
a bed mounted on feet at each end than the cantilever type.

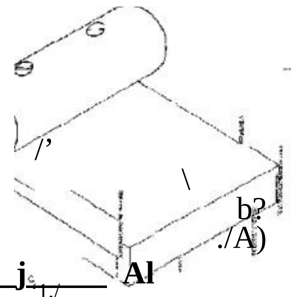
Clean the bed thoroughly with carbon tet. or similar solvent and take a good look at it in c o n j u n c t i o n w i t h t h e s a d d l e , h e a d s t o c k , tail-stock and sketches Fig. 1, identify the main guide faces, these will always be opposite the gib faces.

Now to check the wear present, I doubt if many readers have a fishback surface plate as

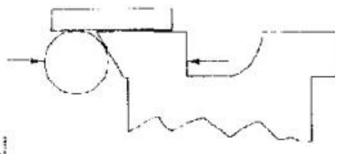

relieve corners
x
y
c


times fitted here.
z
y
x
gib


adjusting screws
gib.
x
y
z
gib
keep plate



Jig for measurement accross vee slides
Fig 2



Jig in use to check parallelism of main and gib faces of lathe bed

long as the bed, but a 24 in. straight-edge can, with care, be used equally well. The thick type of straight-edge as used in combination sets is certainly the best and easiest to use. These straight-edges can be obtained plain without graduations at a considerable saving In cost.

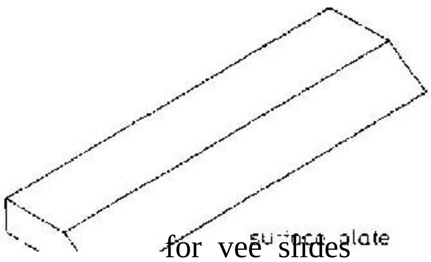
Try along the top flats of the bed with the straight-edge, if the headstock seating is on the same level as the bed, bridge the gap from un-worn seating to bed as far back as possible and try to insert a .0015 in. feeler gauge in worn section; unless wear is excessive you will prob-ably find that It won’t go. Wear will have to be detected by holding the straight-edge firmly down on the bed carefully keeping it vertical and flex-ing it sideways, a little practice and you will be able to feel where the bed is hollow or worn.

Check the bed all over including guide edges in this manner, you will probably be comforted to find that very little wear is causing all that trouble. A check on the actual amount of wear present can be taken by using micrometers, vernier or ordinary calipers over and between all bed surfaces. To measure over vee slides a jig or jigs must be made as shown in Fig. 2. Screw a 1-1/2in. length of ground stock to a piece of 1-1/2 in. x 1/4 in. flat with one face trued flat.

Before scraping the bed a good surface plate at least 6 in. x 6 in. will be necessary and also an off standard one about 2 in. x 1 in. x 8 in. with one edge machined and scraped flat at about 45 degrees. a piece of old cast iron strip from a large machine is excellent, see Fig. 3.

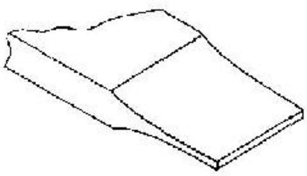
Cast iron tends to form a thin but very hard skin, so a few words on scrapers and the method of attacking the surface are in order. I have not yet found a commercial scraper that is hard enough for use on machine slides, 1 have found the best is a good quality parallel flat file thinned by grinding see Fig. 3 and the end hardened right out by quenching in water; for the work in hand 3/4 in. wide is about right.

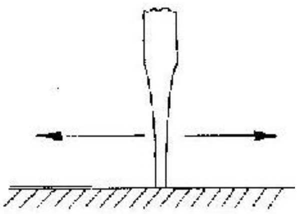
Two different methods of sharpening are used, one for roughing and one finishing. The rough-ing scraper is flat and straight ended, not curved, as the book says and the finishing scraper is



for vee slides

e





oilston

ROUGHING SCRAPER SHARPENING

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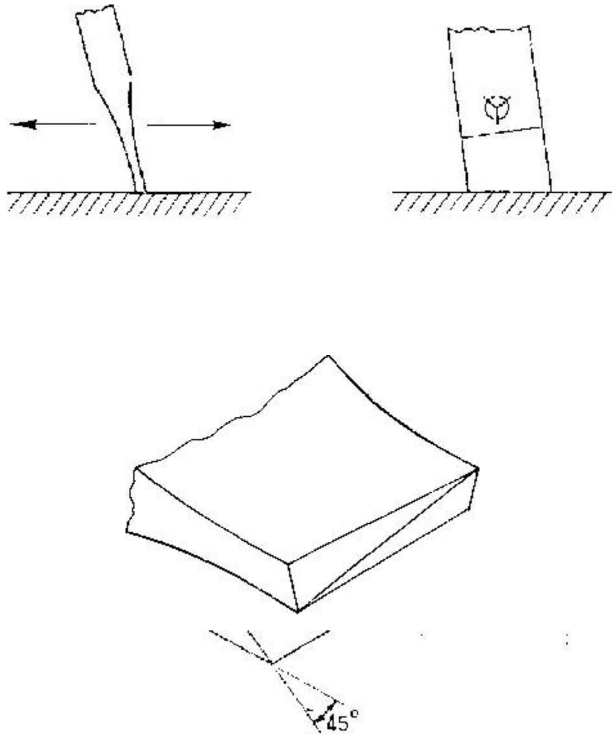
Fig. 3 FINISHING SCRAPER SHARPENING



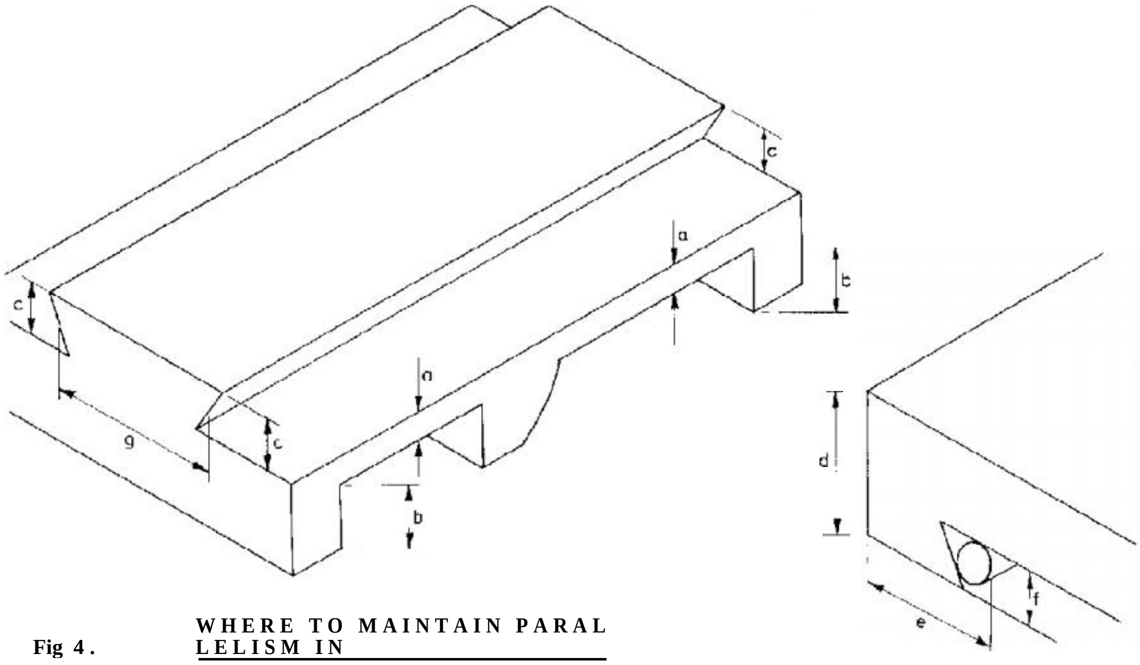


Fig 4. WHERE TO MAINTAIN PARALLELISM IN SADDLE AND CROSS-SLIDE

sharpened as Fig. 3. This scraper is used to remove the high spots and is worked with a sort of forward-sideways-rocking motion, like

digging high out. sorry, but
the spot I am this
is the descripti to give,
best on I am able those

that are able to mottle will understand what I mean and also the difficulty of describing it, how-ever do not despair if you are not able to mottle, a very attractive frosted effect may be obtained quite easily.

Start scraping down the top of the bed with the roughing scraper. Work at about 45 degrees across the bed, use long even strokes and put

som pressur remov met evenly
e e on, try to e al .
difficul encounter breaki skin
If ty is ed ng the use
fin 6 fla fil press agai at
a e in. t e ed firmly, n about

45 degrees across the bed and worked slowly and evenly. This will score the surface to give the scraper a bite. With the skin removed use level, straight-edge and feelers to take the high areas down evenly to the lowest point of wear. The scraper should be sharpened frequently on a

medium India use anything
stone, do not coarser
as it will cause scraper score the bed.

the to Each
pass along the bed should be at 90 degrees to the previous one.

When you are satisfied the bed is dead flat to the straight-edge smear the large surface plate with engineers' marking blue and slide it up and down the bed a few times, the high spots revealed will probably be few and far between, but if the preceding work has been correctly carried out no perceptible rock should be felt in the plate. Still using the roughing scraper, take the high spots off and repeat a few times until a reasonable contact is shown all over the bed. By now smal! bright spots surrounded by blue should begin to appear, using the finishing scraper take these off. A word of caution. large areas of heavy blue do not mean a good bearing, it means too much blue on the plate, 1 repeat, the very high spots will show bright surrounded by blue. If you pick the high spots off with a short forward and sideways motion working at 45 degrees across the bed and the next time the plate is used, at 45 degrees the other way the high spots

will appear in more dense clusters and a very nice frosted effect will take form on the bed. It is now up to the individual how much time, patience and dexterity he puts in to obtain a bearing surface, the more and closer the high spots, the greater bearing and flatter surface, but whenever the work is stopped the bearing should be even all over the bed. All the low areas surrounded the high spots are “oil wells” which will help to retain lubrication on the surface.

Locate the main guide face and carry out the same procedure on it, if this face serves as the headstock location work on this as well to obtain a straight flat face right through. The tailstock is probably guided by the same face as the saddle but if not, this is the next for attention, measurements must be taken from the completed face to ensure parallelism. The secondary or gib faces for the saddle and tailstock are worked on next, not only maintaining straightness and flat-ness but parallelism is of paramount importance. Working clearances are so small that half a thou make the difference between binding s and slack in the assembled machine, so if you can measure a difference, scrape it out. The top and vertical faces complete, the bed can be removed from its stand and turned over for work on the underside of the shears, make sure these faces are kept dead parallel with the top of the bed.

It may be advantageous to remove some vee type beds from the stand at an earlier stage than this but every effort should be made to get the main guide faces completed while firmly held to prevent twist.

The completed bed can be refitted to its stand, take great care to avoid distortion.

Before commencing work on the saddle you should look at the consequences of your actions. Removing metal from the bed means that the saddle will lie in a different plane from the original, lower and to one side, this will be magnified by the time the saddle is trued up, there will be misalignment between leadscrew

bearings and the split nut. Since the intention is to deal with a few thou of wear and not a really "clapped out" machine, there will also be wear in the nut and bearings and it is doubtful that the slight misalignment will have any adverse effects.

When wear is excessive and the bed has to be machined or ground the usual procedure is to machine out the saddle and tailstock and screw o n p l a t e s t o c o m e b a c k t o s t a n d a r d , o t h e r methods can be used depending on the design of the machine, bearings can be repositioned, apron modified etc.

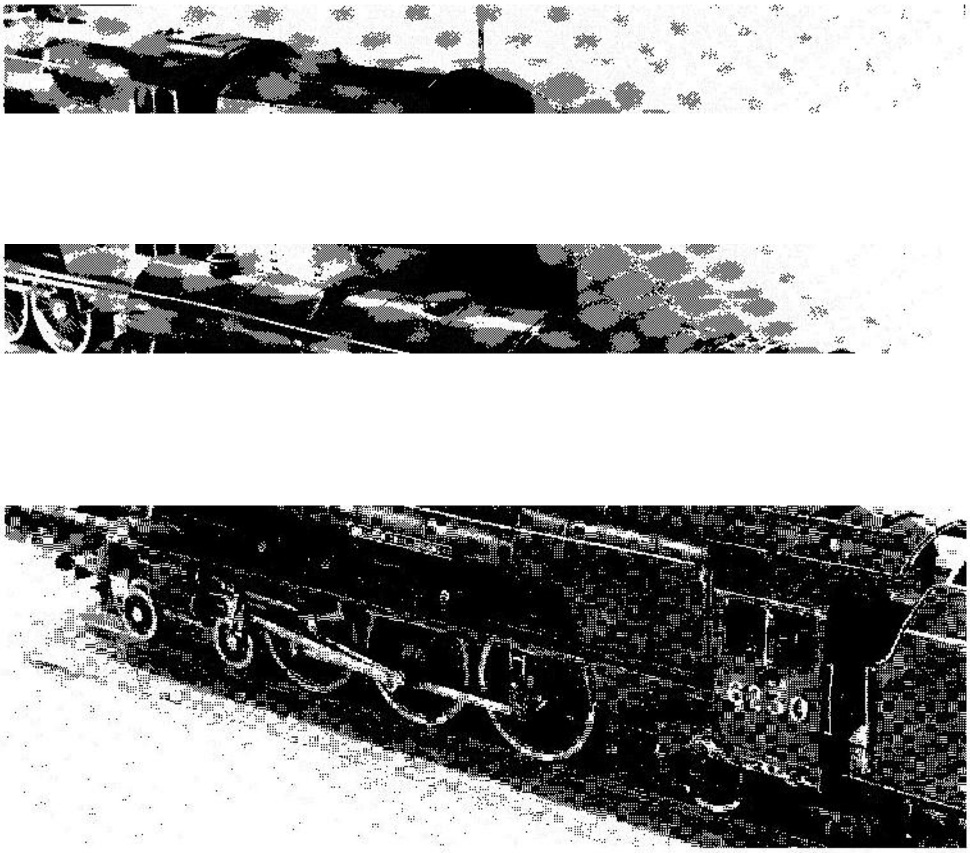
Every individual must use a fair amount of initiative to apply these principles to his own machine, so a warning to use forethought and envisage the consequences of metal removal and the possible action necessary to correct, look even further, the consequence of this action. Be s u r e that curing one problem does not create a bigger one. Clean the saddle off with solvent and check for wear on the bearing surfaces by means of straight edge and feelers, the surface plates can also be of use here, in addition take measure-ments as Fig. 4. It is essential to scrape the bearing faces so that when complete the cross-slide or boring table top face will be dead parallel w i t h t h e b e d . L a t h e s u s e d f o r n o r m a l w o r k almost always suffer most wear on the saddle

main guide face, a straight edge will probably show this face to be bowed, true it when this must be squared with the cross-slide.

Many small lathes have a boring table with vee slides longer than the mating ones on the saddle, it is better to work on this first leaving the saddle until afterwards. The boring table slides will probably resemble those in Fig. 1d,
except th gib is more likely to be
that e as Fig.
lc. under bearing faces true
Scrape the and flat
to the large surface plate, taking care
to keep
measurements top face exactly the
to the same
round. th main guide face true
all Scrape e to
th vee surface and dead parallel to
e plate the
front edge of the table, use a piece of ground stock to take measurements, see Fig. 4. Blue the boring table slides and use as a reference to scrape the flats and main guide face of the saddle cross slide surfaces, take the points of the vees off with a file to give clearance in the corners if necessary. Using the vee surface plate and pieces of ground stock for measurement
scrape gi face with mai guide
the b parallel the n .
If the is of the type Fig. lc,
gib shown in it is
only to scrape bearin
necessary the g face flat to
the surface plate and the cross-slide can be cleaned, oiled and assembled. Test by pushing back and fore by hand, it will be heavy to start but should then move with an even drag with-
ou tight slac
t ork spots.
I i likel tha the gib strip is steel, if
t s y t so, use
a of cuttin oil on the thi
spot soluble g scraper, s
wil preven pic up giv bright cut
l t k and e a clean ,
the scraper will work much more cleanly and smoothly.

Some machines may have a different type of gib strip. there are many different designs in use, a few are shown at Fig. I. The gib at Fig. Id is retained by screws up through it or down through the slide, it is a dead fit and to take up slack it must be carefully filed on the top face to let it in. Sornetimes peeler shims are fitted to help, a good bearing must be obtained on both taper and top face and retaining screws kept dead tight. This type needs a lot of time, patience and skill to fit well. The gib at Fig. la may be a dead fit and have to be treated as Id but it is more likely that there are adjusting screws behind it and the retaining bolts pass through clearance holes in the gib to allow for adjustment. It is unlikely that a
tape ke will met with in small
r y be machines but
s fitte to a good bearing
if o it is d throughout
it leng o faces
s th n both .

To true the saddle main guide face square with the cross-slide put the saddle with boring table
fitted surfac supported
upright on the e plate on
th edg o th this parallel
e front e f e table, is with
slide us a square between plate and
its s, e guide
face, bow true the
file out with square.



A 3-1/2 in. gauge ***L.M.S "Duchess" built by T. A. Bott and loaned by J. E. Langrishe. t'hotographs: Keith Lauderdale.***

Right: Model steam yacht "Alva" by Ian ***Sharp of the Burrow Ship Model Society.***

Z-gauge one from the Manchester M.R.S. occupying only 6 ft. x 3 ft.

The Barrow Ship Model Society againt pu on a show of ship models, both sail and power. Perhaps the most outstanding ship model was the steam yacht by Ian Sharp, powered by a Stuart 1O V engine and a spirit fired boiler.

Among the very fine locomotives was the 3-1/2 in. gauge Vale of Rheidol engine by Alan Green of Urmston. A. Walshaw of Kendal showed his model beam engine, a Silver Medal winner at the M. E. Exhibition, and there were several horse-drawn vehicles, such as a model tip cart by Bill Whidborne, an Oxfordshire hoop-raved wagon and a gypsy straight-sided wagon.

In the School yard, the F.M.R.C.'s 5 in. gauge portable track was kept busy, the Club's

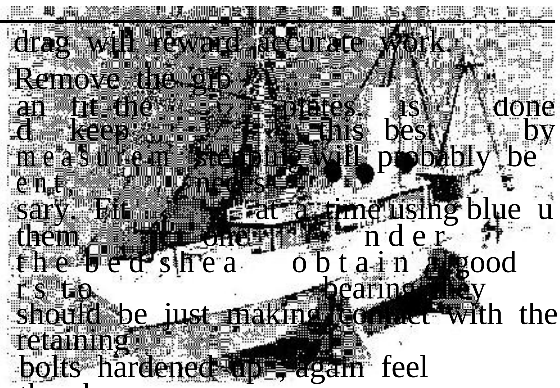
S i m p l e x
giving a good account of itself.

Overhauling the lathe

By B. J. Whitehead

Part II ***From page 803***

FILE AND SCRAPE out any measurable difference in under-saddle to cross-slide thickness. blue the bed and bed in the saddle flats and main guide fac t it i advantage lighte e o ; t is an to n the bearin th centre of the face g in e guide keeping a really good bearing at both ends. True up the gib clean oil saddle and bed, , and fit and adjust the gib and push saddle the from end to end of the bed, any tight spots will be felt, an even



drag will reward accurate work.
Remove the gib
an fit the plates. is done d keep this best by m e a s u r e m ent will probably be e n t nes sary. Fit at a time using blue u them one n d e r the bed s h e a o b t a i n a good r s to bearing. They should be just making contact with the retaining bolts hardened up , again feel the drag.

Assemble saddle. apron. leadscrew. cross-slide an screw check that workin d and everything i s g smoothly and correctly. Refit the headstock and chuck a piece of I in. 1-1/2 in. dia. ground stock about 7 in. long, perfect 8 in. set it to run ly tru through- it length. test e out s fix a dial indicator the cross- magneti stan i excelle on slide. a c d s nt for this if you have one, so that it may be traversed over the ground bar by means of the cross-slide ; take the highest readings at the chuck and unsupported ends of the bar, any discrepancy between these readings indicates the amount the headstock mandrel is out of parallel with the bed. Scrape the underside of the headstock. maintaining a good bearing to correct. With the head-stock refitted and the test bar still chucked and now dead parallel vertically with the bed set the D.T.I. against the side of the bar at centre height ; traverse it by means of the saddle along the length of the bar. The difference in reading end to end must be corrected by scraping the head-stock locating face or using any adjustment incorporated in the machine.

When you are satisfied that the headstock is dead true with the bed, make the acid test on cross-slide squareness. Attach the "clock" to the faceplate so that by swinging it, it makes con-tact with each end of the true front face of the boring table or alternatively each end of a length of straight ground stock laid in the front vee of the cross slide with the table removed. It is usual to set the cross-slide not absolutely dead square but so that it will face .001 in. - .002 in. concave in the diameter of the faceplate, this ensures that faced components will mate together without rock. You will probably find that it will be necessary to again strip the saddle etc. and scrape the main guide face to obtain this setting for the cross-slide.

The next problem is the tailstock. Blue the bed and scrape the tailstock to a good bearing with it. Extend the barrel fully and lock, set the D.T.I. on the faceplate so that it can be swung around the barrel, lock the tailstock on the bed with the D.T.I. at the front end of the extended barrel, take readings around the barrel and move the set-over device to centralise the barrel with the headstock; note any discrepancy in height, Now move the tailstock bodily up the bed and again lock so that reading can be taken as near to the casting as possible. If the barrel at this point is out of centre and is of a different height the tail-stock flats and main guide face will have to be scraped to correct. The barrel should now be parallel to the bed but it is probably low in rela-tion to the headstock, the cures for this are either file and scrape the underside of the headstock to bring it down in line or machine out and fit plates where tailstock is split for set over to bring it up. A quick way out is to use shims instead of machining out and fitting plates. If the barrel is badly worn, some may consider fitting the tail-stock infront of the saddle, just take up the lock to bear and bore out using the saddle to push it along, it is then bound to be in line, either bush or fit an over size barrel.

The top-slide is dealt with in the same way as the cross-slide, anyone that has gone this far will not find it any problem.

I hope these notes will be of some use to readers who are prepared to use time, patience and elbow grease to improve their machines, but are not quite sure how to go about it, I can assure them that their efforts will be amply rewarded, I will bet they will think twice about using emery without precautions on the lathe afterwards.

AROUND THE TRADE

New "Braze-Welder"

Kellers Welding Centre of 32133 Cattle Market Street, Norwich: are manufacturing a new style of welding equipment designed for brazing as well as welding. Known as the Kel -Arc Braze-Welder, this works from the domestic 230-250 volt electricity supply and comprises a fan-cooled transformer, a "Chem-Arc" torch with pencils, a set of welding leads and electrode holder and earth clip. and an industrial head mask. A supply of 16 gauge elec-trodes and flux-coated brazing rods are also included.

The Braze-Welder is designed to braze or weld metals from thin steel sheet of 24 s.w.g. up to 1/8 in. plate.

Drawings of farm carts

We have received samples of the “Mode1 Wheel-wright” plans produced by John Thompson of 15 Darset Avenue, Fleet, Aldershot, Hants.

The drawings include a sketch of the item to show the general appearance, information on the present location of the item, its origin and history etc., and the correct names of the various parts.

The drawings are to scale, key dimensions only being given. They are all of items accessible at the public museums, etc.
Two instruction charts are available, covering tools, materials and methods of construction.
The supplier's list draws attention to the Model Horse Drawn Vehicles Club-Mr. J . B. Pearce, 4 Heron Drive, Westgate, Morecambe, Lanes.

16,000 Official Drawings now available to model engineers

Many readers of the Model Engineer have already availed themselves of the opportunity to secure copies of the authentic works drawines. which have bekn collected, filmed, and marketed by British Rail/ Oxford Publishing Co. over the past 18 months. However, as the total number of plans located has now reached the staeeerine figure of 16.000. and

Users of metal working machines from FUM PORÊBA confirm the very good working properties of plastic linings.

It is important that plastic linings should be lubricated and protected against contamination during their work.

mant company). This resin is put on a roughly machined surface of carriage ways, and then bed ways are impressed in it. This assures identical map-ping of a sliding surface between a bed and a carriage. Carriage and bed mutual setting should be established earlier.

MOGLICE plastic is usually used during metal working machine repair,because it is the simplest method of regeneration and restoring of the ma-chine work accuracy. Losses of way sliding surface can be filled with this

The application of polymer materials on sliding way elements, in the form of linings, assures very good friction conditions and low wear of ways.

The use of these materials in the construction of numerically controlled metal working machines is also advantageous as regards production econo-mics. Polymer materials play an important role during the

there are seevral model hav perhaps engineers w h o e yet to realise what a chance is hav just here I e begged space from the Editor to try and indicate the progress of this collection, and to give some idea of its coverage.

Briefly-its origin came about through the co-operation of an enthusiastic Public Relations Office

4.2.Repair methods for slideways

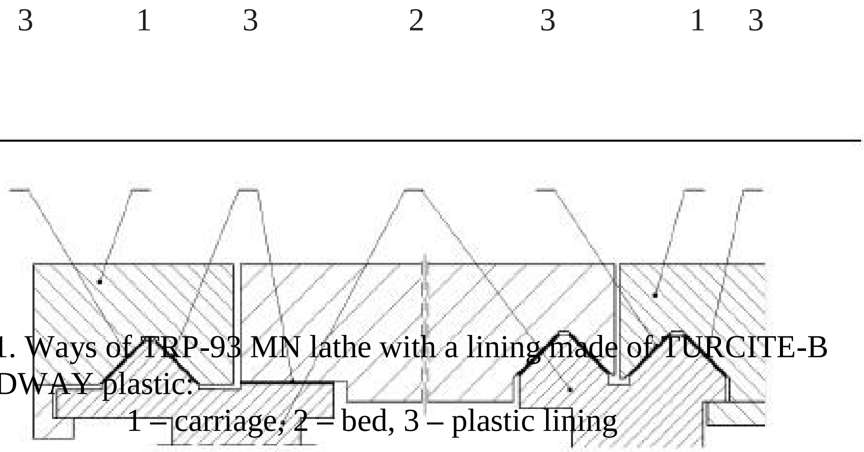


Fig. 1. Ways of TRP-93 MN lathe with a lining made of TURCITE-B SLYDWAY plastic:
1 – carriage, 2 – bed, 3 – plastic lining

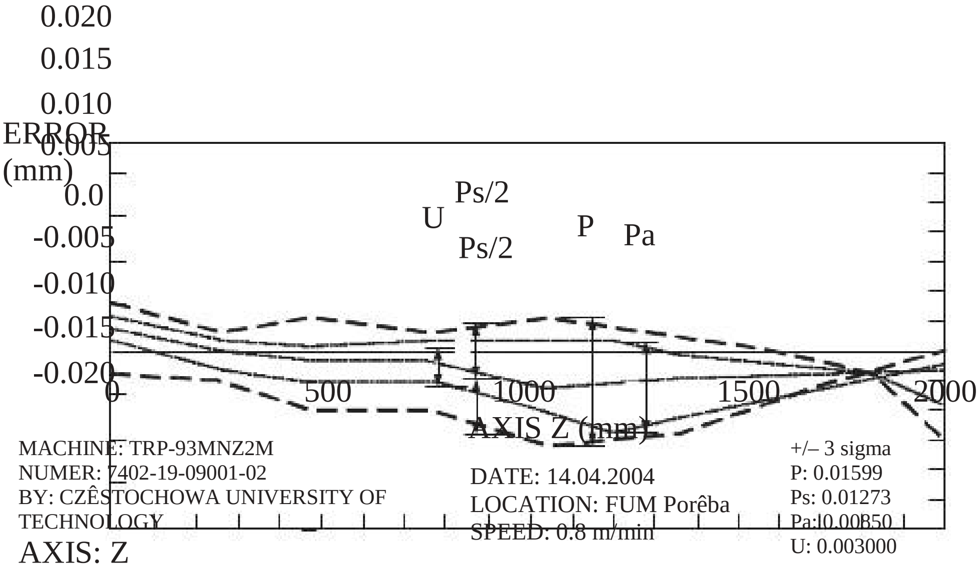


Fig. 2. Diagram of TRP-93MN lathe positioning error along the Z axis,
according to the VDI/DGQ 3441 standard (Standard VDI/DGQ 3441...)

Fault tree analysis (FTA) is a top down, deductive failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level events. This analysis method is mainly used in the fields of safety engineering and reliability engineering to understand how systems can fail, to identify the best ways to reduce risk or to determine (or get a feeling for) event rates of a safety accident or a particular system level (functional) failure. FTA is used in the aerospace, nuclear power, chemical and process,[1][2][3] pharmaceutical, petrochemical and other high-hazard industries; but is also used in fields as diverse as risk factor identification relating to social service system failure.[4]

In aerospace, the more general term "system Failure Condition" is used for the "undesired state" / Top event of the fault tree. These conditions are classified by the severity of their effects. The most severe conditions require the most extensive fault tree analysis. These "system Failure Conditions" and their classification are often previously determined in the functional Hazard analysis.

FTA can be used to:

- understand the logic leading to the top event / undesired state.
- show compliance with the (input) system safety / reliability requirements.
- prioritize the contributors leading to the top event - Creating the Critical Equipment/Parts/Events lists for different importance measures.
- monitor and control the safety performance of the complex system (e.g., is a particular aircraft safe to fly when fuel valve *x* malfunctions? For how long is it allowed to fly with the valve malfunction?).
- minimize and optimize resources.
- assist in designing a system. The FTA can be used as a design tool that helps to create (output / lower level) requirements.
- function as a diagnostic tool to identify and correct causes of the top event. It can help with the creation of diagnostic manuals / processes

History[edit]

Fault Tree Analysis (FTA) was originally developed in 1962 at Bell Laboratories by H.A. Watson, under a U.S. Air Force Ballistics Systems Division contract to evaluate the Minuteman I Intercontinental Ballistic Missile (ICBM) Launch Control System.[5][6][7][8] The use of fault trees has since gained widespread support and is often used as a failure analysis tool by reliability experts.[9] Following the first published use of FTA in the 1962 Minuteman I Launch Control Safety Study, Boeing and AVCO expanded use of FTA to the entire Minuteman II system in 1963-1964. FTA received extensive coverage at a 1965 System Safety Symposium in Seattle sponsored by Boeing and the University of Washington.[10] Boeing began using FTA for civil aircraft design around 1966.[11][12]

Subsequently within the U.S. military, application of FTA for use with fuzes was explored by Picatinny Arsenal in the 1960s and 1970s.[13] In 1976 the U.S. Army Material Command incorporated FTA into an Engineering Design Handbook on Design for Reliability.[14] The Reliability Analysis Center at Rome Laboratory and its successor organizations now with the Defense Technical Information Center (Reliability Information Analysis Center and now Defense Systems Information Analysis Center, http://theriac.org/)has published documents on FTA and reliability block diagrams since the 1960s.[15][16][17] MIL-HDBK-338B provides a more recent reference.[18]

In 1970, the U.S. Federal Aviation Administration (FAA) published a change to 14 CFR 25.1309 airworthiness regulations for transport category aircraft in the Federal Register at 35 FR 5665 (1970-04-08). This change adopted failure probability criteria for aircraft systems and equipment and led to widespread use of FTA in civil aviation. In 1998, the FAA published Order 8040.4,[19] establishing risk management policy including hazard analysis in a range of critical activities beyond aircraft certification, including air traffic control and modernization of the U.S. National Airspace System. This led to the publication of the FAA System Safety Handbook, which describes the use of FTA in various types of formal hazard analysis.[20]

Within the nuclear power industry, the U.S. Nuclear Regulatory Commission began using probabilistic risk assessment (PRA) methods including FTA in 1975, and significantly expanded PRA research following the 1979 incident at Three Mile Island.[21] This eventually led to the 1981 publication of the NRC Fault Tree Handbook NUREG–0492,[22] and mandatory use of PRA under the NRC's regulatory authority.

Following process industry disasters such as the 1984 Bhopal disaster and 1988 Piper Alpha explosion, in 1992 the United States Department of Labor Occupational Safety and Health Administration (OSHA) published in the Federal Register at 57 FR 6356 (1992-02-24) its Process Safety Management (PSM) standard in 19 CFR 1910.119.[23] OSHA PSM recognizes FTA as an acceptable method for process hazard analysis (PHA).

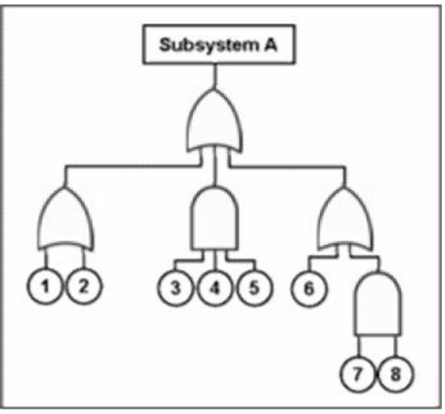
Methodology[edit]

FTA methodology is described in several industry and government standards, including NRC NUREG–0492 for the nuclear power industry, an aerospace-oriented revision to NUREG–0492 for use by NASA,[24] SAE ARP4761 for civil aerospace, MIL–HDBK–338 for military systems, IEC standard IEC 61025[25] is intended for cross-industry use and has been adopted as European Norm EN 61025.

Since no system is perfect, dealing with a subsystem fault is a necessity, and any working system eventually will have a fault in some place. However, the probability for a complete or partial success is greater than the probability of a complete failure or partial failure. Assembling a FTA is thus not as tedious as assembling a success tree which can turn out to be very time consuming.

Because assembling a FTA can be a costly and cumbersome experience, the perfect method is to consider subsystems. In this way dealing with smaller systems can assure less error work probability, less system analysis. Afterward, the subsystems integrate to form the well analyzed big system.

An undesired effect is taken as the root ('top event') of a tree of logic. The logic to get to the right top events can be diverse. One type of analysis that can help with this is called the functional hazard analysis, based on Aerospace Recommended Practise. There should be only one Top Event and all concerns must tree down from it. Then, each situation that could cause that effect is added to the tree as a series of logic expressions. When fault trees are labeled with actual numbers about failure probabilities, computer programs can calculate failure probabilities from fault trees. When a specific event is found to have more than one effect event, i.e. it has impact on several subsystems, it is called a common cause or common mode. Graphically speaking, it means this event will appear at several locations in the tree. Common causes introduce dependency relations between events. The probability computations of a tree which contains some common causes are much more complicated than regular trees where all events are considered as independent. Not all software tools available on the market provide such capability.



A fault tree diagram

The Tree is usually written out using conventional logic gate symbols. The route through a tree between an event and an initiator in the tree is called a Cut Set. The shortest credible way through the tree from fault to initiating event is called a Minimal Cut Set

Some industries use both fault trees and event trees (see Probabilistic Risk Assessment). An Event Tree starts from an undesired initiator (loss of critical supply, component failure etc.) and follows possible further system events through to a series of final consequences. As each new event is considered, a new node on the tree is added with a split of probabilities of taking either branch. The probabilities of a range of 'top events' arising from the initial event can then be seen.

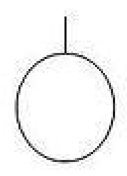
Classic programs include the Electric Power Research Institute's (EPRI) CAFTA software, which is used by many of the US nuclear power plants and by a majority of US and international aerospace manufacturers, and the Idaho National Laboratory's SAPHIRE, which is used by the U.S. Government to evaluate the safety and reliability of nuclear reactors, the Space Shuttle, and the International Space Station. Outside the US, the software RiskSpectrum is a popular tool for Fault Tree and Event Tree analysis and is licensed for use at almost half of the worlds nuclear power plants for Probabilistic Safety Assessment.

Graphic Symbols[edit]

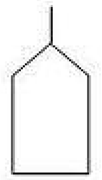
The basic symbols used in FTA are grouped as events, gates, and transfer symbols. Minor variations may be used in FTA software.

Event Symbols[edit]

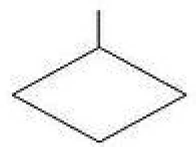
Event symbols are used for *primary events* and *intermediate events*. Primary events are not further developed on the fault tree. Intermediate events are found at the output of a gate. The event symbols are shown below:

- 

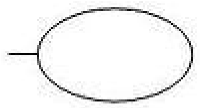
  Basic event

- 

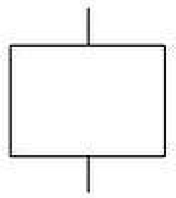
  External event

- 

Undeveloped event

- 

Conditioning event

- 

Intermediate event

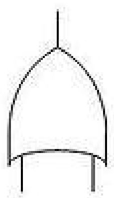
The primary event symbols are typically used as follows:

- **Basic event** - failure or error in a system component or element (example: switch stuck in open position)
- **External event** - normally expected to occur (not of itself a fault)
- **Undeveloped event** - an event about which insufficient information is available, or which is of no consequence
- **Conditioning event** - conditions that restrict or affect logic gates (example: mode of operation in effect)

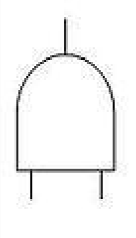
An intermediate event gate can be used immediately above a primary event to provide more room to type the event description. FTA is top to bottom approach.

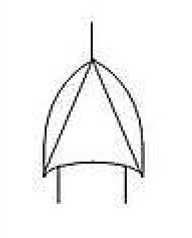
Gate Symbols[edit]

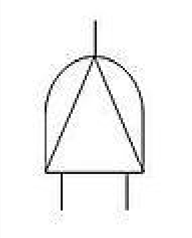
Gate symbols describe the relationship between input and output events. The symbols are derived from Boolean logic symbols:

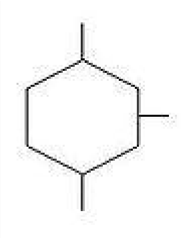
- 

OR gate

- 

  AND gate
- 

  Exclusive OR gate
- 

  Priority AND gate
- 

  Inhibit gate

The gates work as follows:

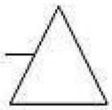
- **OR gate** - the output occurs if any input occurs
- **AND gate** - the output occurs only if all inputs occur (inputs are independent)
- **Exclusive OR gate** - the output occurs if exactly one input occurs
- **Priority AND gate** - the output occurs if the inputs occur in a specific sequence specified by a conditioning event
- **Inhibit gate** - the output occurs if the input occurs under an enabling condition specified by a conditioning event

Transfer Symbols[edit]

Transfer symbols are used to connect the inputs and outputs of related fault trees, such as the fault tree of a subsystem to its system.

- 

Transfer in

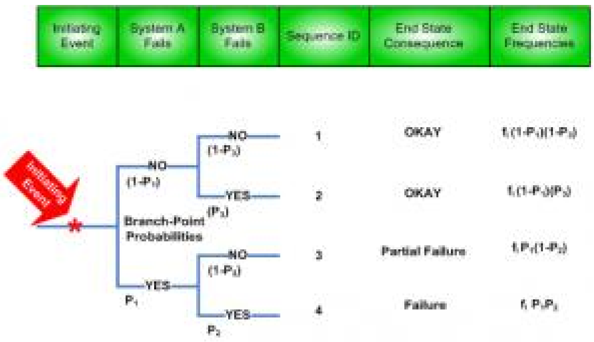
- 

Transfer out

ARES Corporation is skilled at developing event trees and fault trees; providing a systematic method for investigating accident and/or failure scenarios involving complex systems. These trees evaluate the pathways leading to failure of a system and the associated risk(s).

The event tree development process determines the boundaries of the particular analysis by defining the initiating event and the possible outcomes for each sequence of events. The event tree analysis defines possible scenarios including success, and partial and/or complete system/subsystem failure. Fault trees are often used to quantify system events that are part of event tree sequences.

An event tree is a graphical representation of the logic model that identifies and quantifies the possible outcomes following an initiating event. Beginning with an initiating event; the event tree details a sequence of pivotal events that lead to specific end states (e.g. OK, Partial Failure or Failure). As each new top event is considered, a new node on the tree is added with a split of probabilities taking either branch.



Root cause analysis (**RCA**) is a method of problem solving that tries to identify the root causes of faults or problems.[1] A root cause is a cause that once removed from the problem fault sequence, prevents the final undesirable event from recurring. A causal factor is a factor that affects an event's outcome, but is not a root cause. Though removing a causal factor can benefit an outcome, it does not prevent its recurrence for certain. RCA arose in the 1950s as a formal study following the introduction of Kepner-Tregoe Analysis, which had limitations in the highly complex arena of rocket design development and launch in the United States by the National Aeronautics and Space Administration (NASA). New methods of problem analysis developed by NASA included a high level assessment practice called MORT (Management Oversight Risk Tree).[2][3][4] MORT differed from RCA by assigning causes to common classes of cause shortcomings, that summarized became a short list. These included work practice, procedures, management, fatigue, time pressure, along with several others. For example, an aircraft accident could occur as a result of weather augmented by pressure to leave on time. Failure to observe weather precautions could indicate a management or training problem, while lack of any weather concern might indict work practices.

RCA practice solve problems by attempting to identify and correct the root causes of events, as opposed to simply addressing their symptoms. Focusing correction on root causes has the goal of preventing problem recurrence. RCFA (Root Cause Failure Analysis) recognizes that complete prevention of recurrence by one corrective action is not always possible.

Conversely, there may be several effective measures (methods) that address the root causes of a problem. Thus, RCA is an iterative process and a tool of continuous improvement.

RCA is typically used as a reactive method of identifying event(s) causes, revealing problems and solving them. Analysis is done *after* an event has occurred. Insights in RCA may make it useful as a preemptive method. In that event, RCA can be used to *forecast* or predict probable events even *before* they occur. While one follows the other, RCA is a completely separate process to Incident Management.

Root cause analysis is not a single, sharply defined methodology; there are many different tools, processes, and philosophies for performing RCA. However, several very-broadly defined approaches or "schools" can be identified by their basic approach or field of origin: safety-based, production-based, process-based, failure-based, and systems-based.

- Safety-based RCA descends from the fields of accident analysis and occupational safety and health.
- Production-based RCA has its origins in the field of quality control for industrial manufacturing.
- Process-based RCA is basically a follow-on to production-based RCA, but with a scope that has been expanded to include business processes.
- Failure-based RCA is rooted in the practice of failure analysis as employed in engineering and maintenance.
- Systems-based RCA has emerged as an amalgamation of the preceding schools, along with ideas taken from fields such as change management, risk management, and systems analysis.

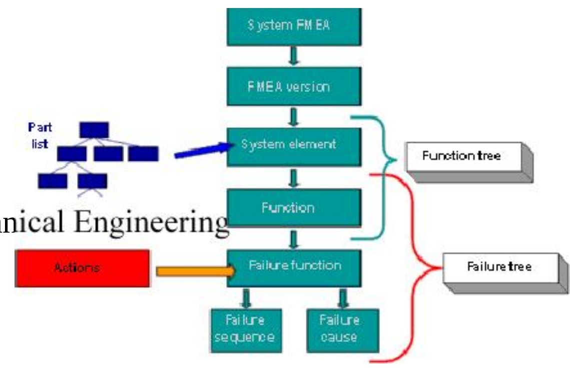
Despite the different approaches among the various schools of root cause analysis, there are some common principles. It is also possible to define several general processes for performing RCA

4.3.FMEA - Failure Modes and Effects Analysis

The main goal of the FMEA (Failure Mode and Effect Analysis) is to prevent failures. Therefor it belongs to the important tools of the quality planning. It is assumed that the general meaning is known.
iQ-FMEA has been developed under various aspects:

the system has to meet the practical requirements according to the VDA series of publications
it has to support the structured process of FMEA sessions through algorithms, tables and methods
the history of a FMEA is to be shown for every step of improvement
experiences (knowledge base) of previous FMEAs have to be able to enter in current FMEAs. Therefor certain parts of a FMEA are emphasized as standard. They are independent of the current product or process.
employees without a lot of knowledge about information processing
have also be able to use the FMEA

FMEA structure



FMEA header, that contains general information for the most common standard forms
FMEA versions; each version describes a segment of the FMEA-development
system elements as units for analysis
functions of a system element
possible malfunctions of a function
integrated knowledge base
extensive provisions for action management

The structure elements in detail

FMEA header

FMEA id and short description
FMEA type
method of evaluation
material
drawings
initial part/process or optimization analysis
extensive text description
entire status of the FMEA

Version

FMEA can have several versions.
One version describes the **FMEA progress** from the realisation of corrective actions to the recommendation of further actions. A new version closes the predecessor.
cost input after each session; time and money investments in persons; direct costs
cost cumulation over all sessions of a version and over the whole period of a FMEA
divers further management data on version level

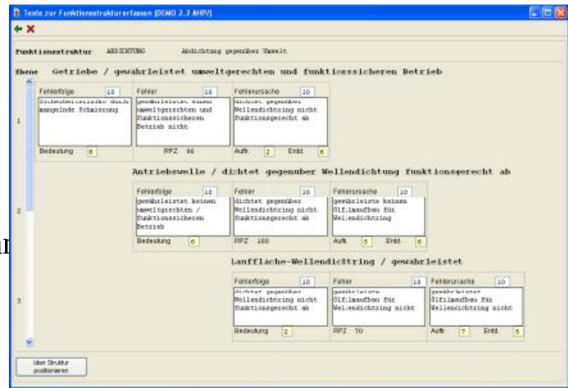
System elements (SE)

any number of system elements in a version
assignment of a system element to a **SE class**. This makes it possible to define arbitrarily structured search criteria (**knowledge base**).
SEs can be ordered hierarchically in a parts list structure

Function and error tree

SEs within the SE hierarchy are in following relationship with each other: the function of the inferior SEs (rubberlip) builds a chain to the superior (sealing ring), the function tree
one FMEA may contain several function trees
the **function tree** can be set up top down or bottom up
errors on a lower level can automatically be taken as a failure cause on a higher level
complete support of **system FMEA** (see form)

Failure analysis



failure analysis can be considered in isolation for each malfunction
failure analysis can be made within the function tree
a failure can cause several **consecutive failures**

a failure can result from several **reasons**
you can assign the RPZ factor meaning to a failure sequence
you can assign the RPZ factor occurrence probability and detectability to a failure cause
B, E and A from a catalogue, which can be created by the user (VDA, DGQ etc.)

Adjustment actions

The complete feature set of **iQ-Projekte** is used
differentiation in **preventive actions** (design engineer) and **detecting actions** (later quality assurance)
information about responsible person, appointments, performance, estimation of planned improvements etc.
appointment traceability, follow-up actions in case of missed deadlines etc.

FMEA form

form for complete FMEA
form for certain system elements

Knowledgebase

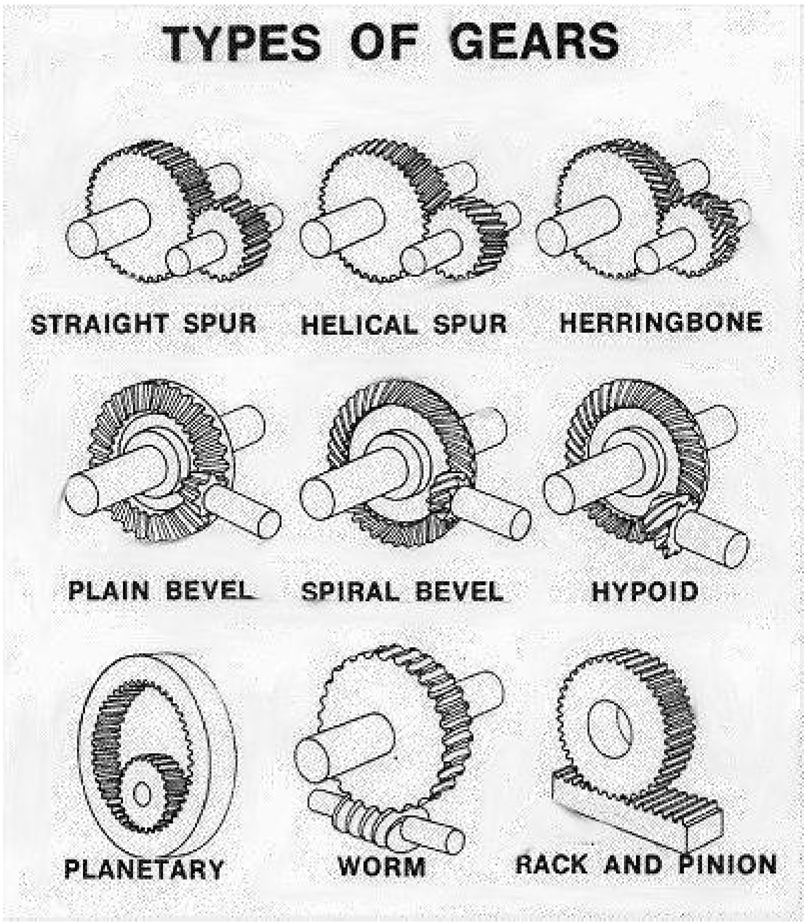
structure and identification of FMEAs and SEs, which appear similar in other constructions or processes (for example bore for fit, rotation and parallel translation)
search algorithms based on **class systems**
adoption of already described SEs, depending on RPZ-experiences

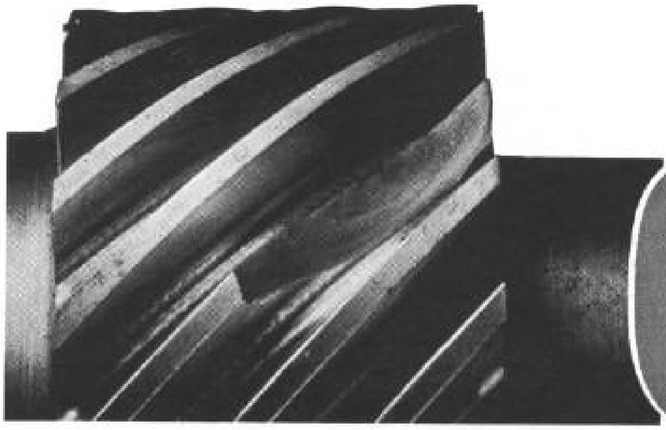
Analysis

history of a FMEA about the version
Pareto-diagram to a version over RPZ
graphic comparison of the RPZs over SEs and functions **between two versions**
standard forms

4.4.Gears

- A **gear** or **cogwheel** is a rotating machine part having cut *teeth*, or *cogs*, which *mesh* with another toothed part in order to transmit torque, in most cases with teeth on the one gear being of identical shape, and often also with that shape on the other gear. Two or more gears working in tandem are called a *transmission* and can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, torque, and direction of a power source. The most common situation is for a gear to mesh with another gear; however, a gear can also mesh with a non-rotating toothed part, called a rack, thereby producing translation instead of rotation.
- The gears in a transmission are analogous to the wheels in a crossed belt pulley system. An advantage of gears is that the teeth of a gear prevent slippage.
- When two gears mesh, and one gear is bigger than the other (even though the size of the teeth must match), a mechanical advantage is produced, with the rotational speeds and the torques of the two gears differing in an inverse relationship.
- In transmissions which offer multiple gear ratios, such as bicycles, motorcycles, and cars, the term **gear**, as in *first gear*, refers to a gear ratio rather than an actual physical gear. The term is used to describe similar devices even when the gear ratio is continuous rather than discrete, or when the device does not actually contain any gears, as in a continuously variable transmission


TYPES OF GEARS
STRAIGHT SPUR
HELICAL SPUR
HERRINGBONE
PLAIN BEVEL
SPIRAL BEVEL
HYPOID
PLANETARY
WORM
RACK AND PINION



GEAR

• how to recognize them

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A GEAR has failed when it can no longer efficiently do the job for which it was designed. Cause of failure may range from excessive wear to catastrophic breakage.

Failure in a gear train can in many cases be prevented. When it does occur, the proper redesign will ensure a trouble-free unit. Regardless of when the trouble is rectified—at the design or redesign stage—the most important aid to the designer is the ability to recognize the exact type of incipient failure, how far it has progressed, and the cause and cure of the ailment.

This article rounds up every type—and the major stages—of gear failures. Included are photographs of actual failures, along with probable cause and the most effective remedies.

WEAR: a surface phenomenon in which layers of metal are removed, or "worn away," more or less uniformly from the contacting surfaces of the gear teeth.

Polishing

Polishing is a very slow wearing-in process in which the asperities of the contacting surfaces are gradually worn off until a very fine, smooth surface develops.

Cause: This condition is usually caused by metal-to-metal contact during operation. Generally, "polishing-in" occurs on slow-speed applications where the elasto-hydrodynamic lubrication film is not sufficiently thick and the gears are operating near the boundary-lubrication regime.

Remedy: Often this condition need not be avoided unless the design life of the equipment is much longer than the predicted wear life based on polishing-in. Polishing gives good conformity of the surfaces.

After the gear is well polished-in, the surface can be protected by substituting a lubricant with a higher viscosity, by reducing the transmitted load substantially, or, in some cases, by increasing the operating speed to obtain a better elasto-hydrodynamic oil film.

Polishing: Run-in under operating conditions, this hardened hypoid pinion has developed a highly polished surface. Undoubtedly the extreme-pressure additives in the lubricant had a tendency to promote polishing on the tooth surfaces.

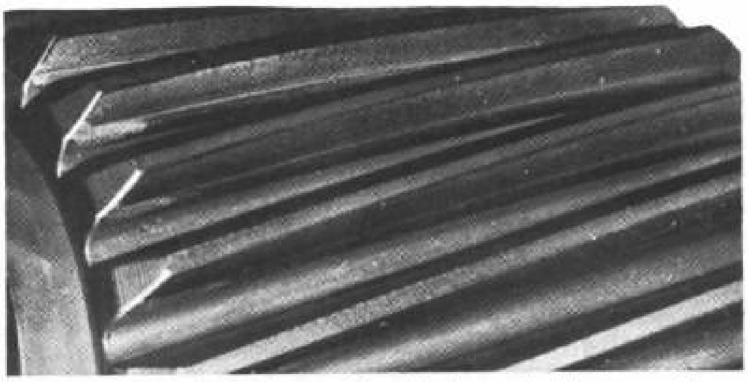
FAILURES

• what causes them • how to avoid them

Moderate Wear

The type of wear classified as moderate takes place over a relatively long period of time. The contact pattern indicates that metal has been removed in the addendum and dedendum area; also, the pitch line begins to show as an unbroken line.

Cause: Moderate wear is most commonly caused by an inadequate lubrication film, with the film thickness being too thin for the load. Dirt in the lubrication system can also cause this type of wear.



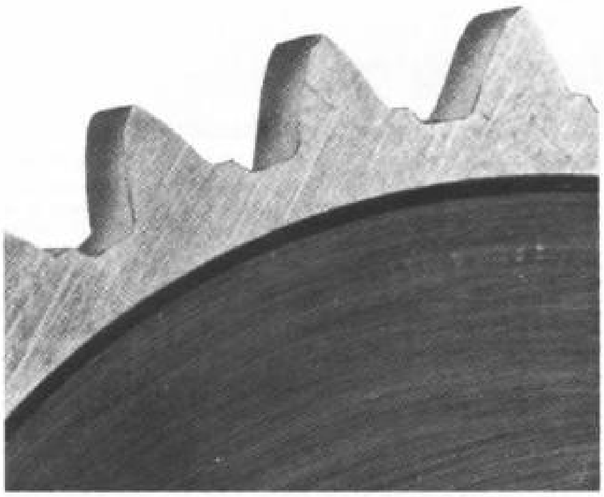
Moderate Wear: The addendum and dedendum sections of these medium-hard gear teeth have worn, causing the operating pitch line to become visible because little if any material has been removed along this line.

Remedy: One solution is to specify a lubricant with a greater film strength, or one with a higher viscosity. Also, the unit can be operated at a greater speed to build up the lubricating film. Finally, a gear material with a higher wear resistance can be specified.

Excessive Wear

This is simply normal wear which has progressed to the point where a considerable amount of material has been removed from the surfaces. The pitch line is very prominent and may show signs of pitting.

Cause: This problem is usually caused by the failure to notice early enough that wear is in progress. When enough material has been worn from the tooth surface, the involute profiles are destroyed and the gears begin to run roughly. The situation is aggravated by the rough running, causing still



Excessive Wear: Material has been uniformly worn away from the tooth surface causing a deep step. The tooth thickness has been decreased and the involute profile destroyed. Some slow-speed gears can operate on such a profile until so much material has been worn away that the tooth fails under beam bending fatigue.

greater wear. Eventually the surface is such that the gears are no longer fit for reliable service.

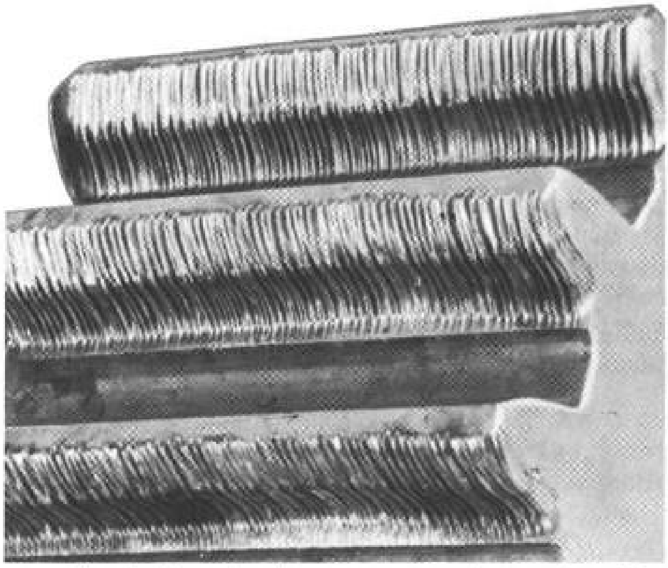
Remedy: This condition could be avoided by using the same methods given for moderate wear—increasing lubricant film strength or viscosity, or increasing pitch-line velocity.

If the gear unit is splash-fed, changing to a positive spray lubrication system with a filter will help keep wear particles out of the gear mesh and ensure that adequate lubricating oil is delivered to the working surfaces.

Abrasive Wear

When abrasive wear has taken place, contacting surfaces show signs of a lapped finish, radial scratch marks or grooves, or some other unmistakable indication that contact has taken place.

Cause: Foreign material in the lubrication system ordinarily causes abrasive wear. The particles may



Abrasive Wear: In this extreme case, a large portion of the tooth of the bronze pinion has worn away due to an accumulation of abrasive particles in the lubricant. Note the deep ridges, and the ends of the gear teeth, which were not subjected to the abrasive action.

be metallic debris from the gear and bearing system, weld spatter, scale, rust, sand, etc. Abrasive wear is often noted soon after startup of a new installation, before the filter has had a chance to clean the system.

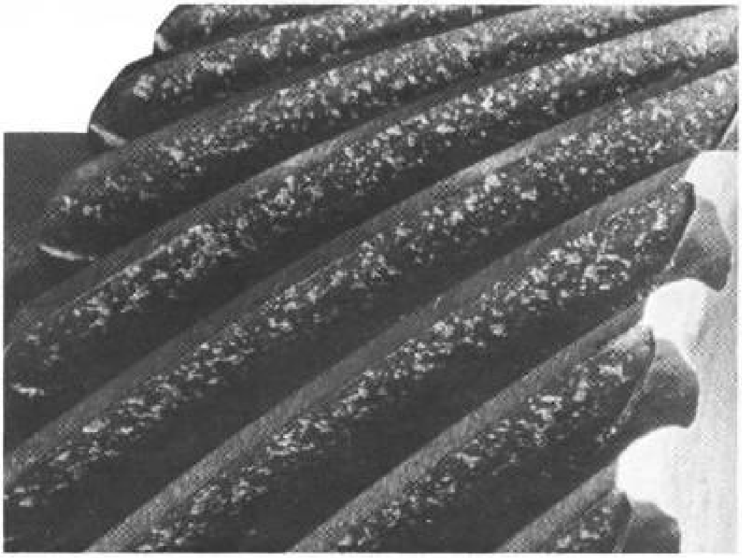
Remedy: This type of wear can be remedied by the use of a filter or, where a filter is already being used, a finer grade of filter. Alternatively, a higher-viscosity lubricant will develop a thicker oil film, which will pass fine particles without scratching. Of course, the best way to guard against early abrasive wear is to see that the gearbox and lubricating system are carefully cleaned before use.

Trouble is often encountered in closed gearboxes without a circulating lubrication system, so that whatever foreign material that accumulates in the box remains there. Therefore, in such cases it is important to change oil often.

Corrosive Wear

This is a deterioration of the surface due to chemical action. It is often caused by active ingredients in the lubricating oil, such as acid, moisture, and extreme-pressure additives.

Cause: The oil breaks down so that corrosive chemicals present in the oil attack contacting surfaces. Often this action affects the grain boundaries, causing fine pitting more or less uniformly over the tooth surfaces. At high temperatures, extreme-



Corrosive Wear: Although considerable wear has taken place, the surface still shows signs of having been attacked chemically. Wear of this nature will continue until the gear surface is beyond usefulness.

pressure additives sometimes form very active corrosive agents. Lubricants can also become contaminated from absorption of foreign material from external sources.

Remedy: Because they are chemically active, lubricants with high anti-scoring, anti-wear additive content must be kept under careful observation to ensure that they are not attacking working surfaces. By checking the lube oil for breakdown and by changing the lube oil at regular intervals, corrosive wear can be avoided.

Often gear lubricants are contaminated with various chemicals from the atmosphere or from foreign material such as salt water or liquid chemicals. In such cases, the gear unit should be sealed from its environment.

At times, gear-tooth surfaces can be affected chemically during processing in the factory—for example, when copper plate is stripped from the gear after carburizing or when nital-etch is used to detect grinding burns. To avoid trouble of this nature, proper processing procedures must be set up and carefully followed.

PITTING: a surface fatigue failure which occurs when the endurance limit of the material is exceeded, a failure of this nature depends on surface contact stress and number of stress cycles.

Initial Pitting

This condition is characterized by small pits from 1/64 to 1/32-in. in diameter. Initial pitting occurs in localized, over-stressed areas; it tends to redistribute the load by progressively removing high contact spots. Generally, when the load has been redistributed, the pitting stops and the contact surfaces smooth over.

Cause: Initial pitting is usually caused by gear-tooth surfaces not properly conforming with each other or not fitting together properly. This can be a result of minor involute errors or local surface irregularities, but most often it occurs because there is not proper alignment across the full face width of the gear mesh.

Initial Pitting: Pitting began on the outside end of the helix because of a small amount of misalignment, with pits of small diameter. The pitting worked its way from the end to the middle of the tooth. Eventually pitting stopped and the pitted surface began to burnish over, indicating that the load across the tooth had become more evenly distributed. This type of pitting, often called corrective pitting, is most common in medium hard gears.

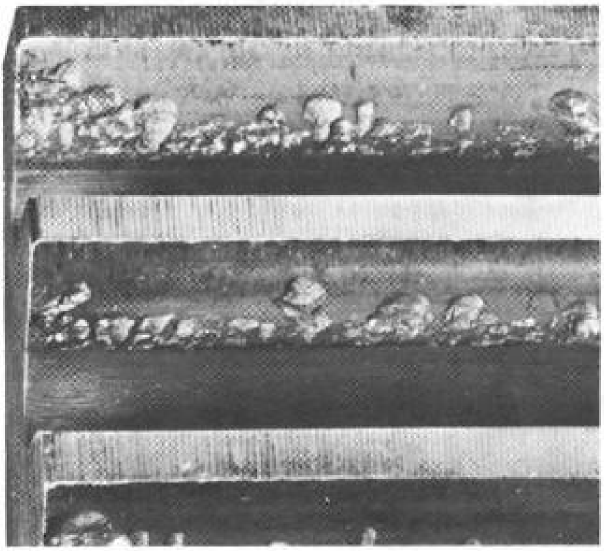
Remedy: This type of pitting can be avoided by providing smooth gear-tooth surfaces and gear-tooth contact patterns that distribute the load evenly across the gear mesh from the very start of operation. To some extent, pitting can be controlled by improving the accuracy of the involute profiles and by introducing profile modification to smooth the meshing action and reduce dynamic loading on the teeth.

Destructive Pitting

In this type of pitting the surface pits are usually considerably larger in diameter than those associated with initial pitting.

The dedendum section of the drive gear is often the first to experience serious pitting damage; however, as operation continues, pitting usually progresses to the point where a considerable portion of all the tooth surfaces have developed pitting craters of various shapes and sizes.

Cause: Destructive pitting usually results from surface overload which cannot be alleviated by corrective (initial) pitting. Once enough stress cycles have been built up, pitting continues until the tooth profile is completely destroyed, causing extremely rough operation and considerable noise. Often a bending fatigue crack will originate from a pit, causing a premature tooth breakage failure.



Destructive Pitting: Heavy pitting has taken place, predominantly in the dedendum region. The pitted craters are larger than those in initial pitting. Some pitting has also taken place in the addendum region.

Remedy: Destructive pitting can be avoided by keeping the load on the surface below the endurance limit for the material. Also, hardness of the material can be increased so that the endurance limit of the material will rise to a point where pitting will not take place. Sometimes pitting can be arrested by increasing the hardness level of only the driving member.

Spalling

Spalling is similar to destructive pitting except that the pits are usually larger in diameter and quite shallow. Often the spalled area does not have a uniform diameter.

Spalling often occurs in medium-hard material, as well as in highly loaded fully hardened material. Spalling of this kind should not be confused with "case crushing" which is associated with case-hardened gear material.

Cause: Spalling is usually caused by excessively high contact stresses. Usually, large pits are formed; because stress levels are high, the edges of the

Spalling: This hardened pinion shows an advanced stage of tooth spalling. Material has progressively fatigued away from the surface until a large irregular patch has been removed.

initial pits break away rapidly and large irregular voids are formed. Often these voids join together.

Remedy: Contact stress on the gear surface can be reduced below the endurance limit of the material. If the gear material is not hardened, hardening will give the material increased surface strength. Often a complete redesign of the gear elements is best since destructive pitting and spalling are evidence that the gears do not have sufficient surface capacity.

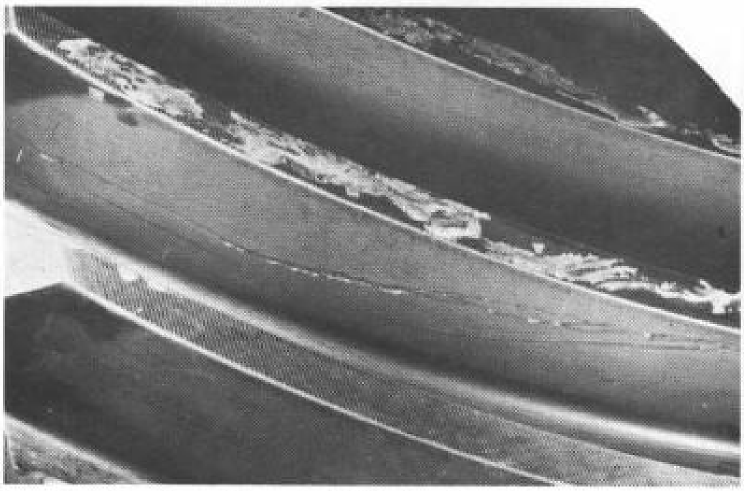
Case Crushing

Although not considered a pitting failure, case crushing may appear similar in that damage has occurred on the contacting surface. It occurs in heavily loaded case-hardened gears, such as those which are case-carburized or nitrided.

Failure often occurs on only one or two teeth of a pinion or gear; the other teeth appear to be undamaged. Often, longitudinal cracks appear on the surface and large, long pieces of the tooth surface break away. The general appearance suggests that the case material has chipped away in large flakes at a parting line just below the case-to-core junction.

Cause: Cracks originate at the subsurface when stresses exceed the strength of the subsurface material. The cracks propagate along the case-to-core boundary and to the surface of the gear tooth. When several cracks reach the tooth surface, large chunks of material are removed. Failures are caused by insufficient case depth or by very high residual stresses in the gear.

Remedy: Failures most often can be overcome by increasing the effective depth of the case material. A change in basic material can be considered—for example, one that produces a hard core material for the same depth of case. Some carburizing materials will produce a 40-Rc core whereas others will only produce 30-32 Rc. This amounts to a considerable difference in strength.



Case Crushing: Several large longitudinal cracks, and several smaller ones, have appeared in the contact surface of this case-carburized bevel gear. The major cracks originated deep in the case-core structure and worked their way to the surface. Long chunks of material are about to break loose from the surface. The cracks should not be confused with normal fatigue cracks, which result from high root stresses and normally form below the contacting face.

SCORING: rapid wear resulting from a failure of the oil film due to overheating of the mesh, permitting metal-to-metal contact; this contact produces alternate welding and tearing which removes metal rapidly from the tooth surfaces.

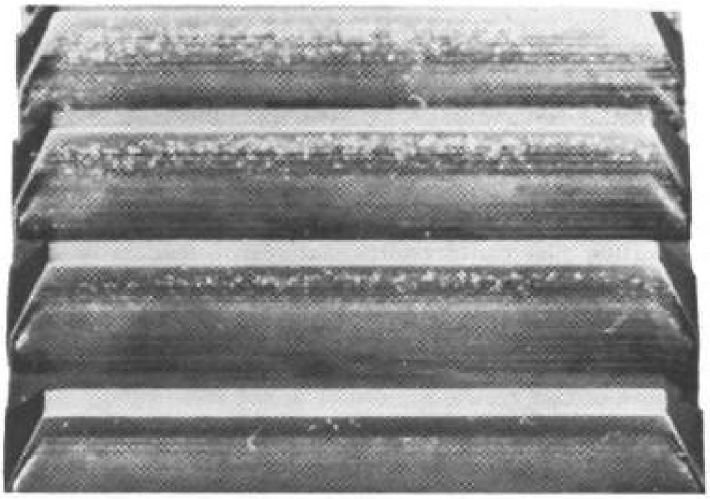
Frosting

Frosting occurs in the early stages of scoring. Usually the dedendum section of the driving gear is the first to show signs of surface distress, although frosting can first show up on the addendum section.

As the name implies, the wear pattern appears frosted. The normal polish of the surface has an etch-like finish. Under magnification, the surface appears to be a field of very fine micro-pits less than 0.0001 in. deep. The frosted pattern will sometimes follow the slightly higher ridges caused from cutter marks or other surface undulations.

Cause: Frosting is caused by heat in the mesh, which results in only marginal lubrication. The heat of the mesh and the bulk temperature of the rotating gears combine to break down the lubrication film.

Remedy: A very careful break-in cycle is often beneficial. A break-in cycle starting with reduced



Frosting: This hardened and ground spur gear shows the early stages of frosting. In this case the addendum portion of the teeth shows the spotty frosting pattern. Damage to this gear is negligible at this stage.

Frosting: This hardened helical gear shows a typical frosting pattern. Note that frosting is predominantly in the dedendum section, although patches do appear in the addendum section. This frosting pattern shows no radial welding and tear marks.

speeds and reduced load will condition the gear-tooth surfaces and improve the conformity of the contacting surfaces so that less local heat will be generated because of better load distribution. Reduced oil temperatures or better control of temperature fluctuations will tend to keep the heat level within safe limits. A mild extreme-pressure oil may be helpful but may not be necessary.

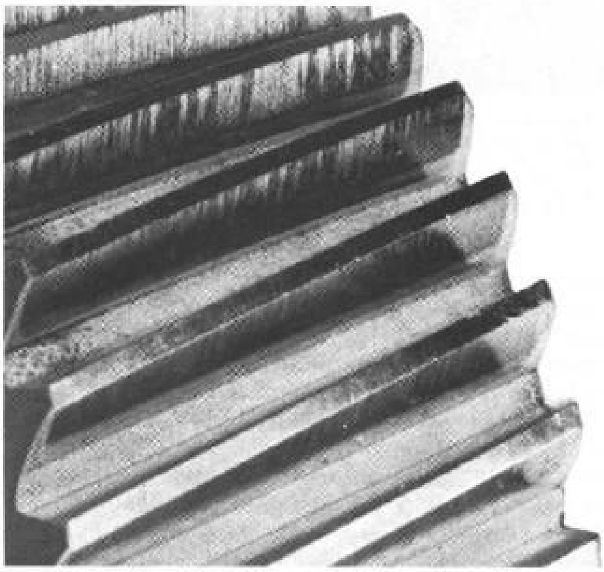
Often, where frosting appears, subsequent operation of the unit will slowly polish away the frosted areas if all operating conditions remain constant.

Moderate Scoring

In this type of failure, a characteristic wear pattern shows up on the addendum or dedendum (or both) of the gear teeth, often in patches. At times, there are indications of radial tear marks; however, this is not always the case. Generally, hard gears appear more frosted. Softer gears show some frosted appearance along with fine radial tear marks.

Cause: Excessive heat in the gear mesh causes this condition, causing lubricant breakdown.

Remedy: The obvious remedy is to reduce the amount of heat in the mesh by cutting down on



Light to Moderate Scoring: At this stage, scoring has a frosty appearance. On close examination, it can be seen that there has been metal-to-metal contact, and alternating welding and tearing.

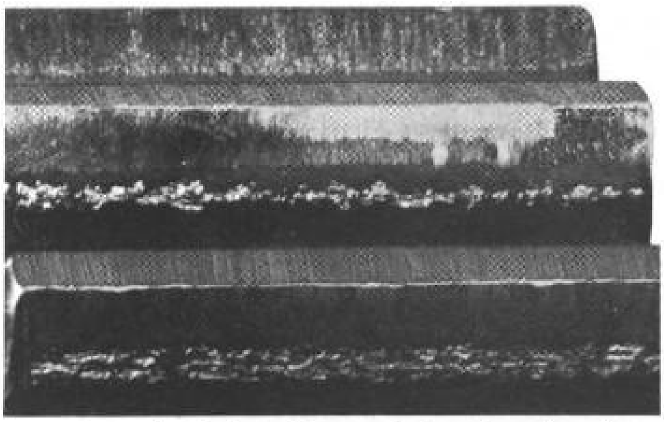
the load being transmitted or the speed of the rotors, or by reducing the inlet oil temperature, which in effect reduces the bulk temperature of the gear rotors. A lubricant with extreme-pressure additives can be substituted. In some cases, a solid lubricant plated on the contact surface helps prevent the scoring from progressing. Also, honing has found increasing use in guarding against scoring.

Destructive Scoring

This type of failure shows definite indications of radial scratch and tear marks in the direction of sliding. Often material has been displaced radially over the tips of the gears. Also, there are indications that considerable material has been removed from above and below the pitch line, and the pitch line itself stands out prominently. The profile is completely destroyed and for all practical purposes the gear is not fit for service.

Cause: This failure is usually caused by inadequate lubrication or by excessive operating temperature, surface load, or surface speed, all of which generate excessive heat. When the lubricant breaks down, the welding and tearing destroys the profile in minutes.

Remedy: The lubricant must be able to stand up under the load, speed, and temperature con-



Destructive Scoring: Heavy scoring has taken place above and below the pitch line, leaving the material at the pitch line. As a result, the pitch line pits away as it attempts to redistribute the load. Usually the gear cannot correct itself and ultimately fails.

ditions of the mesh. Extreme-pressure additives are useful. Also, special high-viscosity compounded gear oil will often prevent scoring of this nature. Synthetic fluids with anti-scoring additives will prevent scoring at higher temperature.

In general, a careful analysis of the amount of heat being generated by the mesh is necessary, so that a fluid can be chosen that matches these conditions. If this is not possible, the gear set must be redesigned to reduce surface stresses, mesh losses, pitch-line velocity, and inlet-oil temperature.

Localized Scoring

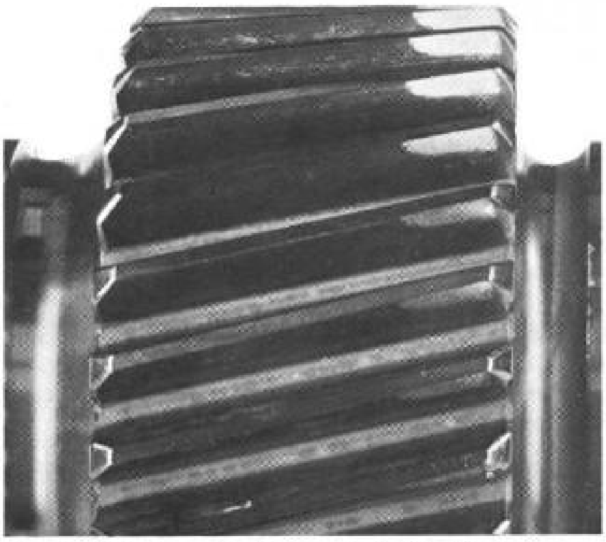
This scoring, similar to moderate scoring, takes place in localized areas along the contacting pattern of the gear teeth. Scoring is usually concentrated in these areas and does not spread across the full face width of the contacting gears.

Cause: Scoring of this nature is usually the result of local load concentrations caused either by design or by unintentional factors such as a misalignment resulting from poor manufacture, deflections under load, or temperature gradients across the face due to non-uniform cooling of the mesh. If the load concentration is near the ends of the teeth, the cause is misalignment, with more load being carried on this portion of the teeth than the lubrication film can support. Sometimes load is concentrated in the center of the gear teeth.

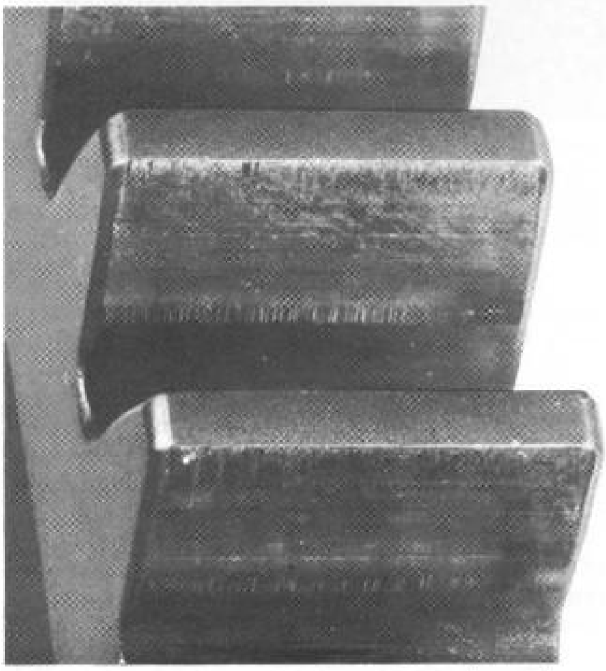
A crown is sometimes used at the center of the tooth to prevent the load from shifting if the design is prone to misalignment under operation. Because of this crown, the center of the tooth carries more load; often the higher load breaks down the lubrication film, permitting metal-to-metal contact and subsequent scoring. Sometimes an "effective crown" can be caused by unequal cooling of the mesh, which in effect causes the diameter of the gear in the center to grow with respect to the diameter of the two ends. Wide-face gears are particularly prone to this difficulty.

Remedy: Scoring failures of this nature can be avoided by eliminating localized loading. If misalignment is present, the gear casing may be deflecting non-uniformly, gear-shaft deflection may be excessive, bores of the casing may be out of parallel, or the gears themselves may be cut with a helix-angle error.

To eliminate localized scoring due to temperature gradients, particular attention must be paid to obtaining uniform heat removal across the mesh. Changes may be necessary in the amount of cooling oil and how it is applied to the mesh. If scor-



Localized Scoring: This high-speed, high-load helical gear shows localized scoring on the ends of the teeth. This failure was caused by a design oversight: when the gear casing reached operating temperature, differential expansion caused a shift in alignment across the face of the gear. The resulting load distribution caused scoring.



Tip and Root Interference: This gear shows clear evidence that the tip of its mating gear is fouling the root section. Localized scoring has taken place, causing rapid metal removal in the root section. Generally, interference of this nature can cause considerable damage.

ing is the result of too much crown, this crown can be reduced to a safer level.

Tip and Root Interference

In this type of scoring, the deep-dedendum portion of the gear shows definite signs of metal removal and may often show destructive radial scratch marks. Other portions of the contacting face look undamaged. Sometimes the tip of the gear or pinion shows unmistakable signs of metal removal, with the damaged tips having an abraded look and tear marks in the direction of rotation.

Causes: This condition is not entirely dependent on the normal causes of scoring failure. The tip of the pinion may require tip modification, the root section of the gear may have a profile error, or the gear pair may be running on tight centers. The heavy loading at the tip or root of the mating pair or the interference caused by a tight mesh prematurely breaks down the lubricant film, causing rapid metal removal at the tips and roots and general abrasion of the teeth.

Remedy: Tip and root interference can be avoided by designing a generous profile modification into the true involute form. Often, tight centers can be avoided by specifying more backlash for the assembled gear pair.

FRACTURE: failure caused by breakage of a whole tooth or a substantial portion of a tooth; this can result from overload or, more commonly, by cyclic stressing of the gear tooth beyond the endurance limit of the material.

Fatigue Breakage

Gear-tooth failure from bending fatigue generally results from a crack originating in the root section of the gear tooth. The whole tooth, or a part of the tooth, breaks away. Most often there is evidence of a fatigue "eye" or focal point of the break. The break shows signs of fretting and conventional smooth beach marks in the break area. Generally there is a small area that shows a rough, jagged appearance, indicating this was the last portion of the tooth to break away.

Cause: The causes of bending fatigue failures are many. Most failures result from excessive tooth loads, which result in root stresses higher than the endurance limit of the material. When gears are loaded in this manner and subjected to enough repeated stress cycles, the gear tooth will fail.

Sometimes stress risers help to aggravate this condition and subject the gear to higher root stress levels than would normally be predicted. Such risers include notches in the root fillet, hob tears, inclusions, small heat-treat cracks, grinding burns, and residual stresses.

Remedy: The best way to avoid fatigue breakage is to design the gear-tooth elements so that the transmitted load will result in stresses well within the endurance limit of the material. Alternatively, a higher-strength material may be specified.

Root fillets can be polished and shot-peened. Often, adjustments to the root fillet areas are helpful. A full fillet-radius tooth has more capacity than a tooth having two sharp fillet radii.

Care should be taken that the material has been properly heat-treated to obtain the best structure and to minimize any harmful residual stresses.

Beam Bending Fatigue: (right) This aircraft power spur gear shows a fatigue crack caused by stresses at the root fillet.

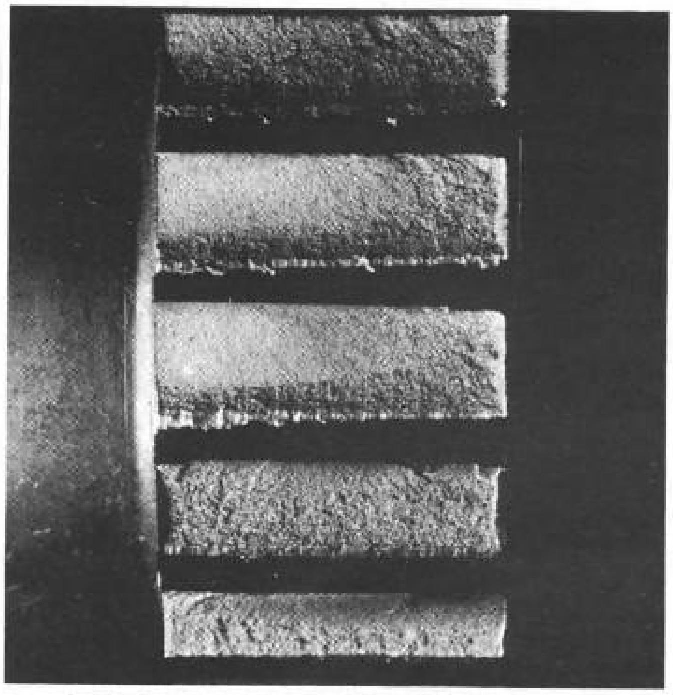
Beam Bending Fatigue: (left) Each failed tooth started at a crack that had been in progress for some time. All the failed teeth show evidence of fretting corrosion and typical beach marks common to this kind of failure. Undoubtedly one tooth broke away first, causing an impact that then quickly broke the remainder of the teeth.

Overload Breakage

An overload fracture results in a stringy, fibrous break showing evidence of having been pulled or torn apart. In harder materials the break has a finer stringy appearance but still shows evidence of being pulled apart abruptly.

Cause: Tooth breakage is caused by an overload which exceeds the tensile strength of the gear material; this results in a short-cycle break generally starting on the tensile side of the root fillet. Overload may result from a bearing seizure, failure of driven equipment, foreign material passing through the mesh, or a sudden misalignment from a failed or wiped gear bearing.

Remedy: It is difficult to design against failures of this type, since often the failure is a direct result of some unpredictable occurrence. It may



Overload Breakage: The break in this hardened and ground spur gear has a brittle fibrous appearance and the complete absence of any of the common beach marks associated with fatigue failure. In this case, one tooth failed from shock and the force was transmitted to successive teeth. As a result, several teeth were stripped from the rotating pinion.

be possible to incorporate overload-protection devices, such as torque-limiting couplings with shear sections.

Random Fracture

Gear-tooth breakage is usually associated with the root-fillet section of the gear tooth; however, breakage failure can occur in other portions of the gear tooth. Sometimes, the top of a gear tooth will break away or large chips will fatigue away from the end of a tooth.

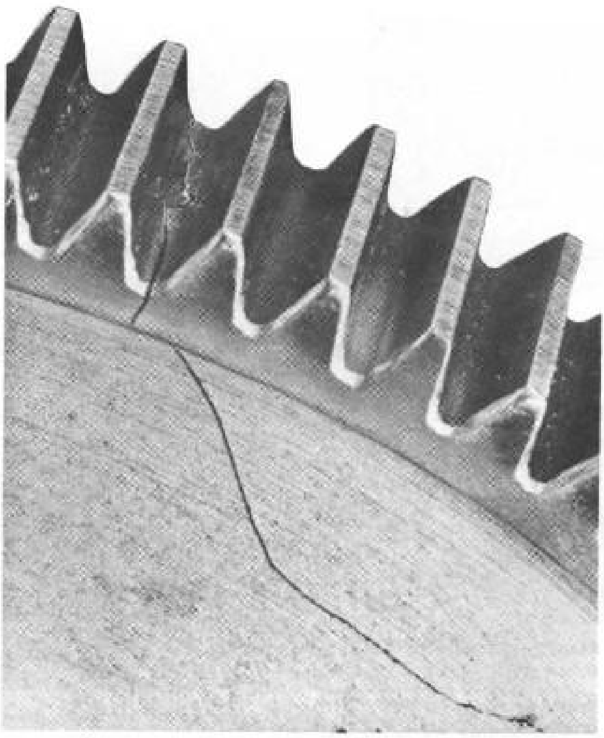
Random Fatigue Breaks: These breaks are not typical beam bending failures. They originate high on the tooth flank and are somewhat uniformly dispersed across the face of the gear. Failures of this nature originate from stress risers other than at the root fillet. In this installation, fatigue failure resulted from grinding cracks on the tooth flanks.

Cause: Failures of this kind are often caused by deficiencies in the gear tooth which result in a high stress concentration at a particular area. Often, flaws or minute grinding cracks will propogate under repeated stress cycling and a fracture will eventually develop. Foreign material passing through the gear mesh will also produce short-cycle failure of a small portion of a tooth. High residual stresses due to improper heat treatment can cause local fractures that do not originate in the tooth section.

Remedy: It is difficult to prevent failures of this type except by good design and manufacturing practices. If trouble is encountered, the gear surfaces should be checked for possible previous damage that may have contributed to local stress risers. The history of heat treatment and manufacturing techniques should be reviewed to ensure that proper processing was carried out during all steps of the manufacturing cycle. Cleanliness of the gear material should also be examined.

Rim and Web Failure

The rim of a gear usually fails between two adjacent teeth. Cracks propogate through the rim and into the web. Sometimes, cracks appear in the web near the rim and web junction without disturbing the rim itself.



Rim and Web Failure: This hardened and ground spur gear fractured through the root section. The crack propagated from the root section into the web of the gear. Such failures are not uncommon on highly loaded thin rims and webs.

Cause: Often, the failures are caused by flexure stresses in the gear teeth. If the crack starts from a high stress point, it may propagate through the rim instead of across the tooth at the root section. Web cracks may be caused by stress risers from holes in the web, or by web vibrations.

Remedy: If the gear fails through the rim, the rim thickness may be increased. The rim thickness below the root diameter should be a minimum of 1.5 times the whole depth of the root. Stress risers in the root section—such as hob tears, grinding-wheel nicks, and grinding cracks—must be eliminated. If the web fails, increasing the web thickness may be helpful. All stress risers in the web area—such as deep tool marks, lightening holes in the web, and sharp fillets in the web-to-rim junction—should be eliminated.

Often, rim and web failures are caused by vibrations. In cases of this nature, the natural frequencies of the gear must be changed either by redesign of the gear or by damping.

PLASTIC FLOW: cold working of the tooth surfaces, caused by high contact stresses and the rolling and sliding action of the mesh; it is a surface deformation resulting from the yielding of the surface and subsurface material, and is usually associated with the softer gear materials—although it often occurs in heavily loaded case-hardened and through-hardened gears.

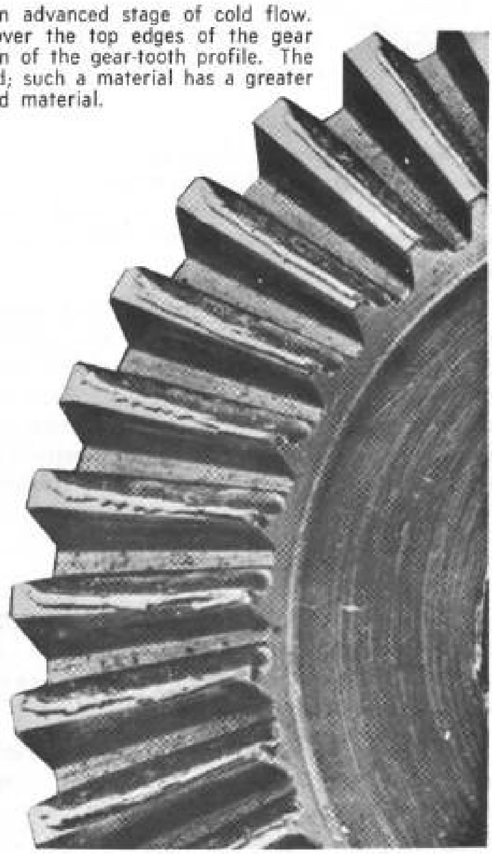
Cold Flow

In this type of failure, the surface and subsurface material shows evidence of metal flow. Often surface material has been worked over the tips of the gear teeth, giving a finned appearance. Sometimes the tooth tips are heavily rounded-over and a depression appears on the contacting tooth surface.

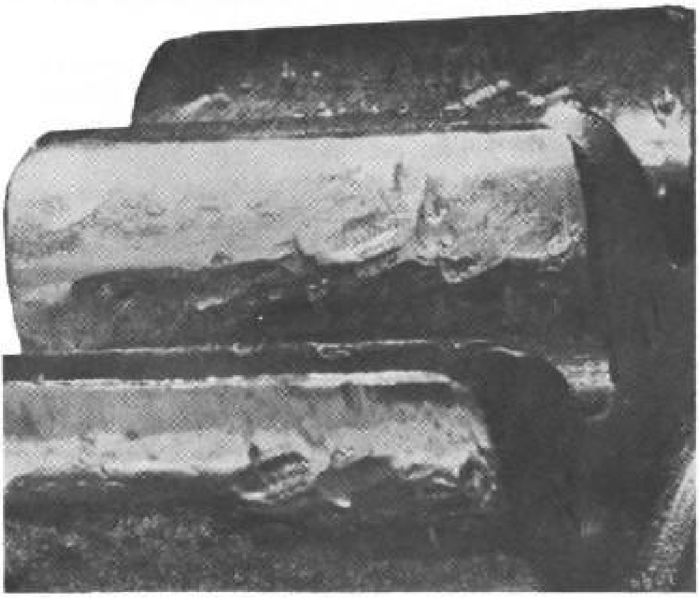
Cause: Under heavy load the rolling and peening action of the mesh cold-works the surface and subsurface material. The sliding action tends to push or pull the material in the direction of sliding, if the contact stresses are high enough. The dents and battered appearance of the surface are the result of dynamic loading due to errors produced during the manufacturing process, or caused by continuous operation while the profile is in the process of deteriorating from a combination of cold-working and wear.

Remedy: Failures of this type can be eliminated by reducing the contact stress and by increasing the hardness of the contacting surface and subsurface material. Increasing the accuracy of tooth-to-tooth spacing and reducing profile deviations will give better tooth action and reduce dynamic loads.

Cold Flow: This bevel gear shows an advanced stage of cold flow. Much material has been rolled out over the top edges of the gear teeth, resulting in complete destruction of the gear-tooth profile. The material of this gear was medium-hard; such a material has a greater tendency to flow than a case-hardened material.



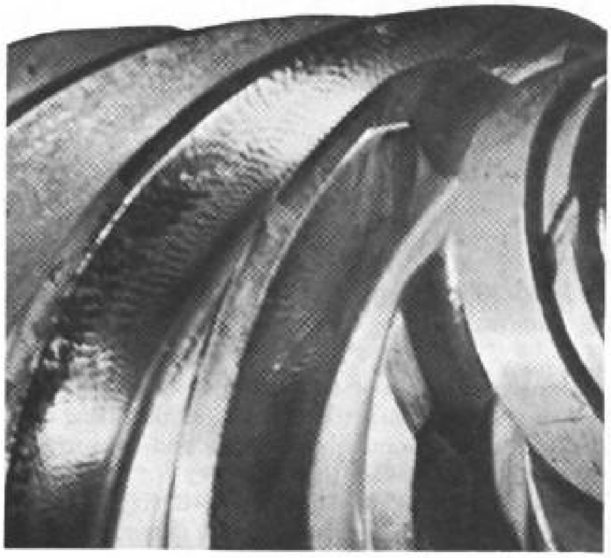
Cold Flow: This medium-hard spur gear shows signs of bad surface deformation due to rolling and peening action. This gear was operated long after the initial surface distress occurred, resulting in a battered cold-worked surface.



Rippling

This is a periodic wave-like formation at right angles to the direction of sliding or motion. It has a fish-scale appearance and is usually observed on hardened gear surfaces, although it can occur on softer tooth surfaces under certain conditions. Rippling is not always considered a surface failure, unless it has progressed to an advanced stage.

Cause: High contact stresses under cyclic operation tend to roll and knead the surface causing the immediate subsurface material to flow. Slow-speed operation is usually associated with this type



Rippling: A typical case of rippling appears on this hardened hypoid pinion. Note the waviness or fish-scale pattern. Rippling often shows up on highly loaded hypoid gears but can be produced on highly loaded spur gears as well.

of failure, because it does not build up adequate elasto-hydrodynamic film thickness. This combination of high contact stress, repeated cycles, and an inadequate lubricating film will produce a rippled surface.

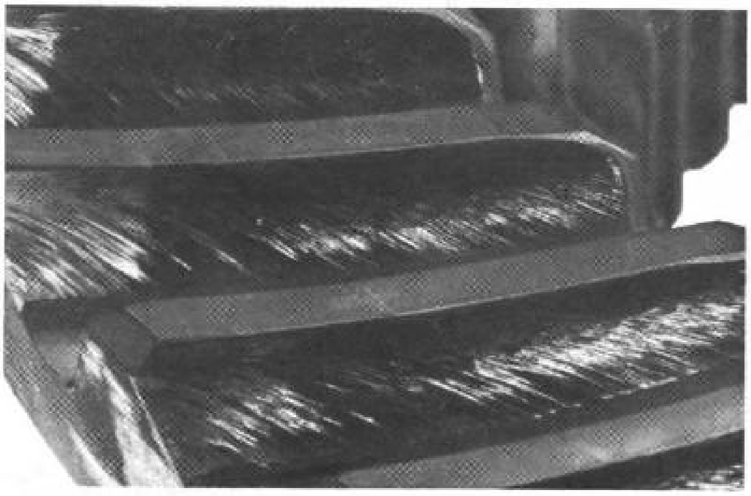
Remedy: If the gear material is soft, rippling can be prevented by case-hardening the tooth surface. Also, reduction in contact stress will reduce the tendency of the surface to ripple. Since the lubricating film is marginal, extreme-pressure additive in the oil and an increase in viscosity of the oil will be beneficial. An increase in rubbing speed is sometimes helpful.

Ridging

This is the formation of deep ridges by plastic flow of surface and subsurface material. It shows definite peaks and valleys or ridges across the tooth surface in the direction of sliding.

Cause: Ridging is caused by the plastic flow of surface and subsurface material due to high contact compressive stresses and high relative sliding velocities. It is often present on heavily loaded worm

Ridging: On this hardened pinion, note that some wear has taken place and that some surface pitting is present although the predominant mode of failure is ridging.



Ridging: This is an excellent example of how ridges form on the surface of a hardened gear. Although the surfaces are very hard, the ridges show a definite peak-to-valley effect in the direction of sliding.

and wormwheel drives and on hypoid pinions and gear drives.

Often, ridging exists on low-hardness materials but may also be present in high-hardness materials if the contact stresses are high, such as in case-hardened hypoid rear axles.

Remedy: Ridging can be prevented by reducing the contact stress, increasing the hardness of the material, and using a more viscous lubricating oil with extreme-pressure additives. It is also helpful in drives that do not have circulating lubricating systems to change the oil often and to ensure that no foreign particles remain in the lubricant.

ACKNOWLEDGMENT

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4.5. Bearings

Bearing materials- desired characteristics

Load capacity-

- The allowable compressive strength the material can withstand without any appreciable change in shape is the primary deciding factor in deciding a bearing material
- Plain bearings are expected to have the following characteristics for the ease of functioning and satisfying the design criteria
- Strength to take care of load-speed combinations
- Fatigue strength, where bearing materials are subjected to stress cycle as in internal combustion engines
- The retention of strength characteristics of softer bearing materials at temperature of operation which may rise within the design limit
- The material must easily conform to shape of the journal and should be soft enough to allow the particulate contaminants to get embedded

Bearing materials- desired characteristics

- **Compatibility-**
  - The shaft and bearing materials in rubbing condition should not produce localized welds leading to scoring or seizure.
  - A good bearing-shaft metal combination is necessary
- **Corrosion resistance-**
  - The oxidised products of oils corrode many bearing alloys.
  - Some protection can be provided by forming a thin layer of anti-corrosion materials on the bearing alloy surface
- **Conformability-**
  - It helps to accommodate misalignment and increase the pressure bearing area (reduce the localized forcse).
  - Relatively softer bearing alloys are better in this respect
- **Embeddability-**
  - It is the ability of a material to embed dirt and foreign particles to prevent scoring and wear (decrease 3rd. Body abrasion).
  - Materials with high hardness values have poor embeddability characteristics

Bearing materials- desired characteristics (contd.)

- **Low coefficient of friction-** the material combinations of sliding surfaces, along with the lubricant should provide a low friction coefficient for reducing damage and lower running costs
- **Low thermal expansion-** The size should remain nearly constant during periods of temperature change
- **High thermal conductivity-** The ability to dissipate heat quickly due to friction
- **Wettability-** An affinity for lubricants so that they adhere and spread to form a protective film over the bearing surface
- **Relative hardness-**
  - The bearing material should usually be softer than that of the journal to prevent shaft wear but hard enough to resist adhesive and abrasive wear of its own surface.
  - Bearings are more easy to replace than shafts (that require dismantling of the whole engine). If one bearing is worn out only that bearing needs replacement instead of the whole shaft

Bearing materials- desired characteristics (contd.)

- **Elasticity-** should be elastic enough to allow the bearing to return to original shape upon relief of stresses that may cause temporary distortion, such as misalignment and overloading
- **Availability-** The material should be readily and sufficiently available, not only for initial installation but also to facilitate replacement in the event of bearing failure
- **Cost-** The economic consideration is the ultimate deciding factor in selecting a bearing material

Aluminium alloys

- Good fatigue strength, load bearing capacity, thermal conductivity, and corrosion resistance
- Less expensive than babbitt materials
- Most aluminium allows contain tin as an element which remains in the free state to provide a better bearing surface
- The strongest aluminium alloy used is aluminium-silicon
- Thermal expansion is relatively high and this restricts their usage at high temperatures
- Emeddability, conformability, and compatibility are not very good and these are improved by providing a babbitt overlay

Cadmium and silver alloys

Cadmium:

- **Cadmium alloys offer good fatigue resistance and excellent compatibility characteristics**
- **Their corrosion resistance is poor and are they are expensive**

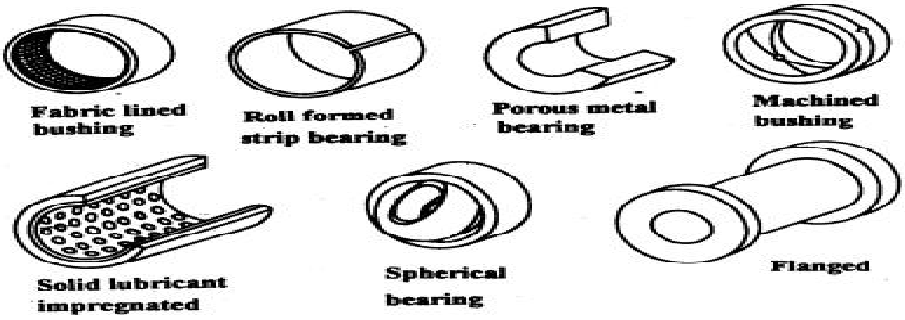
Silver:

- **Used as deposited material on steel with an overlay of lead**
- **The addition of lead improves the embeddability, anti-weld and anti-scoring properties**

Multilayered bearings (contd.)

- **The thickness of overlay can be as low as 120 mm for babbitts**
- **The wall thickness of backing material in bimetal bearings is of he order of 0.3 times the bore with a minimum value of 1.5 mm**
- **In trimetal bearings the surface layer thickness could be as low as 25 mm**
- **With increase in babbitt thickness, the overall fatigue strength decreases**

Plain bearings: Sliding motion takes place



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Types of plain bearings

Porous bearings:

- Made using powder metallurgy techniques by sintering powdered bronze, iron, brass, graphite etc. and obtaining the requisite bearing housing shape by compressing the powder.
- This yields a porous bearing housing which is then impregnated with oil.
- The quantity of oil depends on load and speed for which the bearing is used.
- The variation of pressure during the operation of the bearing along with the circumferential direction and the temperature variation causes oil to flow through the pores due to capillary action into the clearance space between the bearing housing and journal.
- From the loaded portion bearing, the oil flows back along the pores into the bearing housing.
- Applications are mixers, washing machine, garden equipment etc.

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Rolled or strip bearings

- Made by rolling a sheet or strip and due to the nature of the manufacturing process, the bearing housing is split requiring various joining techniques to close this split.
- Sometimes they are provided with a fiber lined cloth of PTFE/Graphite fibers on the inside of the housing for friction reduction and improved strength.
- Among non-metallic bushes, rubber and graphite have been traditionally used.
- Nylon is a valuable plastic material for bushing because of low friction though it has low strength and is suitable for low speeds due to heating effect.
- These are used in grinders and mixers because of resistance to corrosion and quiet operation.

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Non-metallic bearing materials

Rubber bearings

- Used where quiet operation is desired, large clearances and misalignment encountered.
- Found in bearings for propeller and rudder shafts of boats and ships.
- Found where water acts as a lubricant or likely to be a contaminant.
- Even when sand and gravel are present, the resilience of water is an added advantage.
- Wet rubber is very slippery hence its use in such situations to reduce friction.

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Carbon graphite

- Used for food handling equipment and in the textile industry.
- Because of the self lubricating property, no additional lubricant is required, hence limiting lubricant contamination prospects.
- Since it is resistant to corrosion, it can be used even in water.

Teflon (PTFE)

- Another plastic with self-lubricating properties and low friction.
- However, it has poor strength, low wear resistance and a tendency to deform under load.
- Reinforcing with fibers improves the strength.

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Phenolic plastic bearings

- Laminated phenolics are formed by treating sheets of either paper or cotton fabric with asbestos or other filler materials bonded using phenolic resin.
- These are stacked to obtain the desired thickness and subjected to heat and presssure to bond the sheets firmly and later formed into required shapes.
- Used in aircraft landing gears and in several applications where water is a lubricant, such as in rolling mills where water is used for cooling and to lubricate.
- Also used in rudder bearings and centrifugal pumps .

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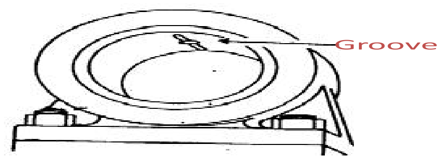
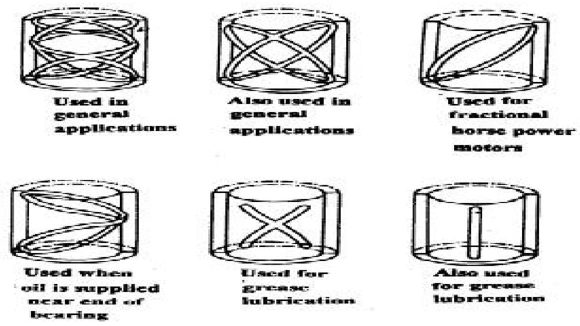
Grooved bearings



Grooves are provided in bearing surfaces to enable oil flow into the bearing area and to spread along the surface



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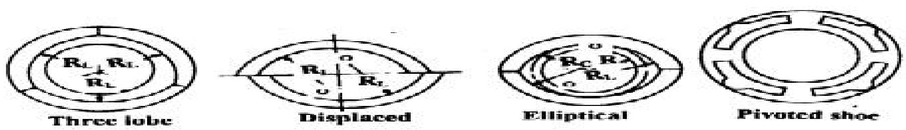
Non-circular journal bearings

- Oil lubricated bearings have serious limitations as the surface speeds increase.
- The limit to operation is due to journal whirling in the clearance space within the housing in such a manner as to cause danger of surfaces coming in contact leading to failure
- For this various non-circular configurations have been devised to accommodate for the whirl and provide better stability



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4.6.Factors Influencing the Performance of Ball and Rolling Bearing

There are many factors that affect the performance of ball and roller bearings. Some are obvious and some are not very obvious. This course starts out explaining the performance characteristics of the various ball and roller bearings. It then deals with some of the aspects affecting performance such as; how different types of bearing loads can affect expected life calculations; how the material used and different refining and heat treatment methods can improve bearing performance; how oil lube film thickness affects expected life; and what the effect of misalignment and preloading have on a machine tool bearing application. This course is intended to enhance the understanding of all the above to ensure that bearing application engineering will be a more successful venture.

Performance Characteristics of Rolling Contact Bearings

Ball bearings are a common type of a rolling contact bearing. Radial ball bearings can support radial loads and a lesser amount of bi-directional thrust loads. Angular contact ball bearings can support both radial and thrust loads and are often used in pairs (See Figures 1, 2 and 3). Because of the much smaller contact between balls and rings, ball bearings cannot support loads as heavy as equal sized roller bearings; however, ball bearings can operate with lower torque and higher speed and precision than roller bearings. Radial ball bearings can be furnished prelubricated and sealed and can operate for life without maintenance.
Ball and roller bearings can be furnished with snap rings installed in grooves in the outer ring outside for mounting purposes.

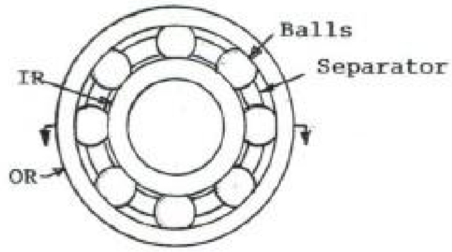
Roller bearings are also a common type of a rolling bearing. Cylindrical roller bearings can support higher radial loads than similar size ball bearings but lack the capacity to support substantial thrust loads. Tapered roller bearings can support high radial and high thrust loads and are often used in pairs (See Figures 4 and 5).

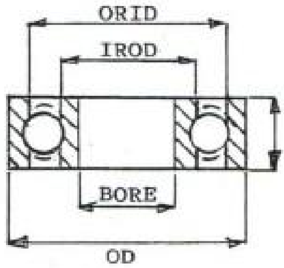
Following is a summary of Figure 6 which has a table of the characteristics of ball and roller bearings:

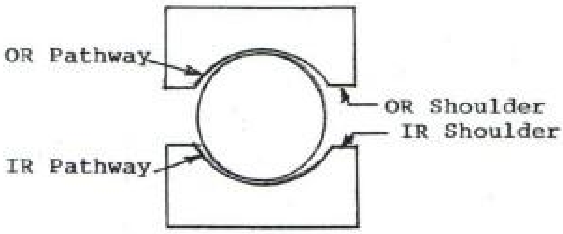
- Radial ball bearings have fair radial and thrust load carrying capability. They are excellent for high speed, high accuracy, low torque, and good for shaft misalignment. They can be used on both ends of a shaft. Angular contact ball bearings have good radial and thrust load carrying capability. They are excellent for high speed and high accuracy, fair for low torque, but poor for supporting shafts that are misaligned.
- Angular contact pairs are good for radial and thrust loads. They are good for high speed and accuracy and are poor for supporting shafts that are misaligned. They are commonly used on both ends of a shaft.
- Some forms of a cylindrical roller bearing have good radial load and fair thrust load carrying capacity. Others are excellent for high speed and accuracy. All are fair for shaft misalignment. Some forms are good for mounting on both ends of a shaft.
- Tapered roller bearings have excellent radial and good thrust load carrying capability. They are good for high speed and accuracy. Tapered roller bearings pairs are excellent for radial and thrust loads. They are good for accuracy and poor for misalignment. They too are commonly mounted on both ends of the same shaft.

Figure 1

Ball Bearing Terminology



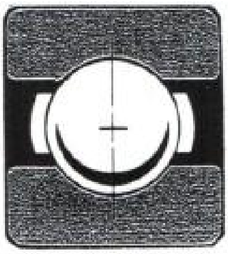




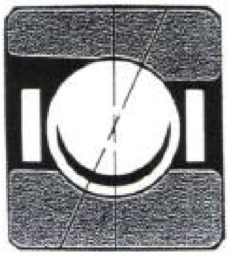
(Exaggerated View)

Figure 2

Ball Bearing Types



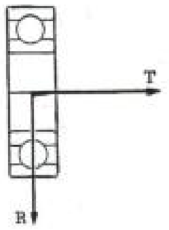
Radial Ball Bearing



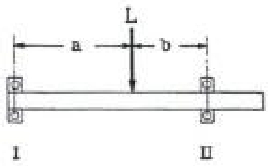
Angular Contact Ball Bearing

Figure 3

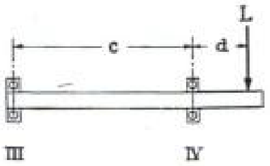
Bearing Loads



Bearing Load



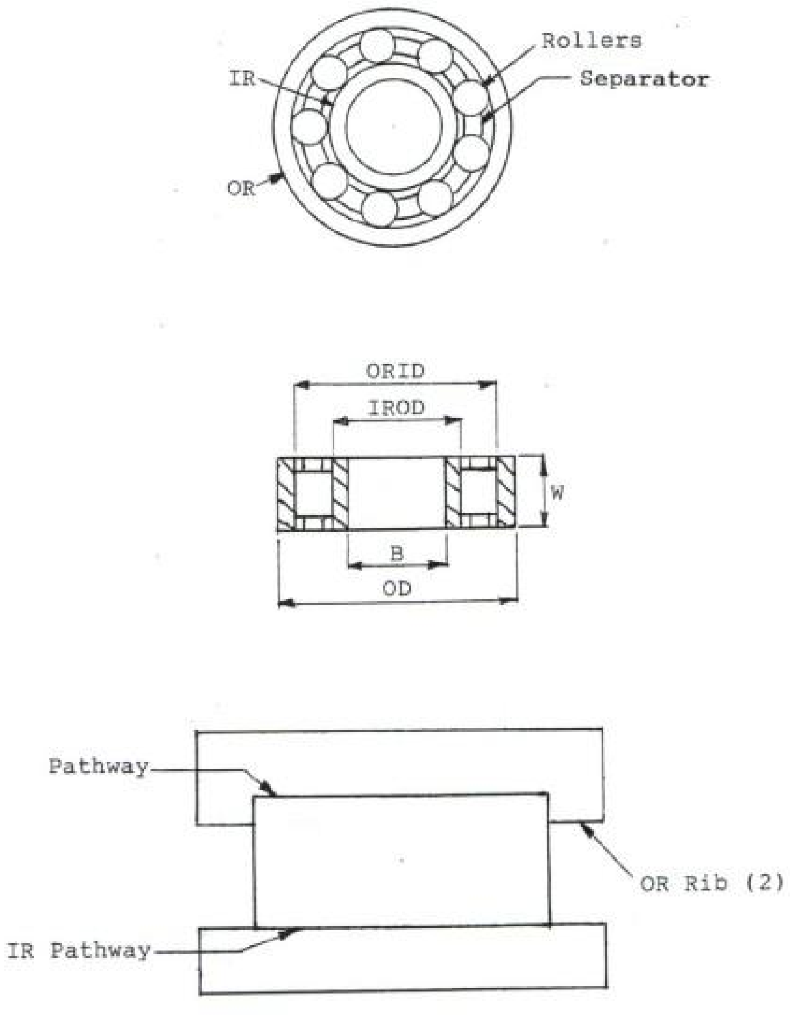
Bearing Location



Bearing Location

Figure 4

Cylindrical Roller Bearing



(Enlarged Section)

Figure 5

Tapered Roller Bearing

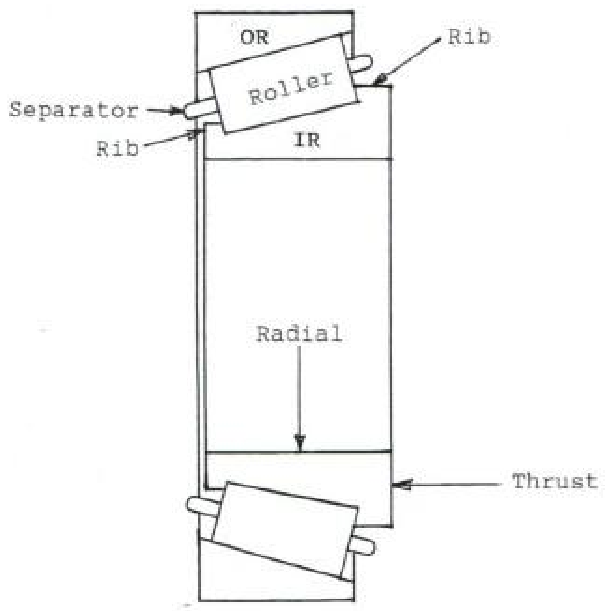


Figure 6

Bearing Characteristics

	Radial Ball Brg	Ang Contact Ball Brg	Cylindrical Roller Brg	Tapered Roller Brg	Double Row Ang Contact	Double Row Taper Roller
Radial Load)	Fair	Good	Good	Good	Good	Excellent
Thrust Load)	Fair	Good	Fair	Good	Good	Good
Combined Load)	Fair	Good	Fair	Good	Good	Excellent
High Speed)	Excellent	Excellent	Excellent	Good	Good	Good
High Accuracy)	Excellent	Excellent	Excellent	Good	Good	Good
Low Torque)	Excellent	Fair	Good	Fair	Fair	Fair
Misalignment)	Good	Poor	Fair	Fair	Poor	Poor

*The above ratings may vary somewhat for some forms of some of the bearings.

Bearing Life Calculation Factors

The equation for calculating the life of a rolling contact bearing is as follows:

L10=3000(C/P)n(500/S)

- L10 is the life in hours that 90% of the bearings are expected to endure. This is the standard equation for all ball and roller bearings.
- C is the capacity of the bearing in pounds and is found in industry catalogs. Capacity is largely dependent on the number and diameter of the rolling elements and the bearing material.
- P is the load in pounds that the bearing is expected to support. Radial loads act perpendicular to the bearing axis of rotation while thrust loads act parallel to the bearing axis of rotation. When both types of loads act on the same bearing, industry catalogs will give an equivalent radial load to be used in the equation. In most applications, the load is stationary. When the load rotates with the inner ring, a factor of 1.25 is applied to the load in the equation because of an increase of stress on the inner ring. When the load rotates with the outer ring, no factor is needed. If the load oscillates over 45o, multiply the load times 1.25. Oscillation less than 45o should be avoided because a condition called “false brinelling” can occur resulting in damage to the bearing rings.
- n is 3 for ball bearings and 10/3 for roller bearings.
- S is the speed of rotation of the bearing in revolutions per minute (rpm). In most applications, the inner ring rotates while the outer ring is stationary. When the outer ring rotates and the inner ring is stationary, a factor of 1.25 is applied to the load because of the additional stress put on the inner ring.

When there are a variety of load and speed conditions for a given application, the following equation is used:

L10=1/(t1/L1+t2/L2+t3/L3+etc.)

- L10 is the B10 life of a bearing operating under a number of different load and speed conditions.
- t1 is the percent time operating under B10 life condition L1, t2 is the percent time spent under B10 life condition L2, t3 is the time spend under B10 life condition L3, etc.

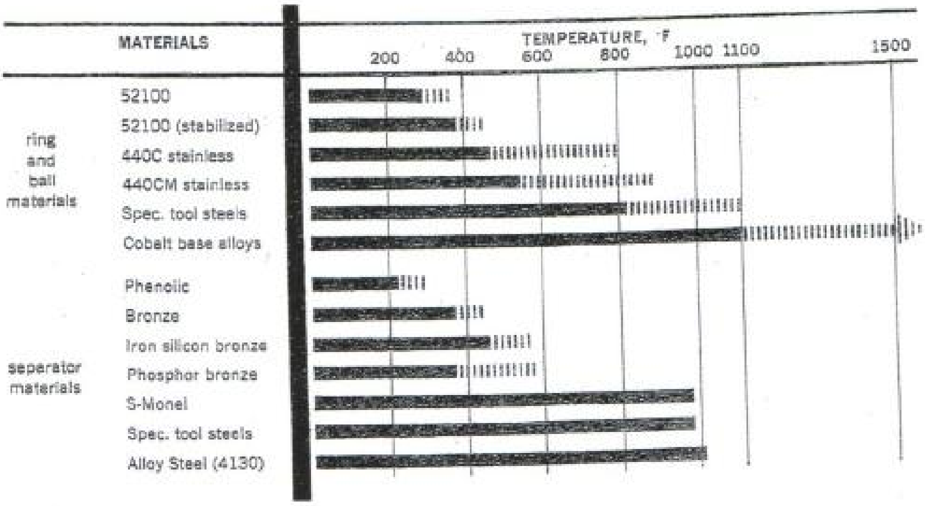
Material and Heat Treatment

The composition, cleanliness and condition of the material used to fabricate rolling contact bearings have a distinct effect on performance. The material used for most ball bearings is thru-hardened AISI 52100 alloy steel. The primary alloying elements are carbon, manganese and chrome. The high carbon content of 1.04% gives the steel responsiveness to heat treatment with corresponding very high strength and hardness. The manganese content of .35% acts as a deoxidizer (purifier) and also imparts strength and responsiveness to heat treatment. The chrome content of 1.45% increases response to heat treatment and depth of hardness penetration. An important part of steel is not only chemical composition, but its cleanliness or freedom from voids and impurities that come from the iron ore refining process. In bearing service, steel must withstand compressive stresses up to 500,000 psi. Impurities and voids in the steel, especially if they are found in the load zone of a bearing, can cause an early failure. Many bearing manufacturers use AISI 52100 "vacuum degassed". This process improves steel cleanliness over "air melt" grades eliminating voids and reducing the chance of an early failure. For extremely critical applications such as aircraft and aerospace bearings, "consumable electrode vacuum melt steel" is used for even more improved cleanliness and bearing life

The material used for roller bearings is case-hardened AISI 8620. The primary alloying elements are .20% carbon, .80% manganese, .55% nickel, .50% chrome and .20% molybdenum. Nickel increases strength and toughness while molybdenum adds to the penetration of hardness and increases toughness. Case hardening involves heating the steel in a carbon rich atmosphere and quenching it producing a hard outer case and softer inner core. Roller bearings have a much higher spring rate than ball bearings. The hard outer case provides support of high compressive stresses while the softer inner core protects against shock loads. Tests have shown that case-hardened steels perform as well as thru-hardened steels. In the past, life improvements factors of 2 for AISI 52100 and 3 for AISI 8620 have been recommended because of improvements in steel cleanliness. Figure 7 shows the temperature limitation of some common bearing materials.

Figure 7

Ball Bearing Material



Ball Bearing Ring, Ball, and Separator

Material Temperature Limitation

Manufacturing Processes

Ball bearing rings are processed as follows:

- They are machined from tubing that is of a special size to reduce cycle time.
- They are heat treated to a high hardness throughout.
- Every surface is fine ground.
- The pathways are honed to an even finer surface finish.

Ball bearing balls are processed as follows:

- Blanks are cut from steel wire.
- The blanks are cold formed into a spherical shape and heat treated.
- The spheres are ground to a fine finish.
- The spheres are then honed to a very fine super finish.
- The finished balls are separated into different diameter class sizes.

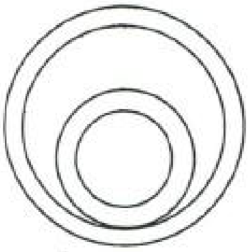
Ball bearings are assembled as follows:

- The inner and outer ring pathway diameters are measured.
- A compliment of balls is selected to obtain the correct internal clearance.
- Radial ball bearings are assembled according to the Conrad method whereby the inner ring is placed off center inside the outer ring, the balls loaded in the crescent space, the rings centered, the balls spaced, and the separator assembled (See Figure 8).

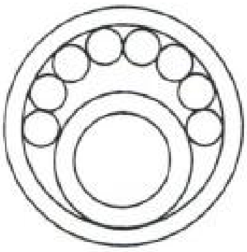
It has been found that grain flow can have an effect on bearing life. The raw tubing for rings is extruded which positions the grain parallel to the tubing central axis. When machining the pathways, end grain is exposed on the surface of the pathway especially higher up the shoulder. It has been found that balls running on end grain have a greater propensity to fail the ring than balls running on the grain itself. This is particularly true for angular contact ball bearings where the balls run higher up the pathway shoulder where end grain is more prevalent than at the center of the pathway where radial bearings run. Forging or roll forming ring blanks prior to further processing has been found to minimize exposed end grain resulting in improved bearing performance.

Figure 8

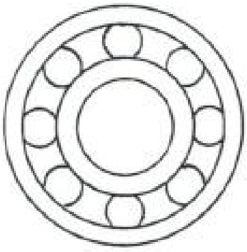
Ball Bearing Assembly



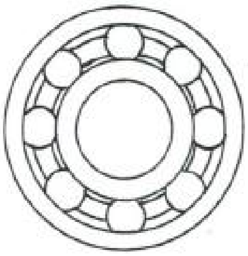
The IR is placed off-center inside the OR.



The balls are placed in the open space.



The IR is centered and the balls spaced.



The separator is installed.

Lubrication

For normal conditions, the best lubricant to use is mineral oil which is refined from petroleum. Synthetics have been developed that have good high temperature and good anti-oxidation properties for special applications but they don't form elastohydrodynamic (EHD) films as well as mineral oils. EHD refers to the film of oil that builds up in the load zone between the rolling element and the rings of rolling contact bearings. It has been found through lab testing that there are several factors that influence the thickness of the film that builds up between the rolling elements and rings. Oil films that are too thin compared to bearing surface finishes can result in performance less than predicted, while films that are thicker result in bearing life that exceeds calculated values.

The following equation is one that can be used to calculate bearing oil film:

T=B(OS)mL-n

- T is a measure of oil film thickness.
- B is a bearing factor which takes into account the physical properties of bearings that influence oil film thickness. B is largely dependent on bearing size with larger diameter bearings developing thicker oil films. The kind of bearing used plays a more minor role with standard design ball and roller bearings falling into the middle of the category.
- O is an oil factor which is influenced primarily by oil viscosity at bearing operating temperature. The type of oil used plays a more minor role with napthenic being the best, paraffinic lying in the middle, and synthetic being the worst.
- S is a speed factor which shows that higher speeds produce thicker oil films.
- L is a load factor showing that higher loads result in thinner oil films.

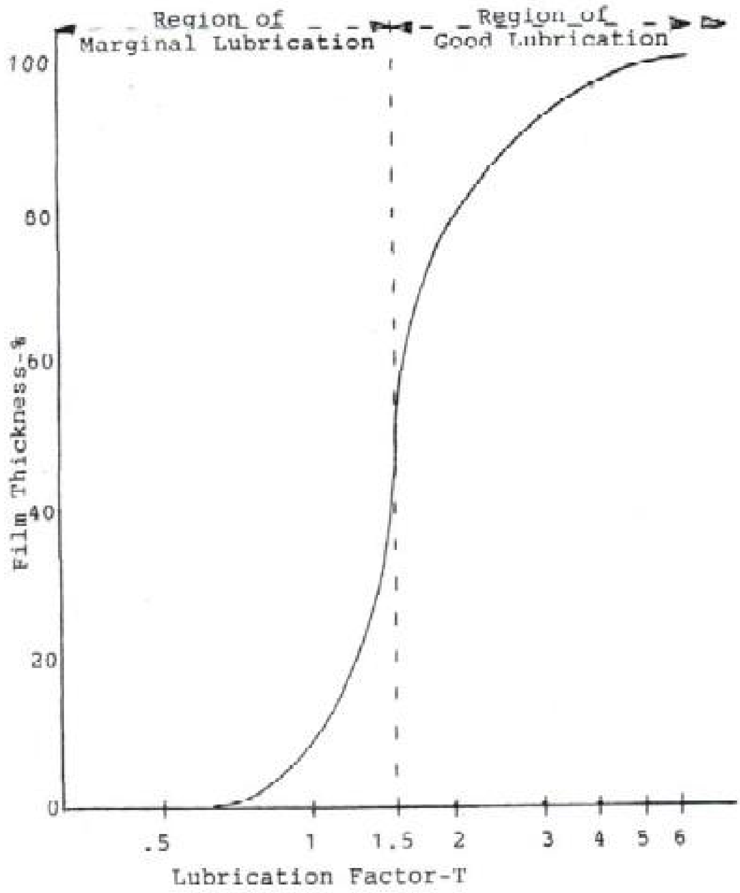
Graphs of all the above factors have been developed which make it easy to calculate oil film thickness and its effect on bearing life. Use of the graphs simplified the equation down to the following:

T=BOSL

Figure 9 has a graph of oil film thickness vs. T which shows that T values below 1.5 result in marginal lubrication and above 1.5 result in good lubrication.

Figure 9

Elastohydrodynamic Lubrication



Misalignment and Mounting

Misalignment refers to the angle made by the center line of the inner ring with respect to the centerline of the outer ring in a bearing. When the two centerlines are collinear, the misalignment is 0o. Normally, ball bearings can tolerate more misalignment than roller bearings because there is less chance of a ball contact pattern moving over the top of the race shoulder than a roller contact moving over the edge the roller. When contact patterns move over an edge, there is a high amount of stress concentration which can lead to early failure. A feature called "crowning" is applied to rollers and rings to reduce edge loading under misalignment operation (See Figures 10 and 11). Normally, cylindrical and tapered roller bearings can tolerate approximately 4 minutes of misalignment while ball bearings can tolerate 16 minutes of misalignment before serious life reduction occurs.

Figure 12 has several different mounting arrangements for ball bearings. The top sketch has the left bearing fixed in the housing and the right bearing free to float. This type of mounting accommodates manufacturing tolerances and shaft thermal expansion without putting unwanted thrust load on the bearings. The middle sketch has both bearings free to float when shaft end play is not critical. The lower sketch has radial ball bearings with loading grooves which are used to load extra balls in the bearing for added capacity.

The top sketch of Figure 13 illustrates how two angular contact ball bearings mounted "back-to-back" can be used to resist shaft misalignment and overturning moments. The middle sketch has two angular contact ball bearings mounted "face-to-face" to accommodate shaft misalignment. The lower sketch illustrates how two angular contact ball bearings can be mounted in "tandem" to accommodate high one direction thrust loads.

Figure 14 has cylindrical roller bearings supporting a spur gearset. The two right bearings are mounted differently above and below the centerline. Above the centerline, the bearings are mounted in the housing cover which necessitates machining the housing bores separately. Below the centerline, the bearings are mounted in a separate cap which allows the housing bores to be machined in one setup providing for better bearing and gear alignment. Figure 15 has tapered roller bearings supporting bevel gears in an automotive drive axle. The two smaller bearings are nut preloaded while the two larger bearings are shim preloaded to provide stiff support for the gears.

Figure 10

Roller Bearing Crowning

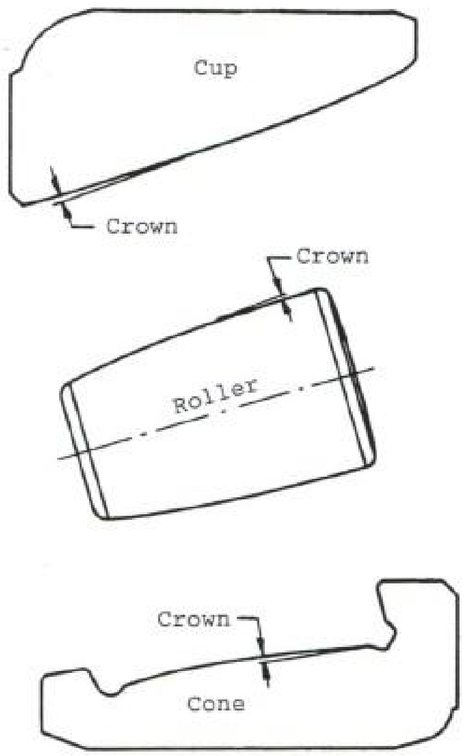
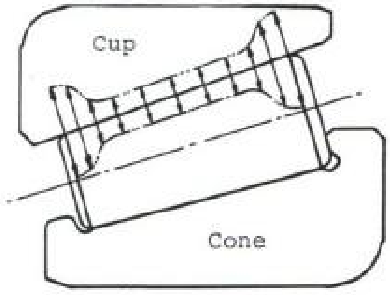
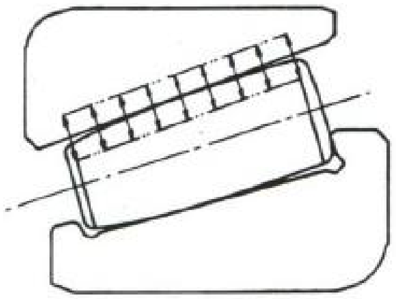


Figure 11

Roller Bearing Stress



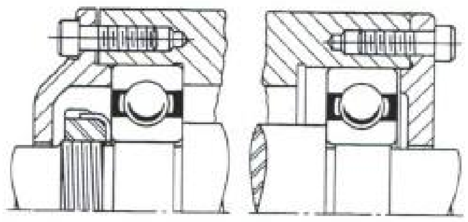
Stress Distribution With
Non-Crowned components.



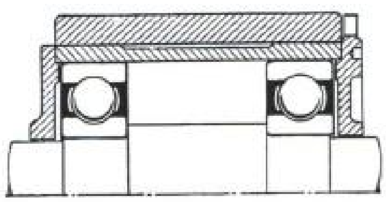
Ideal Stress Distribution
With Crowned Components.

Figure 12

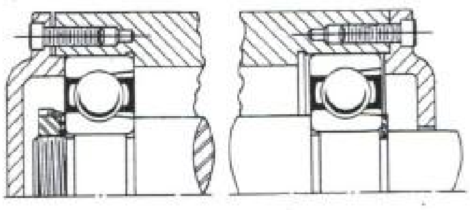
Ball Bearing Mounting



The bearing on the left is clamped to the housing and the shaft. The bearing on the right is free to accomodate shaft thermal expansion and tolerance build-up.



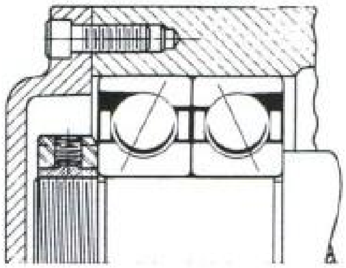
Both bearings can be made to float in the housing if shaft end play is not critical.



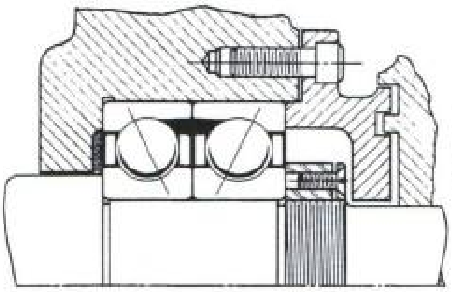
When thrust loads are low, loading groove bearings can be used to take heavy radial loads.

Figure 13

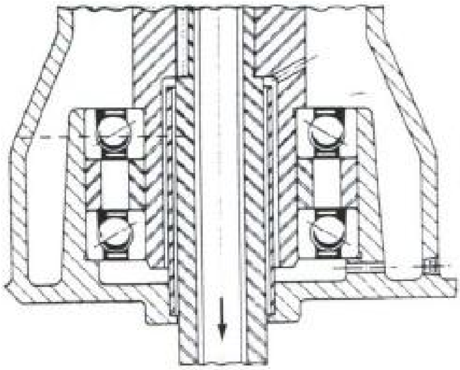
Angular Contact Ball Bearings



Maximum resistance to high moment loading is obtained by using two angular contact ball bearings mounted back-to-back.



Compliance to high shaft misalignment is accomodated by using two angular contact ball bearings mounted face-to-face.



Support of high one-direction thrust loading is accomplished by using two angular contact ball bearings mounted in tandem. The thrust is downward on the shaft.

Figure 14

Cylindrical Roller Bearing Mounting

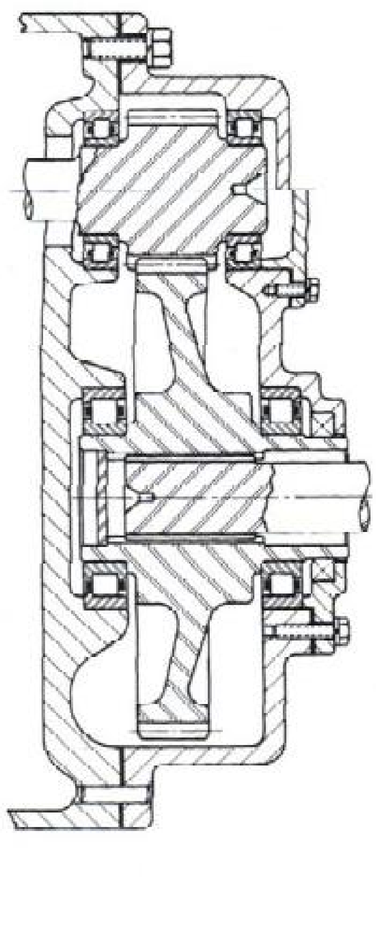
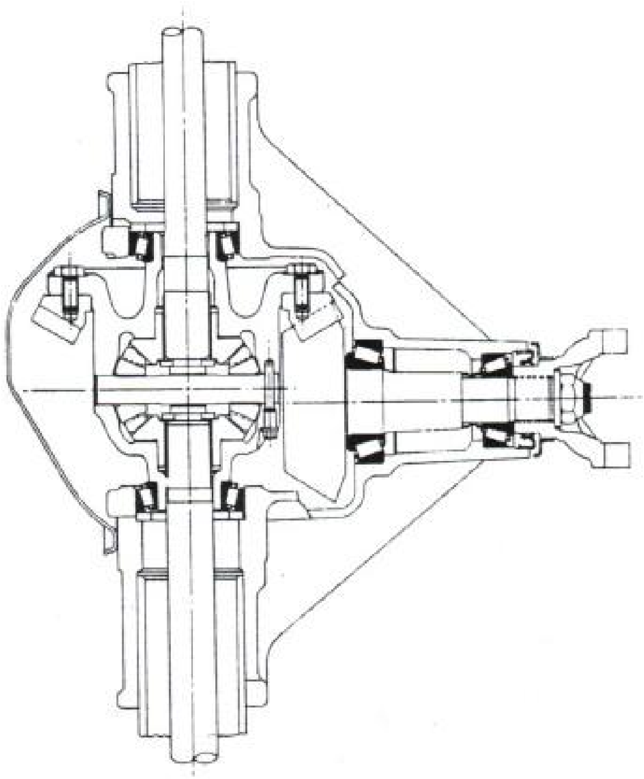


Figure 15

Tapered Roller Bearing Mounting



Drive Axle Bearing and Gear Arrangement

Preloading

Preloading is a method of mounting bearings on a shaft, whereby one is thrust loaded against the other. On manufacturing machines, preloading is done to secure the shaft more rigidly so that the tool attached to it will machine production parts more accurately.

Figure 16 has a drawing of a machine tool spindle (small shaft) supported by two angular contact ball bearings. The inner rings of the two bearings are clamped tightly against the shaft shoulder. Each outer ring is mounted in its own sleeve. Torquing the nut N puts an axial load on the right hand bearing through sleeve B. This load is then transferred through the clamped inner rings to the left bearing; preloading the bearings and putting the shaft in tension.

Let us assume that the nut N is torqued so that a preload of 3000 pounds is put on the bearings and shaft. Then a work force of 2500 pounds is applied to the right on the front left end of the shaft. This additional force increases the load on the front bearing while decreasing the preload (tension) on the shaft and decreasing the load on the rear bearing. The front bearing is now supporting less than the preload and the additional work load (3000+2500=5500 lbs) and the rear bearing is supporting less than the 3000 pound preload.

An analysis will show that the final load on the front bearing is 4500 pounds and the final load on the rear bearing is 2000 pounds. Both bearings are now operating above the steepest part of their load vs. deflection curve and are giving the shaft greater support. Without preload, the 2500 pound work load would have produced a shaft deflection of .003 inch while with preload, the deflection is down to .001 inch which is a big gain considering that some ball bearing components have manufacturing machining tolerances less than .0001 inch.

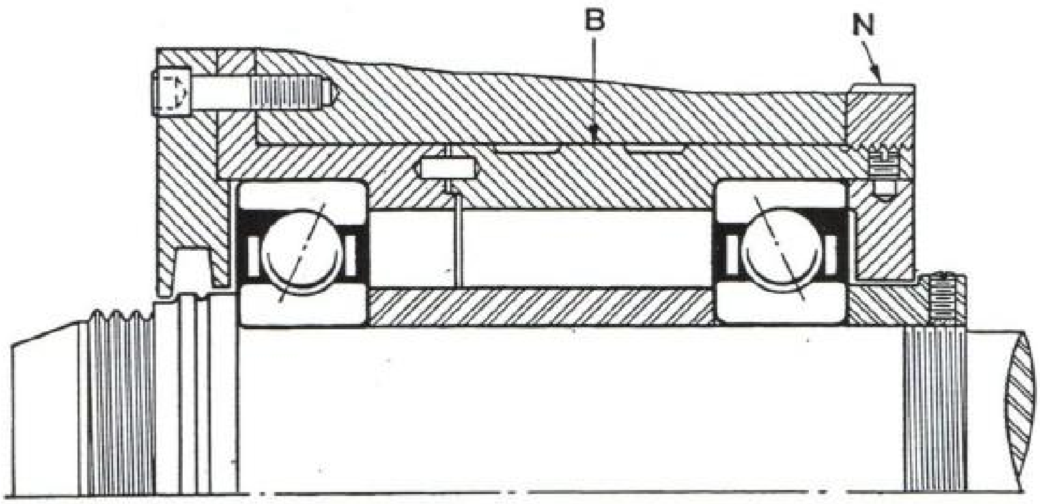
The calculated life of the left bearing with a 2.1654 inch bore and 4650 pound capacity under a 4500 pound thrust load equals:

$$L10=3000(4650/3136)10/3(500/1000)=5575 \text{ hours}$$

The 3136 pound equivalent radial load was obtained from an industry catalog. The life of 5575 B10 hours is equivalent to operating the machine for 2.68 years at 40 hours per week. Angular contact ball bearings are an excellent choice for supporting machine tool spindles and shafts.

Figure 16

There are many factors that affect the performance of ball and roller bearings. Some are obvious and some are not very obvious. This course starts out explaining the performance characteristics of the various ball and roller bearings. It then deals with some of the aspects affecting performance such as; how different types of bearing loads can affect expected life calculations; how the material used and different refining and heat treatment methods can improve bearing performance; how oil lube film thickness affects expected life; and what the effect of misalignment and preloading have on a machine tool bearing application. This course is intended to enhance the understanding of all the above to ensure that bearing application engineering will be a more successful venture.



Machine Tool Spindle

UNIT V REPAIR METHODS FOR MATERIAL HANDLING EQUIPMENT

5.1 Material-handling equipment is equipment that relate to the movement, storage, control and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption and disposal. Material handling equipment is the mechanical equipment involved in the complete system.[1] Material handling equipment is generally separated into four main categories: storage and handling equipment, engineered systems, industrial trucks, and bulk material handling

A systematic approach to material handling maintenance: Maintenance is essential to business success.

The term material handling equipment refers to conveyors, sorters, spirals, carousels, and a wide assortment of electrical and mechanical devices. Proper maintenance of this equipment is essential, because it prevents the loss of business or production caused by mechanical failure. This article introduces a systematic approach to material handling maintenance based on these lessons, and includes important tips to prevent common material handling maintenance mistakes.

The first step in material handling equipment maintenance is to list all material handling equipment. This step is important because it creates a starting point from which a company can develop ways to improve its physical assets.

Within manufacturing operations, the list should include all physical assets, production equipment and processes as well as facility assets. For large distribution centers (DCs), this should include all major areas: mobile equipment, conveyor systems, sorter systems and facility-related assets, as well as bar code scanners, printers and other devices that keep a DC functioning.

Because maintenance depends on more than just knowing what equipment is in place, companies should take into account other factors that could affect how the equipment runs while an equipment list is being compiled. For example, equipment operating in the desert of Nevada with blowing sand requires more maintenance than in a mild climate on the East Coast.

The next step is to develop and implement a strategic maintenance plan. This plan must include a customized preventive maintenance (PM) program to ensure that the equipment runs with high reliability. PM is a continuous process, the objective of which is to minimize future maintenance problems. A PM program costs extra on the front end, but savings come quickly. Studies have shown that operations with PM spend less for maintenance than reactive run-to-failure operations.

The best approach to customizing PM is to let the craftsmen generate the PM program from the ground up. What do they think? They are the ones who will be inspecting the equipment, and if they think it should be looked at daily instead of weekly, this should be the approach to take. It gives them ownership of the equipment and the empowerment to make it work more reliably. When this comes together, look out. The results are significant gains in equipment uptime.

All equipment should be organized in this fashion according to what type of material handling equipment it is. Even the racks should be a part of this (the air-operated flow-through systems will need PM attention.) The air compressor will always be a part of a PM program.

The final steps in the systematic approach to material handling maintenance are validating results and return on investment. Companies should also identify priority areas for improvement based upon a total benchmark evaluation of the maintenance operation. They should also take note of the common mistakes made by those charged with maintaining material handling equipment and make sure that they are eliminated from the process. Of course, the ultimate success will be determined by whether the customer is satisfied.

5.2 Maintenance Strategies for Overhead Cranes and Lifting Equipment

Overhead Crane and Lifting Equipment Maintenance Strategies

Overhead cranes and associated lifting equipment need to be well maintained for safety and business reasons. Regulations and Standards apply that set the minimum requirements for maintenance of this type of equipment, that often performs critical operational functions within a business.

Come share with and learn from others who have are also interest in this topic.

Topics for Discussion

- Outsourcing crane maintenance
- Using crane maintenance service providers and how best to manage them
- Managing major Inspections & Crane Re-certification
- Incident reporting and crane/ people interactions
- Maintenance Strategies, lubrication & CM for Cranes
- Rope, hook, pulley & limit inspections
- Maintenance of chains, slings, lifting frames,
- Maintenance and overhaul of hoist & brake systems

- Maintaining crane motors and gearboxes
- Crane cabins, emergency egress and operator controls issues
- Crane electrical systems including controls, power supplier, catenary systems
- Structural and corrosion issues and resultant inspections
- Planning and scheduling and managing maintenance outages for cranes
- Australian Standards and Crane Legislation issues
- Managing the statutory inspection requirements for cranes
- Wheel maintenance and minimizing wear
- Pre-start operator inspections
- Training for crane operators
- Processes for improving crane driver skill, behavior & minimizing operator damage
- Engaging operators in crane maintenance & reliability issues
- Training for crane maintenance personnel

hoist’s maintenance strategy

ABB’s maintenance support agreement is a flexible, scalable contract structure that meets each instal lifecycle maintenance strategy. It covers the entire spectrum of user and system needs throughout the s lifecycle.

As a worldwide leading hoist systems supplier we have learnt a lot from our customers about their da maintenance needs:

−−All of our customers manage at least some level of in-house maintenance and rely on vendor-provi to support their maintenance activities

−−Most of our customers employ outside resources to fill gaps in the capabilities and capacity in their maintenance staff

−−Many customers rely on vendors to provide customized personnel training to help maintain skills fo system maintenance as well as for advanced learning

−−Customers expect effective vendor supplied evolution and upgrade programs to help them take adv new functionality and to manage product lifecycle status changes

−−Predictable spare parts costs are important to all system owners

−−System application engineers are often employed to modify the user interface and process control configurations to address changing process requirements

All the above needs became the backbone of our consistent approach to maintenance agreement offer

Maintenance support agreements

In a study of the maintenance style and service needs of our customers, we learned even more about th service requirements. This information was used to develop a more comprehensive service contract st maintenance support agreement. This structure provides scalability and value through the bundling of best meet your outsourced maintenance needs.

Service levels

Multiple servcie levels are available for each identified key service requirement. This flexibility allow build an agreement to provide the right amount of service, based upon your in-house capability and st example, level 4 services accommodate customers who rely heavily on ABB knowledge and expertise customers, who maintain their own comprehensive skills and capacity for in-house maintenance, may level 1 or complimentary level services. A short description of the maintenance support agreement co found on the back page of this flyer. The detailed scope of supply for each group of services is depend service level chosen by each customer.

ABB's maintenance support agreements cover the whole hoist system, including:

−−drive system.
−−control system.
−−advant hoist monitors.
−−hydraulic brake units.
−−weighing control systems.
−−low and medium voltage supply systems (switchgears and transformers).

Improving your operational excellence and performance. ABB's maintenance support agreement struc based upon the key customer requirements outlined in the table below.

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5.3 A systems approach for maintenance and renewal efficiency

Facing a competitive environment production utilities are forced to rethink their maintenance strategies[1]. Since the deregulation of the Swedish electrical market in 1996 energy sales have become a competitive market, while distribution and transmission became natural monopolies. For electric production companies the income is a result of the prices for electricity set by supply and demand. The hourly margin cost sets the price for the whole market. Before the change the tariff was essentially the sum of cost of utilities and a reasonable profit: Tariff= Cost + Profit. Under the new regulation the tariff is determined independently of the cost of utilities. Hence, the profit is what is left when utilities costs are subtracted: Profit=Tariff−Costs[2].

A utilities earnings is the difference between incomes andcosts, the incomes can be increased by selling more power orby raising prices. To sell more power new investments must be made, either by purchasing other utilities or by building more power production facilities. But even if this approach is adopted the new investments must be maintained as effectively as possible. To increase the price of electricity is beyond the control of a utility. This means that a utility must be as cost effective as possible to survive on a deregulated power market.

Cost effectiveness means minimizing costs and in the same time still live up to the demand of reliability from costumers and regulatory. In this paper we divide costs into cost of failure, cost of preventive maintenance and capital costs.

To reduce costs by making new investments to reduce capital costs. A manager has to face the fact that he has to manage the assets he is responsible for; he can make new investments just to meet the d of today. The question is what will happen in a long-term perspective of e.g. 25 years? What will the be and what condition will the technical system be in?

Asset management is the ability to model and compare
operational, maintenance and capital options with the goal, to find the overall most cost effective solu
provide the required capability over time. Asset management is how to exploit the asset most profitab
Maintenance in general consists of preventive and corrective maintenance. Preventive maintenance is
at planned intervals, while corrective maintenance is carried out at the time of equipment failure.
Three approaches to maintenance are well established at present [5]:

Time Based Maintenance (TBM)
Condition Based Maintenance (CBM)
Reliability Centred Maintenance (RCM)
Every manager's intention is to run the equipment as much as possible without costly breakdowns. T
way to increase earning in a short-term perspective is to cut down on maintenance and postpone renev
Because of the long operative lifetime of many components, often 50 to 100 years, and the inherent re
such an approach will in most cases be successful. However, in a long-term perspective this might not
effective. It is also difficult.

However, neither of these maintenance approaches alone can be used as decision-making tools for a m
when making decisions about long-term asset management. Aspects like short-term and long-term co
condition and risk can't be dealt with using these approaches. As stated earlier a manager must minim
present value of the costs for failures, preventive maintenance and capital costs. When managing asse
operative lifetime we propose that maintenance management on technical systems are divided this int
condition, and total costs.

This interpretation regards only physical assets and does not include issues like organization, operatio
etc.What we want to point out with out definition of maintenance management is that in order to beco
both long and short term effects of different maintenance strategies it is not enough to cover one or tw
parts, all three must be included in an analysis. Today there is no general methodology that can cope
complex issue. In this work a case study based evaluation of a methodology.

TBM is based on preventive maintenance and is carried out at regular time intervals suggested by the
manufacturer. CBM is a method that tries to find the most efficient intervals between preventive main
checks and measures. This method requires additional equipment to monitor the condition. RCM focu
on the physical assets of the company and the functions they fulfil. It considers how assets could fail t
their required function and what decisions must be taken when any reduction in performance takes pla
method seeks to establish failure modes and the consequences of failure [6].

set up to handle this complex issues is carried out. The methodology was applied on a feed water pum
Forsmark nuclear power plant. The object of this study is to examine pros and cons and use the result
the methodology. Detail vs. scope. When working with the proposed methodology one important issu
is the approach for the study. In order for a study to be possible to carry out,a system can't be divided
components, e.g. nuts and bolts. On the other hand, it is also very difficult to use too large systems an
components. The idea of this methodology is to make a top to bottom analysis and divide a large syste
components. Large systems can be e.g.generators, section of distribution or transmission grids,refiner
transformers etc. These large systems consist of components selected by experts that together represe
condition of the system. This means that in this study we call the lowest level where we collect data a

METHOD

In this study the methodology has been applied to feed water pump system at Forsmark nuclear plant. This system was chosen because of three aspects: importance for production, access to data and system construction. These factors are described in greater detail below.

System construction

The feedwater pumps are built with relatively few inputs and it is relatively easy to measure different values. Also, the three pumps together formed the system we applied the methodology on. Since only two pumps are needed in order for the system to function it was also possible to test the methodology on a system with redundancy

Many technical systems, the production, distribution and power industry often have redundant systems, so in order to make this validation of the methodology a fairly simple system analysis will show strengths and weaknesses. The highest level of system consists of three feedwater pumps. Each one of them is divided into four subsystems,centrifugal pump, motor, oil system and gearbox. These four subsystems are then divided into a number of components. In this study we choose only to use the components representing the centrifugal pump. These are, oil pressure, axial bearing oil pressure, axial bearings 1 and 2 temperature, radial bearings 1 and 2 temperature and axial bearing 1 and 2 cooling water temperature. The maintenance personnel at Forsmark nuclear plant have chosen these components.

RESULT

The results from this study consist of a presentation of each part in the asset management methodology, risk, condition,and costs. These results are then combined and presented in a wider context in an effort to make a systems approach on maintenance and renewals strategies.

5.4 The Computerized Maintenance Management System (CMMS)

A. Proposed CMMS

CAIP, with assistance from the bus companies, studied the existing diesel bus operations and maintenance (O&M) organizations and practices to determine the baseline Egyptian diesel transit bus environment. CAIP then developed a proposed new organizational structure and reporting relationship for the CNG bus garages that is designed to enhance the current system, as well as provide the necessary new equipment and management practices. This effort also includes development of proposed staffing requirements for maintenance personnel and management staff.

The new program is based on CNG transit experience from around the globe, and uses straightforward requirements to allow efficient implementation into the CTA and GCBC organizations. Some technologically sophisticated systems are proposed, but they are being implemented with proper training and provide superior capabilities for monitoring and ensuring the success of the new CNG programs at CTA and GCBC. CAIP is assisting the bus companies with developing detailed management procedures for CNG bus O&M. These include schedules for inspections; procedures for routine and preventive maintenance; management of spare parts and supplies; and monitoring, reporting, follow-up, and resolution of maintenance problems.

B. Need for the CMMS

Currently, all CTA and GCBC maintenance management activities are performed without the use of computers. Significant deficiencies exist, including delay in obtaining spare parts for needed repairs, minimum level of preventive maintenance, redundancies in maintenance functions, inability to track performance of buses, and low level of safety checks.

CNG buses and their support facilities are more sophisticated than their diesel counterparts. CNG is a gas and leaks are harder to detect than those from diesel. The fuel tanks that hold the compressed gas are of a high-tech design. The gas is under high pressure, sometimes exceeding 3,000 PSI. The bus engines and transmissions are computer-controlled and require complex preventive maintenance techniques to keep them operating at optimum conditions.
An enhanced maintenance and safety program is essential for safe and economical operation of the buses and their support facilities.

C. CMMS Description and Goals

For sustainability reasons, CAIP is providing the bus companies with a complete computerized solution for managing and maintaining their new CNG fleets. The system includes software and hardware packages suited for transit service. The system allows implementation of modern management practices, emphasizing preventive rather than corrective maintenance, and includes enhanced quality control for spare parts, tools, and other resources.
CAIRO AIR IMPROVEMENT PROJECT
CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES 3
The CMMS enables management to:

- Schedule preventive and predictive maintenance procedures, and parts and labor utilization for maintenance tasks.
- Project and monitor downtime and causes.
- Project and monitor costs, repairs, and usage of spare parts and labor.
- Analyze failures, costs, maintenance procedures, and resource usage.

CMMS usage helps in:

- Achieving high efficiency in fleet operation (by minimizing failures and maximizing operating time).
- Minimizing usage of parts and labor.
- Maximizing usage of buses and minimizing downtime.
- Maximizing buses’ lifetime and replacement period.
- Minimizing maintenance and operation costs.
- Maximizing profits.
- Raising performance levels.

The goal of this project is to establish a fleet computerized maintenance management system that allows the safe and efficient functioning of a CNG bus fleet for the CTA and GCBC.
CAIRO AIR IMPROVEMENT PROJECT
4 CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES

SECTION III. CMMS Description

A. Primary CMMS Applications

The following are the major elements of the CMMS:

A1. Spare Parts Inventory

Inventory tracking and control is improved resulting in having spare parts when they are needed and, therefore, ensuring that buses are in service the majority of the time. Parts requisitioning and ordering is integrated into the CMMS in order to achieve better ordering efficiency. Vendors and their performance are tracked. Data from the CMMS is then used to expedite future budgeting and planning efforts.

A2. Maintenance Scheduling

Preventive and routine maintenance are especially important for the safe operation of CNG buses and facilities. Scheduling is optimized for this complicated equipment, resulting in more efficient operation of both the buses and the support facilities. Advanced notices of scheduling are issued automatically, resulting in better planning for manpower utilization. Service contract renewals and terms are tracked, and early warning of expirations are produced.

A3. Safety Inspections

Visual and instrumental safety inspections, particularly of the fuel system, are critical to the safe operation of the buses, fueling facilities, and maintenance facilities. Computer scheduling of these inspections ensures an optimum inspection schedule. Furthermore, routine computer analyses of inspection results warn of impending safety problems.

A4. Fuel and Fluids Tracking

The CMMS tracks the rate of fuel and fluids consumption on a per-bus basis and/or for the entire fleet. The system is programmed to automatically warn of excessive fuel and/or fluids usage,indicating a problem situation. This tracking provides early warning of a fuel and/or fluids leak,indicating a potentially hazardous situation.

A5. Performance Monitoring

Tracking performance of drivers, buses, mechanics, inspectors, and systems through use of the CMMS leads to improvement in efficiencies and, therefore, cost savings. Both on-road and inmaintenance tracking is performed. Downtime and its causes, costs, repairs, spare parts’ usage,and labor usage are all tracked. The CMMS is used to analyze tracking data, predict future performance, summarize resources expended, analyze failures, costs, and procedures, and generate reports. Such tracking and analysis is used in continuous quality improvement.

CAIRO AIR IMPROVEMENT PROJECT

CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES 5

A6. Training

CMMS outputs are used in training operators, mechanics, inspectors, management personnel,and other employees. The training schedules are maintained on the system as well. These uses of the CMMS result in improved efficiency and better-trained workers, ultimately resulting in cost savings.

A7. Computer-generated Reports

Many types of reports are generated by the CMMS to support various needs. Both routine and customized reports can be generated, and queries can be made.

A8. Clearinghouse

Maintaining a clearinghouse of data and information about CNG is done on the CMMS. Keeping a computerized inventory of books, pamphlets, service bulletins, CD-ROM’s, etc., allows workers to access needed information easily. The materials and their usage are tracked, and some of the materials are entered directly into the CMMS. Sound and readily available information leads to productivity improvements and safety enhancement.

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There is a significant need to track bus and personnel locations on a real-time basis. There is also a need to analyze current routing and scheduling and make adjustments, as well as to plan new routes. These functions are easily performed using the CMMS.

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The purchasing and inventory control functions interface with the CMMS, resulting in more efficient operations. Ultimately, these efficiencies lead to cost reductions.

A11. Interdepartmental Cooperation

Servicing, operating, and maintaining a CNG fleet will require a higher level of interdepartmental cooperation and a need for sharing information. The CMMS fulfils these needs readily. The technical, procurement, warehouse, human resources, operation, and workshop functions are all linked.

A12. QA/QC and Auditing

Routine and non-routine checks of systems, data, personnel behavior, costs, part failures, and many other items are easily checked by using the CMMS. Solutions, new approaches, remedial measures, and new designs are all indicated by the results of computer analyses. Many parts and failures are predicted and, therefore, preventative measures can be employed. The results of these analyses are a reduction in costs and the increase in the safety of operations.

CAIRO AIR IMPROVEMENT PROJECT

6 CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES

B. CMMS Design Concept

The CMMS design concept is based on a revamped maintenance management structure for both the CTA and GCBC. The existing structure was studied in depth, and the revamped structure is designed to minimize disruption of the current organization. Annex A contains details of the revamped structure and highlights where the CMMS will support and enhance it.

C. CMMS Specifications

C1. General Specifications

The following are the key items required:

- Arabic and English interface.
- Y2K compliant.
- Simple user interface.
- Multiple reports (daily, quarterly, yearly, and historical).
- Simplicity of error messages.
- High security levels.
- Local technical support.

C2. Hardware Architecture

To support the CMMS, CAIP offers the following minimum required hardware specifications for the server and workstations. At each garage, CAIP envisions one server and approximately 10 workstations, each accompanied by a printer (see Annex B, Figure B1 for garage computer network).

The server requires: current Pentium technology; 512MB RAM; 50x CD-ROM drive; 1.44MB floppy drive; 20GB internal tape backup; network card; four 10GB hard disks; 8MB AGP VGA card; two serial, one parallel, and two USB ports; and a 56k/v90 internal modem.

The workstations require: current Pentium technology; 128MB RAM; CD-ROM drive; 1.44MB floppy drive; network card; 10GB hard disk; 8MB AGP VGA card; and two serial, one parallel,and two USB ports.
The monitors for the server and workstations must be plug-and-play compatible and require a nominal, 15-inch (13.8-inch viewable) area.
The network requires a continuous power supply, two hubs (12-port and 8-port) with transceivers to fiber optic cables, two racks and patch panels matching the hubs, and a face plate with external box and surface mounting suitable for an RJ45 connector.
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CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES 7

C3. Software Architecture

The CMMS includes five interrelated modules as follows:
• System Control Module;
• Gate Module;
• Personnel Module;
• Inventory Module; and
• Maintenance Module.

Each of these modules in the CMMS is designed to support multiple companies, branches,currencies, languages, and users, as well as featuring security controls, client/server applications,and the ability to modify screen layouts. Please refer to Annex B for details and flowcharts showing the relationship and interconnectivity of the CMMS modules.The System Control Module controls the other four modules, databases, forms, and the form controls, and can perform this for multiple companies, branches, departments, and divisions. The system setup of users and groups, as well as the assigning of security rights to them, is performed through this module. The operator can also view which users are active on the system at any time through the System Control Module.

The Gate Module is the user-level entry into the CMMS, recording employee timesheets, bus logs, and repair requests.

The Personnel Module holds the electronic records of all employees, assigning each a unique identification number, and allows management to route employees to positions according to skill level and availability, as well as to training courses as required. The module tracks vacation, sick leave, overtime, days absent, etc.

The Inventory Module allows the management to adjust minimum/maximum levels of inventory, dd, issue, receive, and transfer spare parts, and track stock over multiple companies, branches,and stores, and do so by item cost or by average price. The module is barcode-enabled and can produce inventory lists by quantity and cost. The module alerts the operator when inventory is “slow-moving” or needs to be restocked.

The Maintenance Management Module records the technical information for maintenance units,and provides setups for preventive maintenance scheduling, technical and safety procedures, and required resources.
The module notifies all other departments related to maintenance with the required labor skills, materials, and tools needed for each new maintenance operation.

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8 CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES

SECTION IV. Other Factors

A. Proposed Staffing

The figures presented in the table below are the estimated staffing requirements for a garage housing 25 full-size CNG transit buses. The estimates for transportation and maintenance personnel were based on the number of buses and the distance they operate per day. Staffing requirements for the rest of the garage employees are estimates based on the CNG team's experience with facility management in Egypt and the US. The total estimated staff for maintaining and operating the CMMS is two. **The Computerized Maintenance Management System (CMMS)**

A. Proposed CMMS

CAIP, with assistance from the bus companies, studied the existing diesel bus operations and maintenance (O&M) organizations and practices to determine the baseline Egyptian diesel transit bus environment.

CAIP then developed a proposed new organizational structure and reporting relationship for the CNG bus garages that is designed to enhance the current system, as well as provide the necessary new equipment and management practices. This effort also includes development of proposed staffing requirements for maintenance personnel and management staff.

The new program is based on CNG transit experience from around the globe, and uses straightforward requirements to allow efficient implementation into the CTA and GCBC organizations. Some technologically sophisticated systems are proposed, but they are being implemented with proper training and provide superior capabilities for monitoring and ensuring the success of the new CNG programs at CTA and GCBC. CAIP is assisting the bus companies with developing detailed management procedures for CNG bus O&M. These include schedules for inspections; procedures for routine and preventive maintenance; management of spare parts and supplies; and monitoring, reporting, follow-up, and resolution of maintenance problems.

B. Need for the CMMS

Currently, all CTA and GCBC maintenance management activities are performed without the use of computers. Significant deficiencies exist, including delay in obtaining spare parts for needed repairs, minimum level of preventive maintenance, redundancies in maintenance functions, inability to track performance of buses, and low level of safety checks.

CNG buses and their support facilities are more sophisticated than their diesel counterparts. CNG is a gas and leaks are harder to detect than those from diesel. The fuel tanks that hold the compressed gas are of a high-tech design. The gas is under high pressure, sometimes exceeding 3,000 PSI. The bus engines and transmissions are computer-controlled and require complex preventive maintenance techniques to keep them operating at optimum conditions. An enhanced maintenance and safety program is essential for safe and economical operation of the buses and their support facilities.

C. CMMS Description and Goals

For sustainability reasons, CAIP is providing the bus companies with a complete computerized solution for managing and maintaining their new CNG fleets. The system includes software and hardware packages suited for transit service. The system allows implementation of modern management practices, emphasizing preventive rather than corrective maintenance, and includes enhanced quality control for spare parts, tools, and other resources.

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CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES 3
The CMMS enables management to:
- Schedule preventive and predictive maintenance procedures, and parts and labor utilization for maintenance tasks.
- Project and monitor downtime and causes.
- Project and monitor costs, repairs, and usage of spare parts and labor.
- Analyze failures, costs, maintenance procedures, and resource usage.

CMMS usage helps in:
- Achieving high efficiency in fleet operation (by minimizing failures and maximizing operating time).
- Minimizing usage of parts and labor.
- Maximizing usage of buses and minimizing downtime.
- Maximizing buses' lifetime and replacement period.
- Minimizing maintenance and operation costs.
- Maximizing profits.
- Raising performance levels.

The goal of this project is to establish a fleet computerized maintenance management system that allows the safe and efficient functioning of a CNG bus fleet for the CTA and GCBC.

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4 CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES

SECTION III. CMMS Description

A. Primary CMMS Applications

The following are the major elements of the CMMS:

A1. Spare Parts Inventory

Inventory tracking and control is improved resulting in having spare parts when they are needed and, therefore, ensuring that buses are in service the majority of the time. Parts requisitioning and ordering is integrated into the CMMS in order to achieve better ordering efficiency. Vendors and their performance are tracked. Data from the CMMS is then used to expedite future budgeting and planning efforts.

A2. Maintenance Scheduling

Preventive and routine maintenance are especially important for the safe operation of CNG buses and facilities. Scheduling is optimized for this complicated equipment, resulting in more efficient operation of both the buses and the support facilities. Advanced notices of scheduling are issued automatically, resulting in better planning for manpower utilization. Service contract renewals and terms are tracked, and early warning of expirations are produced.

A3. Safety Inspections

Visual and instrumental safety inspections, particularly of the fuel system, are critical to the safe operation of the buses, fueling facilities, and maintenance facilities. Computer scheduling of these inspections ensures an optimum inspection schedule. Furthermore, routine computer analyses of inspection results warn of impending safety problems.

A4. Fuel and Fluids Tracking

The CMMS tracks the rate of fuel and fluids consumption on a per-bus basis and/or for the entire fleet. The system is programmed to automatically warn of excessive fuel and/or fluids usage,indicating a problem situation. This tracking provides early warning of a fuel and/or fluids leak,indicating a potentially hazardous situation.

A5. Performance Monitoring

Tracking performance of drivers, buses, mechanics, inspectors, and systems through use of the CMMS leads to improvement in efficiencies and, therefore, cost savings. Both on-road and inmaintenance tracking is performed. Downtime and its causes, costs, repairs, spare parts' usage,and labor usage are all tracked. The CMMS is used to analyze tracking data, predict future performance, summarize resources expended, analyze failures, costs, and procedures, and generate reports. Such tracking and analysis is used in continuous quality improvement.

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A6. Training

CMMS outputs are used in training operators, mechanics, inspectors, management personnel,and other employees. The training schedules are maintained on the system as well. These uses of the CMMS result in improved efficiency and better-trained workers, ultimately resulting in cost savings.

A7. Computer-generated Reports

Many types of reports are generated by the CMMS to support various needs. Both routine and customized reports can be generated, and queries can be made.

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CAIRO AIR IMPROVEMENT PROJECT
6 CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES

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CMMS DESIGN CONCEPT FOR CNG BUS FACILITIES 7

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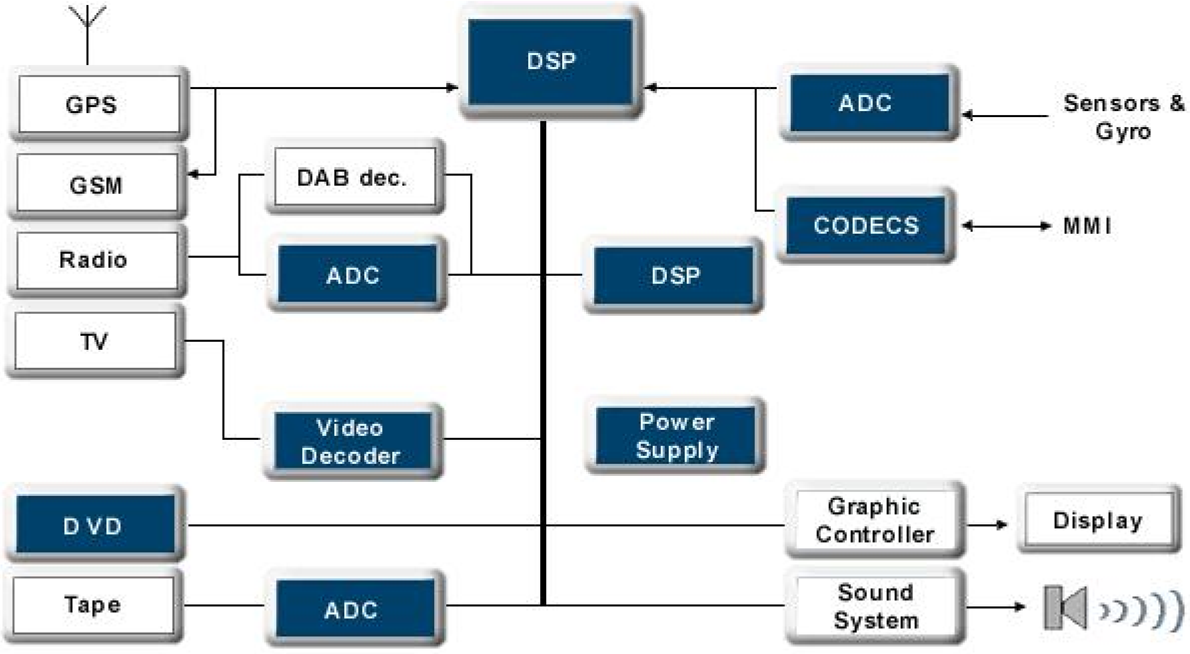


5.5 Work Order System

Work order system is the information system used by the industry to keep track of its maintenance works. Work permits are components of work order. Maintenance department issues work permits to different executing agencies permitting them to start their work.

A maintenance work order are generally gives the following information:

- Work order number and code
- Departments address and code
- Date of issue
- Detail of approval
- Date of receipt of work order
- Priority
- Location
- Equipment details
- Nature of work
- Material requirement
- Completion data and report
- Special requirement

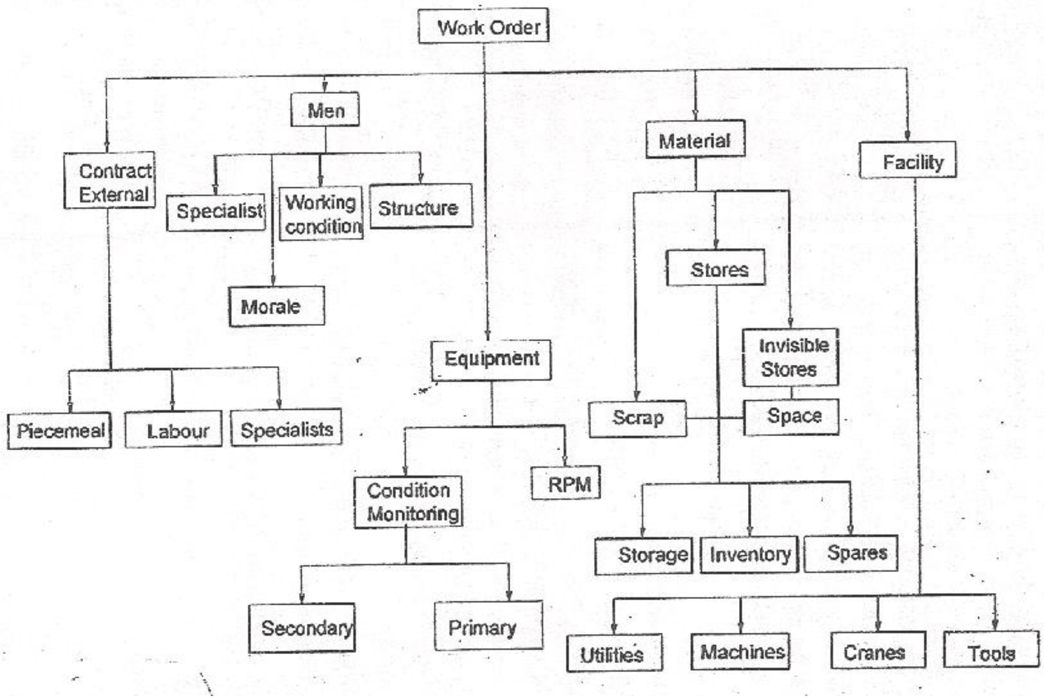
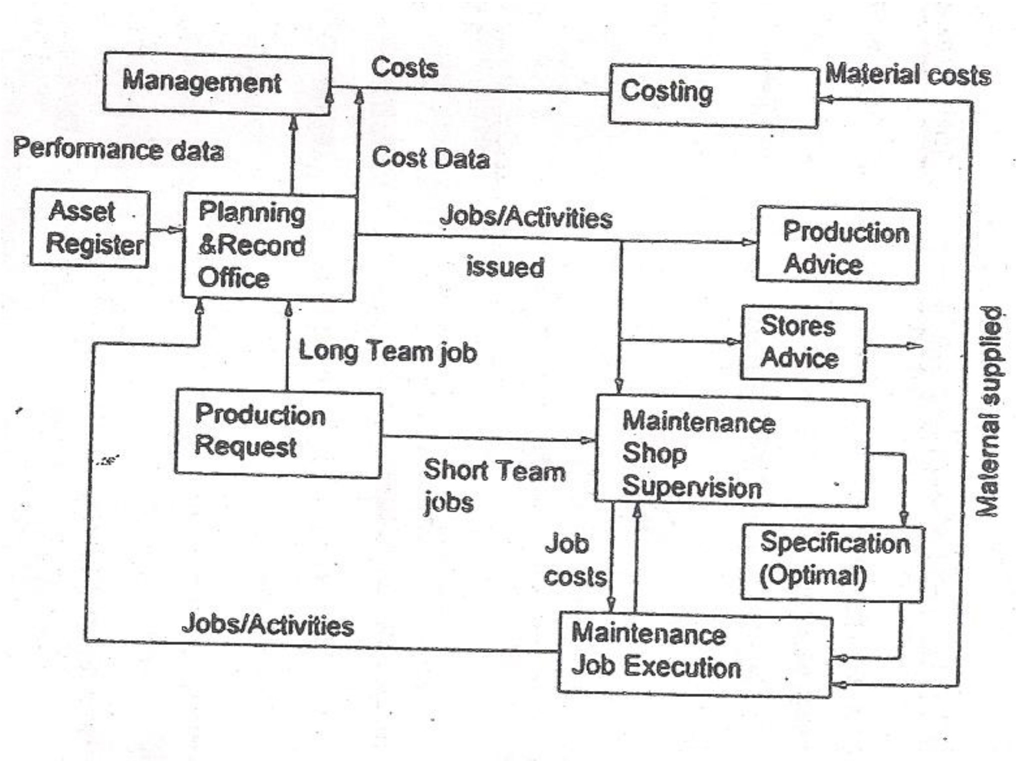


Figure 5.5 Work order tree

Work permit are components of work order. Maintenance department issues work permits to different executing agencies permitting them to start their work. A work permit mentions the work permit number ,work order number, section from which work originated and information as mentioned in work order.

A well designed organization should have proper strategies to execute,monitor and control over the various maintenance tasks**.**



- Monitoring:

a)Gather information about deviation and delay in execution of maintenance may provide idea about the need to add more resources to complete the maintenance task in scheduled time frame b)Communication of the changes in job content to the various follow up agencies

c)ovide information about constraints in technical issues and necessary steps can be taken to improve the existing techniques

Method of monitoring:

Feedback:

- Unscheduled / pending job
- Work status
- Suspended work
- Work completion
- Manpower requirements and actual utilization
- Cost of maintenance
- Technical difficulties

Control:

- Continuous or periodical monitoring
- Inspection of status
- Comparison of status with the predetermined standard and initiating corrective measures.

Maintenance Engineering
Unit I

1. Define maintenance?

Maintenance is the routine and recurring process of keeping a particular machine or asset in its normal operating conditions
So that it can deliver the expected performance or service without any loss or damage.

2. Define reliability?

Reliability is defined as the probability that a component /system, when operating under given condition, will perform its intended functions adequately for a specified period of time. It refers to the like hood that equipment will not fail during its operation.

3. State the benefits of reliability analysis in industries?

The main advantages of imposing reliability requirements are increased productivity and reductions in forced outage equipment due to planned maintenance activity.

4. Define failure rate?

Failure rate is the ratio of the number of failures during particular unit interval to the average population during that interval.
This failure rate is also known as hazard rate and instantaneous failure rate.

5. What is Mean Failure Rate?

The mean failure rate h is obtained by finding the mean of the failures rates for specified period of time.

$$h = \frac{(Z1 + Z2 + Z3 + \ldots + ZT)}{T}$$

where Zt represents failure rates over the specified period of time T.

6. Define Mean Time to Failure.

Let t1 is the time to failure for the first specimen, t2 is the time to failure for the second specimen and t n is the time to failure
for the Nth specimen. Hence the mean time to failure for N specimens are

$$MTTR = (t1+t2+\ldots\ldots+t\,N)\,/N$$

7. What is Mean Time between Failures (MTBF)?

Mean Time between Failures (MTBF) is the mean or average time between successive failures of a product. Mean time between failures refers tom the average time of breakdown until the device is beyond repair.

8. Define Mean Time to Repair (MTTR)?

Mean Time to Repair is the arithmetic mean of the time required to perform maintenance action. MTTR is defined as the
Ratio of total maintenance time and number of maintenance action.

MTTR = Total maintenance time/ Number of maintenance action.

9. Define Maintenance Action Rate?

Maintenance action rate is the number of maintenance action that can be carried out on equipment per hour.

10. Define Failure Density?

Failure Density is the ratio of the number of failures during a given unit interval of time to the total number of items at the very beginning of the test.

11. State the types of reliability?

Reliability can be generally of two types:

(i) Inherent Reliability: It is associated with the quality of the material and design of machine parts.

(ii) Achievable Reliability: It depends upon other factors such as maintenance and operation of the equipment.

12. Draw the equipment life cycle and name the various phases ln it?

Phase I - Failure pattern inherent in a new product because of manufacturing or design defects.

Phase II - Life period of an equipment

Phase III - Failures due to wear out conditions because to aging of the equipment.

13. Define maintainability?

Maintainability is defined as the probability that a unit or system will be restored to specified working conditions within a given period when maintenance action is taken in accordance with the prescribed procedures and resources.

14. Define availability?

Availability is the ratio of the time at which equipment is available for the designated operation/service to the total time of operation and maintenance of the equipment. It is also defined as the ratio of equipments uptime to the equipment uptime and downtime over a specified period of time.

15. State the advantages of life cycle cost analysis.

(i) Integration of engineering, economics and financial aspects lead to the way of robust metric for the selection and purchase equipment required for the industry.

(ii) Reduced operating and maintenance cost of equipments due to cost analysis over span of time.

(iii) It leads to the selection of proper and economically viable equipment.

16. Draw the curve to determine the economic life of equipment?

The economic life of equipment depends on the maintenance and repair costs, availability and operational efficiency. A plot of cumulative efficiency and maintenance and repair cost per cumulative hours Vs operating hours of the equipment to find the economic life of the equipment is shown in the figure.

17. State the components of maintenance cost?

The maintenance cost is comprised of two factors:
(i) Fixed cost: This includes the cost of support facilities including the maintenance staff.
(ii) Variable cost: This includes the consumption of spare parts, replacement of components and cost other facilities requirements of maintenance.

18. State the role of maintenance budget

The maintenance budget is used to set aside certain amount of money to meet the expenditures incurred in achieving the objectives of maintenance.

19. State the types of maintenance budget?
(i) Appropriation Budget: Budget used to allocate money for each activity independently.
(ii) Fixed Budget: Fixed used to allocate money for a specified period of time.
(iii)Variable Budget: Dynamic allocation of expenditure based on maintenance requirements and activities.

20. List the main factors of maintenance cost?

The maintenance cost is comprised of two factors:
(i) Fixed cost: This includes the cost of support facilities including the maintenance staff.
(ii) Variable cost: This includes the consumption of spare parts, replacement of components and cost other facilities requirements of maintenance.

Unit – II

1. Define the term Preventive Maintenance?

It is a maintenance program which is committed to the elimination or prevention of corrective and breakdown maintenance. It is designed for day to day maintenance like cleaning, inspection, lubricating, retightening etc. to retain the healthy condition of equipments.

2. Define predictive maintenance?

Predictive maintenance is a management technique that uses regular evaluation of the actual operating conditions of plant equipment, production systems and plant management function to optimize total plant operation.

3. What is meant by Breakdown maintenance approach?

It is a type of maintenance approach in which equipment is allowed to function / operate till no failure occurs that no maintenance work is carried out ion advance to prevent failure.

4. Classify various planned maintenance approach.
   1. preventive maintenance
   2. corrective maintenance
   3. predictive maintenance
   4. condition based maintenance

5. Define corrective maintenance approach.

Corrective maintenance is the program focused on regular planed tasks that will maintain all critical machinery and system in optimum operation conditions

6. What is meant by preventive maintenance approach?

A comprehensive preventive maintenance program involves periodical evaluation of critical equipment, machinery to detect problem and schedule maintenance task to avoid degradation in operating conditions. It is designed for day to day maintenance like cleaning inspection, lubricating, retightening etc. to retain the healthy condition of equipments.

7. List the objectives of corrective maintenance?
   1. Elimination break downs
   2. Elimination deviations from optimum operating condition.
   3. Elimination unnecessary repairs

8. What is meant by predictive Maintenance?

Predictive maintenance is a management technique that uses regular evaluation of the actual operating conditions of plant equipment production systems and plant management functions to optimize total plant operation.

9. list out some condition based monitoring techniques and briefly discuss on them.
   1. Vibration monitoring
   2. thermograph
   3. tribology
   4. electrical motor analysis

10. What is meant by reliability centered maintenance (RCM)?

Reliability centered maintenance is one of the well established systematic and a step by step instructional tool for selecting applicable and appropriate maintenance operation types. It helps in how to analyze all failure modes in a system and define how to prevent or find those failures early.

11. What is total productive maintenance and discuss its similarities with TQM?

Total productive maintenance is a maintenance program which involves a newly defined concept of maintaining plants and equipments. The goal of tpm program is to significantly increase the production, at the same time increasing employee morale and job satisfaction.

12. What is meant by reliability centered maintenance?

Reliability centered maintenance is one of the well established systematic and a step by step instructional tool for selecting applicable and appropriate maintenance operational types.

13. What does safety, health and environment pillar of TPM aims at?

This pillar aims at achieving Zero accident, Zero health damage and Zero fires.

14. What is limitation of breakdown maintenance?

1. Most repairs are poorly planned due to time constraint caused by production and plant management. This will cost three to four times than the same repair when it is well planned.
2. This approach focus only on repair or the symptoms of failure and not on the root cause of failure. This results only in increase in the frequency of repair and correspondingly the maintenance costs.

15. list the benefits of implementing preventive maintenance.
    1. It maintains the equipment in good condition to prevent them from bigger problems.
    2. Prolongs the effective life of the equipments.
    3. Detects the problem at earlier stages.
    4. minimizes/eliminates the rework/scrap and helps in reducing the process variability
    5. Significantly reduces unplanned downtime.

16. Name the five S principles used for implementations of TPM.
    1. SEIRI – Sort out
    2. SEITON –Organize
    3. SEISO – Shine workplace
    4. SEIKETSU – Standardization
    5. SHITSUKE – Self discipline

17. List the various pillars of TPM?
    1. 5,S Principle
    2. jishu hozen(JH)
    3. Kaizen
    4. planned maintenance
    5. Quality maintenance.
    6. training
    7. office TPM
    8. Safety, health and environment

18. What are the objectives of TPM?

    The main objectives of TPM are
    1. to achieve zero defects
    2. achieve zero accidents and zero break downs in all functional areas of an organization
    3. to create different team of people to have active participation.
    4. To aim at minimization of defects and
    5. To inculcate autonomous policy.

19. Name the various stakeholders of maintenance scheduling.
    1. Operators
    2. Planners
    3. Schedulers
    4. Maintenance supervisors
    5. craftsman
    6. Store's in charge

7. operation superintendent

20. Define Maintenance Scheduling.

Maintenance scheduling is a joint maintenance operations activity in which maintenance agrees to make the recourses available at a specific time when the unit can also be made available by operations.

Unit – III

1. What is equipment health monitoring?
   Conditions monitoring is one of the maintenance methods which are used to assess the health and condition of equipments machines, systems or process by absorbing checking, measuring and monitoring several parameters. This technique is also called as equipment health monitoring.

2. List down the factors for increasing the demand condition monitoring
   1. Increased quality expectations reflected in produces liability legislation
   2. Increased automation to improve profitability and maintain competitiveness
   3. Increased safety and reliability expectations
   4. Increased cost of maintenance due to labour and material cost.

3. List down the key features of condition monitoring.
   1. Links between cause and effect
   2. Systems with sufficient response
   3. Mechanisms for objective data assessment
   4. Benefits outweighing cost
   5. Data storage and review facilities.

4. Write down the basic steps in condition monitoring.
   1. Identifying critical systems
   2. Selecting suitable techniques for condition monitoring
   3. Setting baselines
   4. Data collection
   5. Data assessment
   6. Fault diagnosis and repair
   7. System review

5. What are three types of condition monitoring
   a. Subjective condition monitoring
   b. Minimized breakdown costs
   c. Improved morality of the operating personnel and safety.

6. State the advantages and disadvantages and disadvantages of condition monitoring.

Advantages

1. Improved availability of equipment
2. Minimized breakdown cost
3. Improved reliability

Disadvantages

1. Gives only marginal benefits
2. Increased running cost
3. Sometimes difficult to organize

7. Mention the various costs involved in costing of condition monitoring mainly
    I. Installation cost
    II. Operating cost

8. State the methods of measuring vibration
    a. Amplitude
    b. Frequency
    c. Phase

9. Name the types of pyrometers.
    1. Total radiation pyrometers
    2. Infra red pyrometers
    3. Optical radiation pyrometers

10. Mention the application of bimetallic strip.
    1. Bimetallic strips are frequently used in simple ON – OFF switches.
    2. The bimetal strips are also used in control switches.

11. List down the features of RTD.
    1. High degree of accuracy
    2. Resistance thermometer is interchangeable in a process without compensation or recalibration.

12. State the application and limitation of thermisters.

    Applications:
    1. It is used for varying temperatures
    2. it is used in time delay circuits
    3. Thermistors are used for temperature compensation.

13. What are two main types of infrared themography?
    1. Passive thermography
    2. Active thermography

14. What are the principles very important for the study of eddy current test .
    i. Permeability
    ii. Conductivity
    iii. Material thickness

iv. Edge effect and end effect
v. Lift off
vi. Fill factor

15. Describe the limitation of eddy current test.

The main limitation is the low penetration of parts being examined, using limited to thin walls or near surface flaws. It is difficult to use on ferromagnetic materials. False indications are possible because of mixed variables, edge effects and lift-off effects. Extensive technical knowledge is required for the development of inspection procedures, specific probes and to interpret the inspection data.

16. Mention th effect of X-rays to human body?

I. Injuries to superficial tissue
II. General effects on the body, particularly the blood forming organs; eg. Producers of anema and leukerma
III. Induction of mahgnant tumors.
IV. Genetic effects.

17. What are the limitations of ultrasonic test?

a. Unfavorable geometries and coarse anisotropic grain structures are difficult to inspect.
b. extensive technical knowledge is required for the development of inspection procedure.
c. Parts that are rough, irregular in shape, very small or thin or not homogenous are difficult to examine, specific probes and to interpret the inspection data.

18. Name some of the methods of leakage monitoring.

1. Interstitial monitoring
2. level monitoring
3. Vapor monitoring
4. Liquid Monitoring

19. Define see back effect?

The basic principle of thermocouple is ‘when two dissimilar metals are joined together and emf will exist between the two points A and B, which is primarily a function of the junction temperature. The above said to be principle of see back effect.

20. State the various methods of corrosion monitoring?

d. Weight loss method
e. Electrical resistance method
f. linear polarization method
g. corrosion potential measurement
h. Ultrasonic testing
i. Sentinel hole method.

Unit –IV

1. Define the term failure.

The term failure may be defined as

1. Any loss that interrupts the continuity of production
2. A loss of assets availability
3. The unavailability of equipment
4. A deviation from the status quo
5. Not meeting target expectations
6. Any secondary defect.

2. What are the various possible causes for a failure?

U n e x p e c t e d and unintentional damage \
W o r k m a n s h i p
i m p r o p e r design
Manufacturing defects
Incorrect usage of equipment

3. Define failure analysis?

Failure analysis is the process by which information/data about failure occurring in equipments/ systems are collected and analyzed to find the root cause of failures, and the causes are addressed to prevent recurrence of failures.

4. Name the three types of failure models?

Predictable failure model
Unpredictable failure model
Running-In-Failure model

5. What are called age-dependent failures?

Time dependent failures are called age dependent failures

6. What are predictable failures?

In spite of all the working conditions maintained at same level, the cause of failure will be random in nature and cannot be assigned to any particular mechanism of failure. This type of failures is called Unpredictable Failures.

7. What are Running In Failures?
   Suppose if some components/ equipments are installed with unnoticed defects, may fail in a short duration after installation than during its useful life. This type of failures is Running In Failures.

8. Define Fault tree diagrams
   Fault tree diagrams are logic block diagrams that display the state of a system in terms of the states of its components.

9. Write down the capabilities of Fault Tree Diagram.
   1. Fault tree analysis and failure modes and effects analysis,
   2. Design for reliability
   3. Design for safety

10. Define Event tree Analysis
    An event tree is a visual representation of all the events which can occur in a system. As the number of events increases, the pictures fans out like the branches of a tree

11. What is the aim of event tree analysis?
    The aim of event tree is to determine the probability of an event based on the outcomes of each event in the chronological sequence of events leading up to it. By analyzing all possible outcomes, we can determine the percentage of outcomes which lead to the desired result.

12. Define Root cause analysis?
    RCA is a step by step method that leads to the discovery of faults first or root cause. Every equipment failure happens for a number of reasons. There is a definite progression of actions and consequences that lead to a failure. An RCA investigation from the end failure is back to the root cause.

13. Define FMEA?
    FMEA is methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome the issues, thereby enhancing reliability through design.
14. Define Risk Priority Number(RPN)
    Risk priority numbers is the product of the numerical severity, occurrence and detection ratings.
    RPN = (S) X (O)X(D)

15. Name the factors based on the satisfactory performance of gears/drives.
    I. Proper design and manufacture of drive
    II. Selection of proper type and size
    III. Proper installation
    IV. Proper use of service
    V. Proper maintenance of unit in it entire life.

16. Name the factors that contribute to tooth breakage.
    The common reasons for gear tooth breakage may be due to any of the following reasons
    a. Fatigue
    b. Heavy wear
    c. Overload
    d. Cracking

17. list some of the inspection performed on gears
    1. Pitch error
    2. Axial and
    3. Radial run out
    4. Tooth profile etc.

18. Name some of the geometric properties that are checked for guide ways.
    1. Straightness
    2. Flatness
    3. Parallel both on horizontal and vertical surfaces.

19. What are the factors influence the performance of sleeve bearings.
    The following are the factors that affect the bearing performance:
    1. Dirt
    2. Fatigue
    3. Hot Shot phenomenon and
    4. Crush problem

20. Define Crush

Normally, the bearings are manufactured so that they are slightly longer circumferentially than the mating housing. The bearing will be elastically deformed during assembly. If the amount of crush is insufficient, relative motion occurs between the bearing and its bore, which causes fretting and makes the bearing back a highly polished or pitted.

Unit –V

1. State few examples of material handling equipments.

Material handling equipments include carts, hand trucks, fork lifts, conveyors, shelf pickers and other specialized industrial trucks powered by electric motors or internal combustion engines.

2. State the benefits of proper maintenance of material handling equipments.

The benefits of a maintenance program for material handling equipments are to maintain the high efficiency, keep them in running condition, reduce the cost of repairs, safer operation and enhanced productivity.

3. State the major stages in preventive maintenance of material handling equipments.

There are three stages of preventive maintenance are:
1. Inspection
2. Repair and
3. over haul

4. State the various phases present in a good maintenance management system.
    1. Work identification
    2. Planning
    3. Scheduling
    4. Execution
    5. Recording and
    6. Analysis

5. Define the term computerized maintenance management system (CMMS)

Computerized maintenance management system is the application of computers in planning, scheduling, monitoring and control of maintenance activities.

6. State the objectives of CMMS.

1. Maintenance of existing equipments
2. Inspection and service of the equipment
3. installation or revamping of the equipment
4. Maintenance storekeeping
5. craft administration

7. State the advantages of CMMS.
    1. Improve maintenance efficiency
    2. Reduce maintenance costs
    3. Reduce the equipment downtime by proper scheduling preventative maintenance.
    4. provide maintenance reports in specific formats depending on the requirements.
    5. Quicker access to plant maintenance statistics

8. Define work order system.
   Work order system is the information system used by the industry to keep track of its maintenance works.

9. Mention the use of work order backlog.
   Work order back log is used to find out all active maintenance works order in an industry.

10. What is work permit?
    Work permits are components of work order. Maintenance department issues work permits to different executing agencies permitting them to start their work.

11. What is job card?
    Job cards contain necessary details for performing individual job in maintenance organizations. Job card may be in the form of a card, sheet or printout.

12. State the benefits of job card system.
    1. Information about maintenance history
    2. Knowledge of frequency of frequency of maintenance for equipments
    3. Details of equipments which require maximum resources
    4. Helps in job auditing
    5. Evaluation of cost of maintenance.

13. State the role equipment records in maintenance.
    Equipment records are information containing the details of installation, service, repair, maintenance activities, schedules and plans for future implementation. Equipment records are to be used to maintain control on maintenance cost, reliability and availability.

14. State the benefits of keeping equipments records.
    1. clear picture about the details of maintenance programmes is obtained.
    2. information about completed, pending and regular jobs carried out to the equipment are available
    3. Records disseminated to various units of the industry.

4. Helps in standardization of procedures.
5. Evaluation of performance of maintenance tasks.

15. List some of the inspection performed on gears

Pitch error
Axial and
Radial run out
Tooth profile etc

16. Define Root cause analysis?

RCA is a step by step method that leads to the discovery of faults first or root cause. Every equipment failure happens for a number of reasons. There is a definite progression of actions and consequences that lead to a failure. An RCA investigation from the end failure is back to the root cause.

17.List the main factors of maintenance cost?

The maintenance cost is comprised of two factors:

(i) Fixed cost: This includes the cost of support facilities including the maintenance staff.
(ii) Variable cost: This includes the consumption of spare parts, replacement of components and cost other facilities requirements of maintenance.

18.Name the three types of failure models?

Predictable failure model
Unpredictable failure model
Running-In-Failure model

19.Define Event tree Analysis

An event tree is a visual representation of all the events which can occur in a system. As the number of events increases, the pictures fans out like the branches of a tree

20.What are two main types of infrared themography?

1. Passive thermography
3. Active thermography

16 Marks Questions and Answers

UNIT I

1) What are the principles of maintenance?

a) Plant management in maintenance work:

The main role of a maintenance function is to provide safe and effective operation of the equipment to achive the desired targets on time with economics usage of resources.

b) Production and maintenance objectives:

The plant operation is driven by the production targets.The objective of maintenance function is to support these target.The achivement of desired goals of athe production system is to be supported by both the production and maintenance department to ensure smooth and succesfull operation of the industry.

c) Establishment of work order and recording system:

The maintenance system should have proper work and recording system.The work order for the maintenance function indicates the nature of work to be performed and the series of operations to be followed to execute a particular job. It is necessary to maintain proper records and entries to monitor the maintenance function.

d) Information based decision making:

The maintenance objectives are successfully achieved by the use of reliable information system. This information is used to meet the manpower and spare parts re4quirements of the industry.

e) Adherence to planned maintenance strategy:

A sound maintenance management should adhere to the planned maintenance stratergy.This also includes the use of manufacturer information on the life and maintenance schedules of the equipment and other material resources available.

f) Planning of maintenance function:

All the maintenance function are to be carefully executed by a way of proper planning to ensure the effective utilization of manpower and materials.

g) Manpower for maintenance:

The manpower requirement of the maintenance system must be carefully evaluated based on the time and motion study.The requirements should also satisfies the need arising in case of overhauls, component replacement, emergency and unscheduled repair.

h) Work force control:

Determination of exact work force required to meet the maintenance objectives of the system is difficulty task due to the element of uncertainty.Hence the proper control and monitoring of workforce are needs to be ensured.

i) Role of spare parts :
j) A good maintenance management system requires appropriate tools.So the system should have good quality tools and that too available in required quantities to ensure the proper function of the maintenance work.
k) Training of maintenance work force:

Training of the workforce must be integral part of any good maintenance management system.Training helps the workforce to learn about the modern techniques,recent trents in maintenance and to chalk out a strategy to meet the growing demands of the industry.

2) What are important factors considered in maintenance planning?

a) Job distribution:

The first and foremost task in maintenance planning is the distribution of the jobs to the personnel for preventive and emergency maintenance works.It is the practice to form two separate task groups to tacle the both.If not possible a same group can also be used to tacle both the situations in such way that during scheduling,time must be devoted for unforeseen breakdowns or situations in maintenance.

b) Programme :

The development of maintenance programs involves

- o Selection of activities for maintenance
- o Determination of the frequency of preventive maintenance
- o Decision on the cost effective methodology

Selection of activities

This selection is based on cost involved between preventive and breakdown maintenance.

c) Manpower allocation:

The manpower allocation is the most important task of the maintenance management group.It provides adequate manpower to execute various jobs in the system.This should also take into consideration the skill level of personal deputed for the maintenance tasks.The central idea of manpower allocation can be drafted using the information available from maintenance records and planning the task to meet the objectives of the organization.

d) Staffing:

Staffing is the task of providing the required manpower for the maintenance function.This has to be achieved at optimum cost.Staffing is depent upon the ability of the organization to tackle the regular as well as attending the unforeseen situations.Staffing should be sufficient to handle preventive and emergency maintenance task.

e) Planning technique :

The planning methods are Gantt charts,Milestone method,Critical path method and program evaluation review.Evolutionary computation based techniques are recently used for maintenance planning and scheduling.

f) Planning procedure:

Planning procedure involves four step processes.

- Organising maintenance resources to ensure their effective use in future
- Scheduling the resources for the planned period
- Execution of plans according to the schedules
- Establishing a feedback system for all the above processes to know the deficiencies of each of the processes.

g) Estimation of maintenance work:

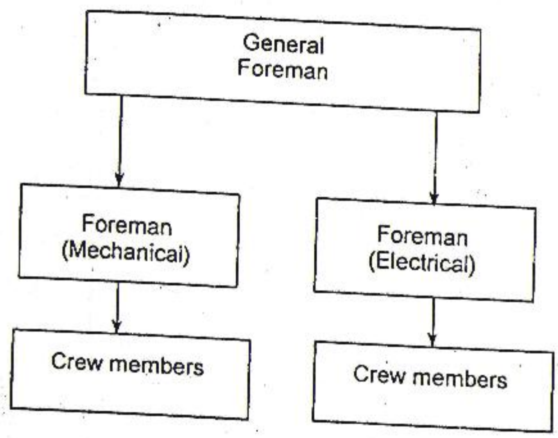
h) Estimation is used to find out the quantity and quality of the maintenance work.This will help in allocation of the required manpower.The following methods are used for the estimation of maintenance wok. Measurement by estimates,historical data and by conventional standard time data.

i) Maintenance control:

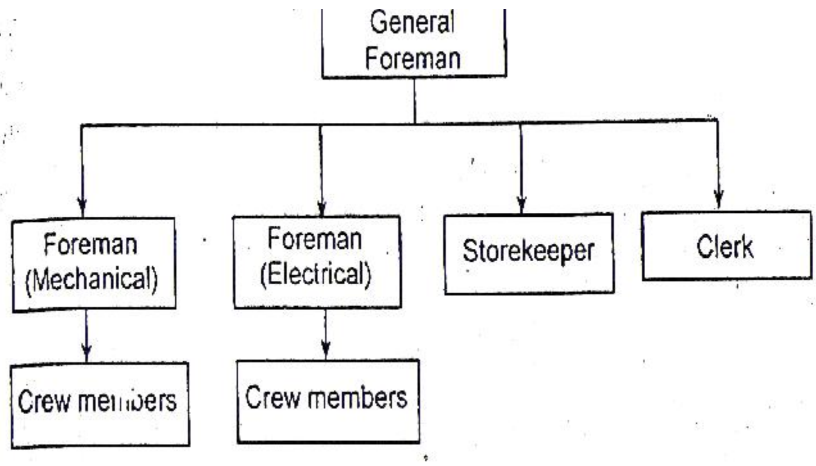
Maintenance control is the auditing techniques to ensure the effective utilization of the maintenance budget.This involves the integration of accountability with in the system.Prope accounting of maintenance work should be carried out at every level of the maintenance organization.

3) what are the different types of organizations are in use in Indian industries?

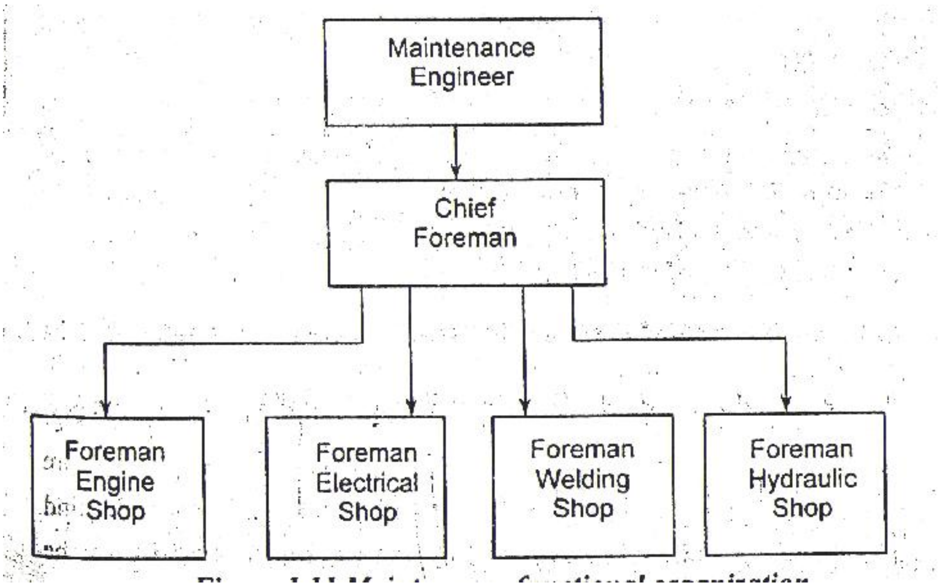
a) line organization



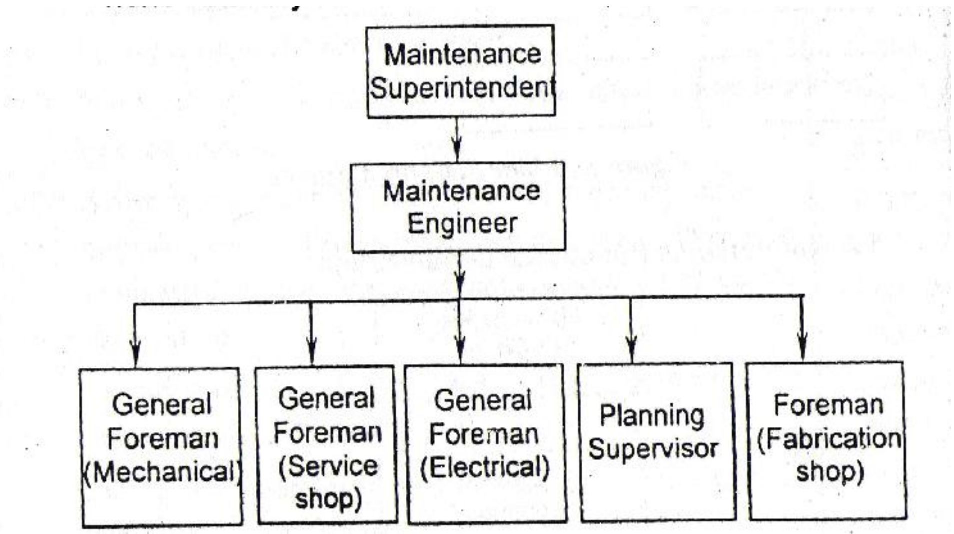
b)line staff organization



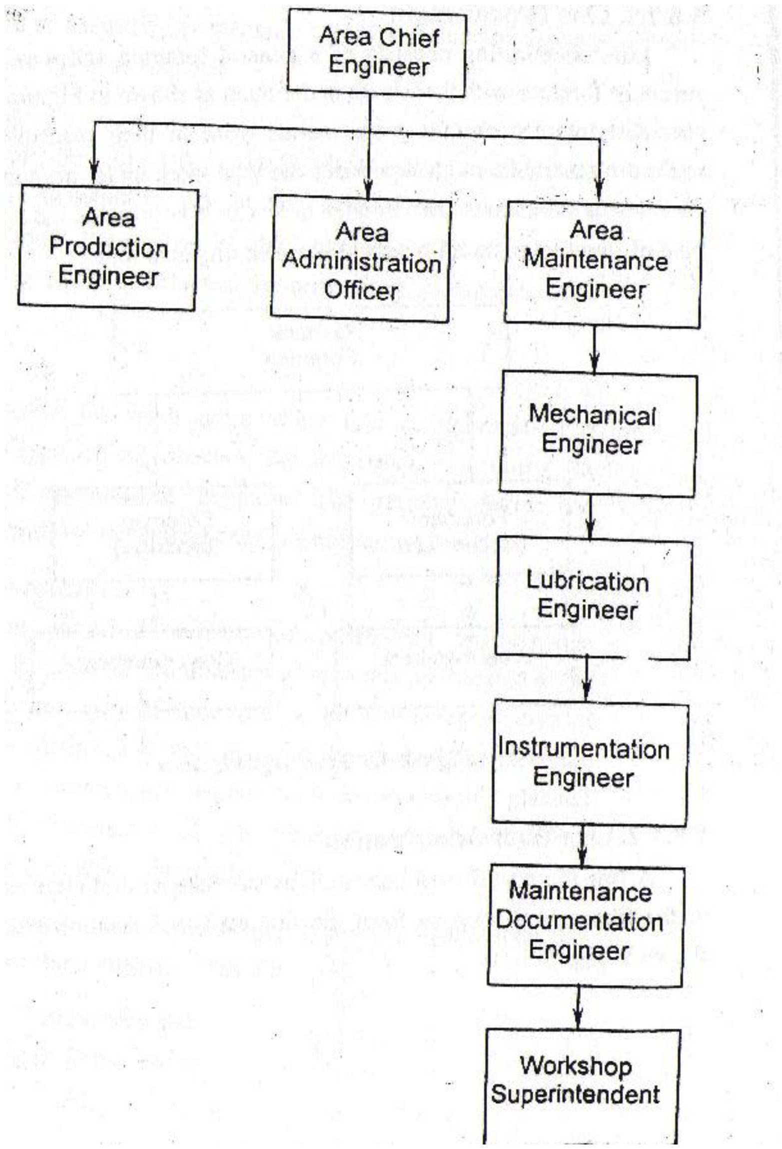
C) maintenance functional organization



d) centrally controlled maintenance organization



e)area maintenance organization



4) Mention the maintenance function and activities?

The functions and activities of the maintenance organization are as follows:

(i) Identifying areas for implementation of preventive maintenance program

(ii) Making suitable arrangements for maintenance facilities for carrying out the maintenance work properly

(iii) Planning and scheduling the total maintenance work

(iv) Ensuring proper and timely supply of spare parts

(v) Managing proper inventory control of materials spares and tools required for the maintenance

(vi) Standardization of maintenance work

(vii) Implementing modifications to the existing equipment wherever possible

(viii) Assisting the purchase department in procuring materials Disbursement of services such as water, electricity, steam, compressed air and other amenities required to carryout the maintenance

(ix) Identification of obsolete and surplus equipment for replacement and disposal

(x) Designing the systematic way for disposal of equipment and for maintaining floor space

(xi) Training of maintenance personnel

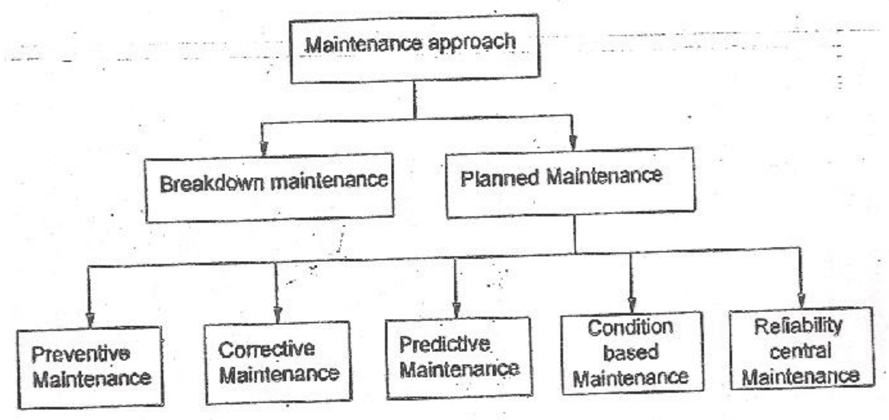
(xii) Analysis of future demands and forecast the role of maintenance activities

(xiii) Implementation safety norms and procedures

(xiv) Ensuring safety of personnel and equipment

Unit II

5. Explain with sketch various types of maintenance approach?



Basically there are two types of maintenance tasks they are

Breakdown maintenance
Planned maintenance

Planned maintenance may further be classified into

Preventive maintenance
Corrective maintenance
Predictive maintenance
Condition based maintenance
Reliability centered maintenance

Corrective maintenance

The main objectives of this program are to

Eliminate breakdowns
Eliminate deviations from optimum operating conditions
Eliminate unnecessary repairs
Optimize all critical plant systems

Preventive maintenance

It is a maintenance program which is committed to the elimination or prevention of corrective and break down maintenance.

Benefits of preventive maintenance

It maintains the equipment in good condition to preventin them from bigger problems.
Prolongs the effective life of the equipments.
Detects the problem at earlier stages.
Minimize/eliminates the rework/scrap and helps in reducing the process variability.
Significantly reduces unplanned downtime.

Predictive Maintenance

Predictive maintenance is a management technique that uses regular evaluation of the actual operating conditions of the plant equipment.

Benefits of preventive maintenance

Reduced breakdown losses.

Reduction of quality defects.
Increased net operating profit
Reduced maintenance costs

Condition based maintenance techniques

Vibration Monitoring

Determines the actual conditions of equipments/machines by studying the noise or vibration produced during functioning.

Thermography

Determines the condition of plant machinery, systems etc. by studying the emissions of infra red energy i.e. temperature

Reliability Centered maintenance

The rough process of RCM is as follows

1. Target products or systems of maintenance should be clearly identified and necessary data should be collected
2. All possible failures and their effect on target products or systems are systematically analyzed

Application of RCM

When designing, selecting and installing new systems in a plant.

When setting up preventive maintenance for complex equipment and systems for which we are not clear on how they work.

When teaching people the basics of reliability it helps to explain the matters in a detailed fashion using RCM.

6.Explain briefly about TPM with the help of flow chart?

TPM is a maintenance program which involves a newly defined concept of maintaining plants and equipments. The goal of TPM program is to significantly increases the production, at the same time increasing employee morale and job satisfaction. TPM philosophically resembles TQM in many aspect such as

Requirements of commitment by top level management
Requirement of empowering employees to initiate corrective action
Accepting long range plan on any on goin

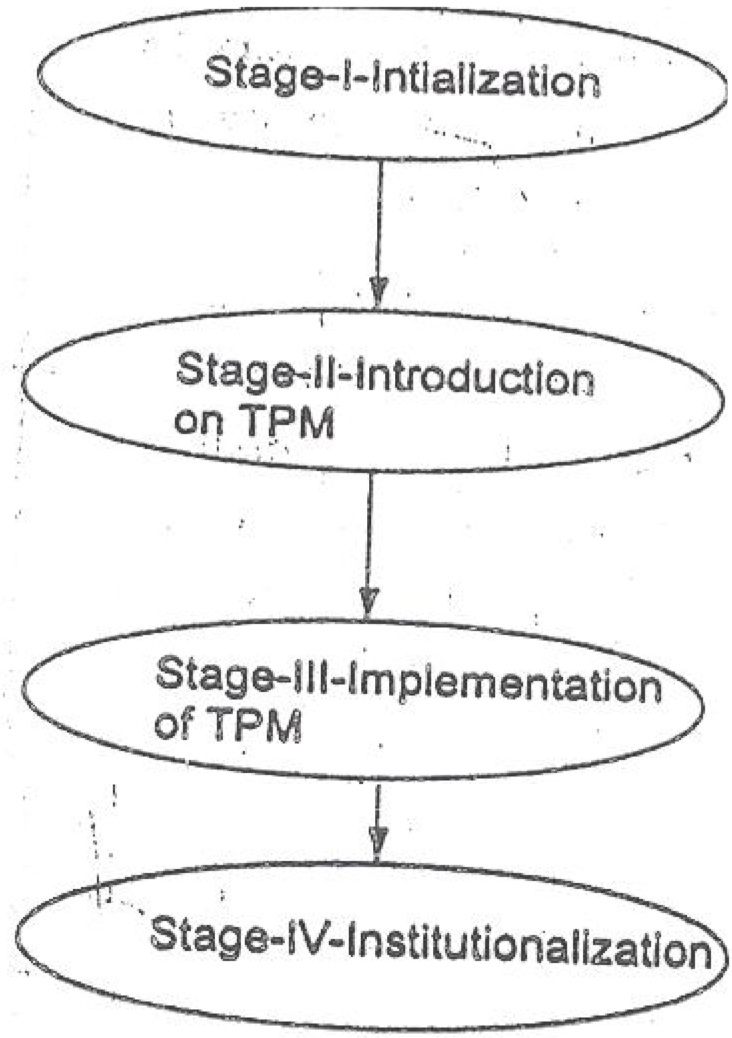
process. The five S principles used for implementations of TPM.

- SEIRI – Sort out
- SEITON –Organize
- SEISO – Shine workplace
- SEIKETSU – Standardization
- SHITSUKE – Self discipline

various pillars of TPM

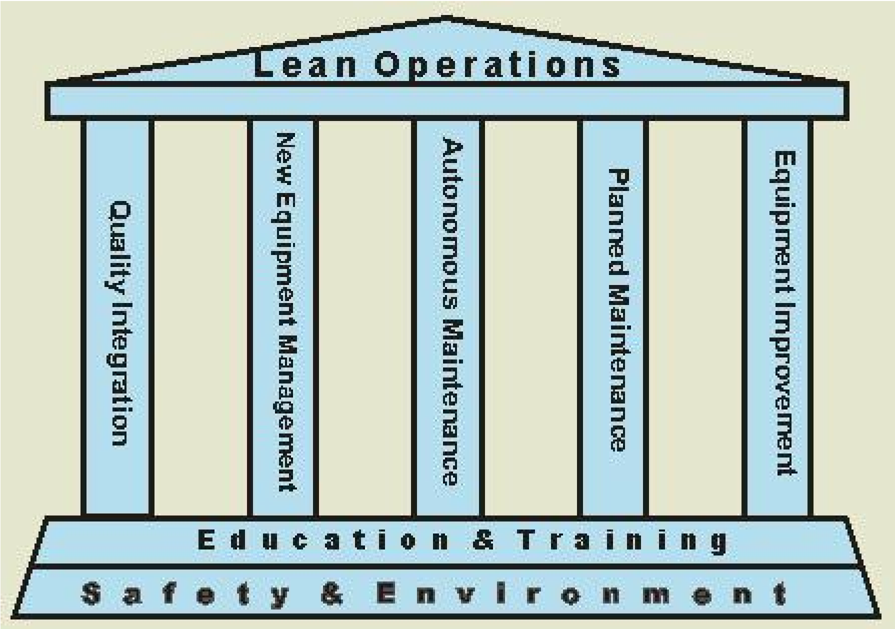
- 5,S Principle
- jishu hozen(JH)
- Kaizen
- planned maintenance
- Quality maintenance.
- training
- office TPM
- Safety, health and environment

Implementation of TPM:



The main objectives of TPM are

- to achieve zero defects
- achieve zero accidents and zero break downs in all functional areas of an organization
- to create different team of people to have active participation.
- To aim at minimization of defects and
- To inculcate autonomous policy.



7.Discuss in brief the roles of various stakeholders of maintenance scheduling communication chain?

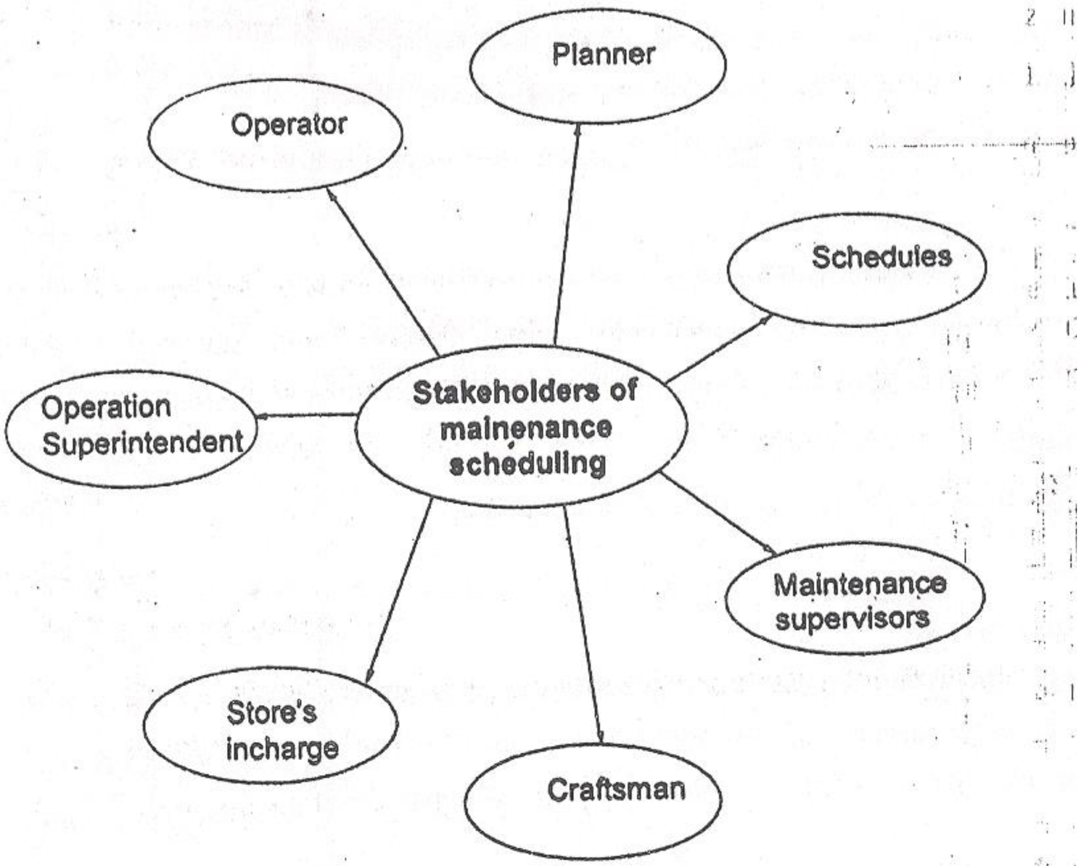
Maintenance scheduling is a joint maintenance operations activity in which maintenance agrees to make the recourses available at a specific time when the unit can also be made available by operations

various stakeholders of maintenance scheduling.

- Operators
- Planners
- Schedulers
- Maintenance supervisors
- craftsman
- Store's in charge
- operation superintendent

Planner:

He/She should ensure that the work is properly planned with respect to customer requirements, stores material, directly purchased material and special service mentioned on work order. Also the work to be carried out with the line of safety requirements should be described.



Scheduler:

He/She should ensure that

Trades are available to conduct the work during the schedule duration

Materials and/or service availability

Communicating the details of the above to person involved in maintenance and operations

Maintenance supervisor:

He/She will be the responsible for the day-to-day activities comprised in weekly schedule and also determines the business availability. They attend to specify such as to who-what-where-when.

Craftsman:

He/She executes the assigned task and keep informing the maintenance team, the outcome as well as any practical difficulty in their part, for any further analysis

Storeroom Personnel:

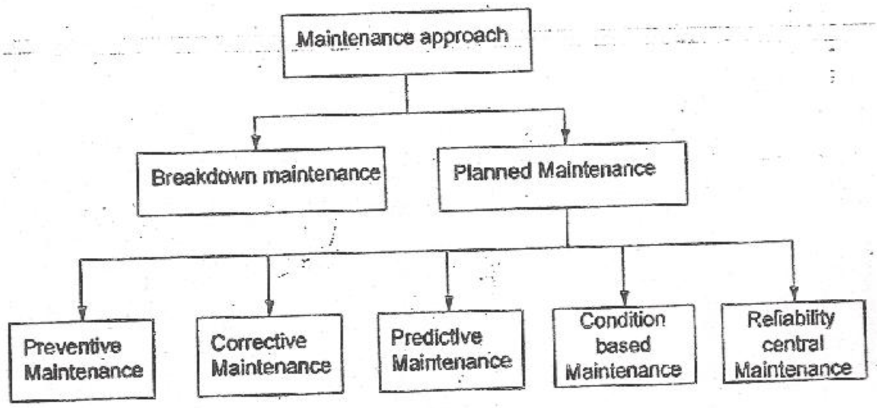
They maintain the records of the receipt of goods and notify if any damages exists.

Operations Superintendent:

He must be kept informed in advance about the equipment condition. Since he is well aware of production schedule, should determine the opportune time with maintenance to release the equipment.

Operator:

He is the person responsible for securing the equipment and report back to the maintenance personnel if any deviation is observed.



8.Write a brief notes on JISHU HOZEN (autonomous maintenance)and its benefits?

b) JISHU HOZEN Target:

1.Reduce oil consumptionby50%
2.Reduce process time by 50%
3.Increase use of JH by 50%

.

Steps in JISHU HOZEN:

1. Training employees.
2. Initial cleanup of machines.
3. Taking counter measures
4. Fixing tentative JH standards
5. General inspection
6. Autonomous inspection
7. Standardization and
8. Autonomous management.

Training Employees :

The employees should be educated

About TPM, its advantages,

JH advantages and Steps in JH. Also

About the abnormalities in equipments.

Initial cleanup of machines :

Dust, stains, oils and grease are to be removed.

Oil leakage, loose wires, unfastened nits and bolts and worn out parts are the things that have to be taken care while cleaning.

After clean up problems are categorized and suitably tagged. White tags are place where problems can be solved by operators. Pink tag is placed where the aid of maintenance department is needed.

Supervisor and technician should discuss and set a date for implementing step1

Arrange all items needed for cleaning

On the arranged date, employees should clean the equipment completely with the help of maintenance department.

Contents of tag should be transferred to a register.

Area which were inaccessible to be noted down.

Finally, close the open parts of the machine and run the machine.

Counter Measures :

Inaccessible regions had to be reached easily. e.g. If there are many screw to open a fly wheel door, hinge door can be used. Instead of opening a door for inspecting the machine, acrylic sheets can be used.

To prevent work out of machine parts necessary action must be taken.

Machine parts should be modified to prevent accumulation of dirt and dust.

Tentative Standard :

JH schedule has to be made and followed strictly.

Schedule should be made regarding cleaning, inspection and lubrication and it also should include details like when, what and how.

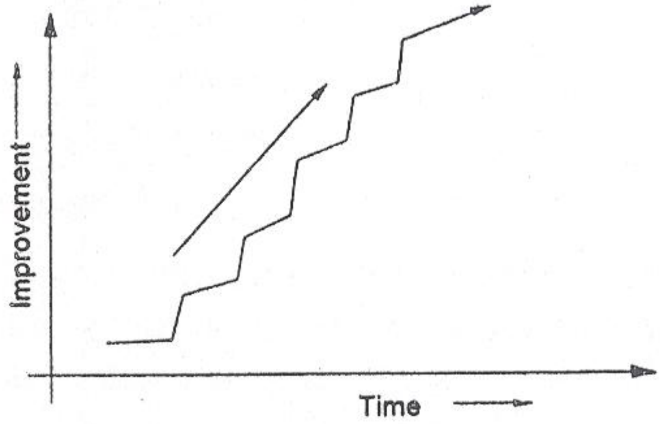
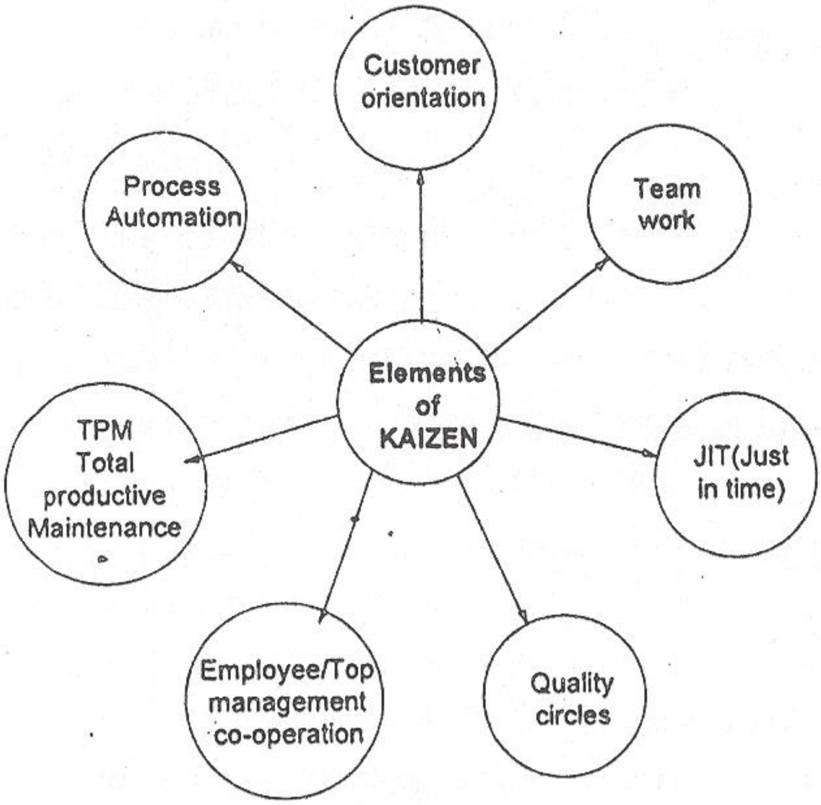


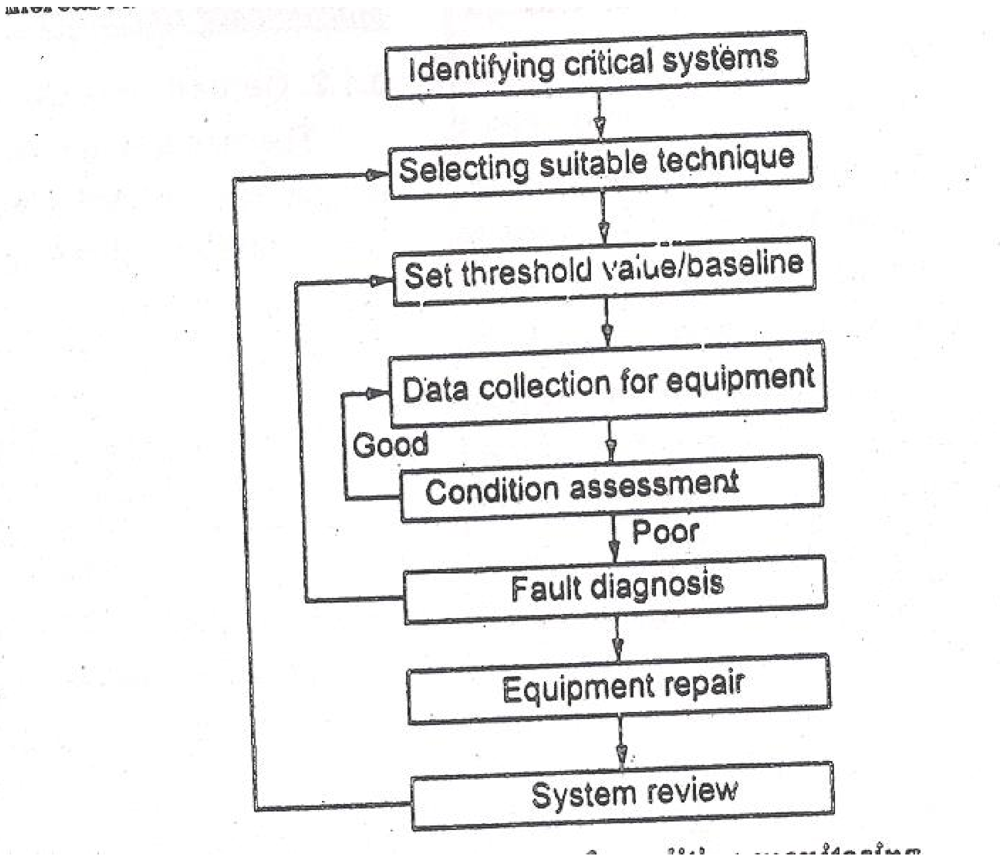
Figure 2.5 Continuous and step-by step improvement



Unit III

8.Explain briefly the process involved in condition monitoring?

Conditions monitoring is one of the maintenance methods which are used to assess the health and condition of equipments machines, systems or process by absorbing checking, measuring and monitoring several parameters. This technique is also called as equipment health monitoring.



1. Identifying critical systems
2. Selecting suitable techniques for condition monitoring
3. Setting baselines
4. Data collection

5. Data assessment
6. Fault diagnosis and repair
7. System review

advantages and disadvantages and disadvantages of condition monitoring.

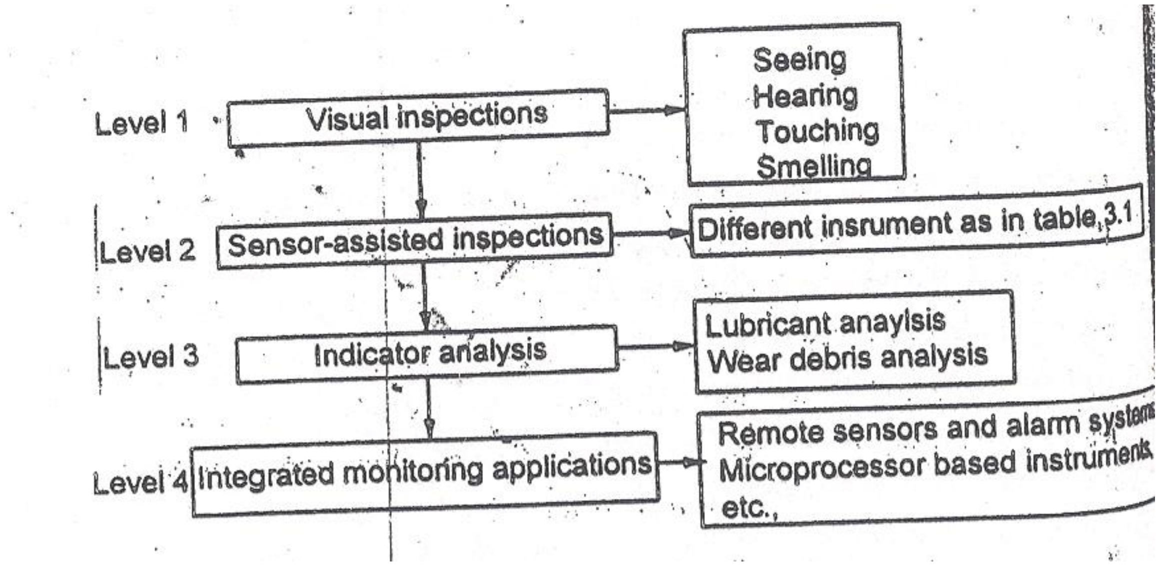
Advantages

- Improved availability of equipment
- Minimized breakdown cost
- Improved reliability

Disadvantages

- Gives only marginal benefits
- Increased running cost
- Sometimes difficult to organize

9.Discuss the various levels of condition monitoring?



S.NO	Parameters to measure	Instrument used
1	**Temperature**	**Pistol therometer,Pyrometer,temperature sensitive taps**
2	**Speed** and distance	**Tachometer,odometer**
3	**Vibration**	**Accelerometer,vibration analyzer**
4	**Electrical quantities such as volt,amp,ohm**	**Voltmeter,ammeter**
5	**Wear**	**Thickness gauges**
6	**Corrosion**	**Corrosion monitor**
7	**Fits and clearence**	**Proximitymeter**

Visual monitoring:

Machine components are visually inspected to determine their condition
a.Sight Leaks
Smoke or casing colour change, indicating overheating.
b.Smell Overheating
Leaks
c.Hearing Abnormal noise, indicating some malfunction.
d.Feel Abnormal vibration, indicating some malfunction, high casing temperatures, indicating overheating

Wear debris and contaminant monitoring.

1. Direct detection of the debris in the oil in the machine optical methods.
2. Electrically conducting filters.
3. Inductive and capacitative methods.
4. Collection of the debris in the machine for regular examination.
5. Existing filtration system.
6. Special filters.
7. Magnetic plugs.
8. Regular sampling of the lubricant for an analysis of its contents.
9. Elemental (spectrometric) analysis.
10. Magnetic particle separation.
11. Automatic particle counting.

10.Explain on-load and off-load testing used in condition monitoring with its flow chart?

Condition monitoring can be done in two methods viz,off-line or on- line.In off-line condition monitoring,the machine is withdrawn from service and disconnected from its normal supply.Measurements therefore, tended to be taken more infrequently to provide satisfactory trending data for diagnosing and identifying rapidly developing fault conditions. In this system, monitoring equipments are used in parallel to the equipment to be monitored. Various monitoring points are provided for attaching such equipments as and when needed. *Off load monitoring* is for interior or inaccessible parts which need to be stopped temporarily to check the condition. However, there may be several situations like, the two-shift working or the plant's temporary shut down for other reasons, when this class can be conducted without productions loss.

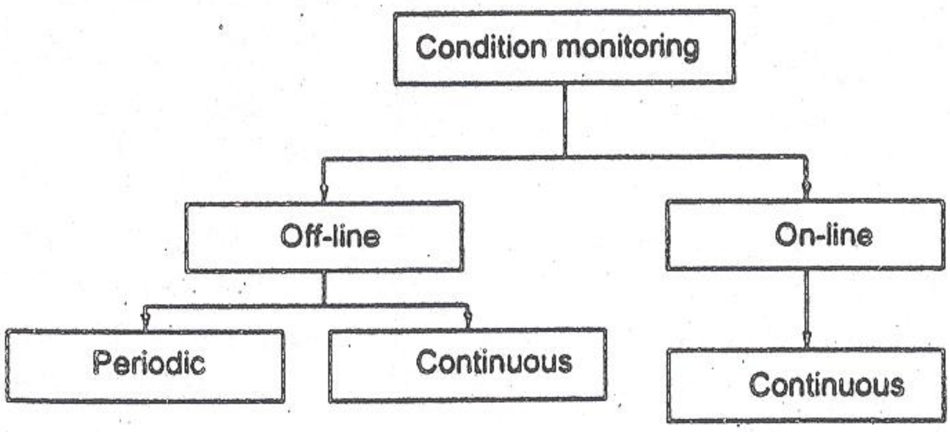


Figure 3.7 Block diagram of Online and Off-line system

Off-line monitoring systems can be periodic or continuous. In periodic system, monitoring equipments are connected during the time of monitoring or taking data or reading and then removed. In continuous monitoring, the monitoring equipments or instruments are connected as long as equipments operate.

On load monitoring means monitoring or adjusting the parameters while the machine or equipment is running. Thus, it is done for superficial, easily accessible and non-interfering parts of the equipment which can be carried out without interruption to the operation.

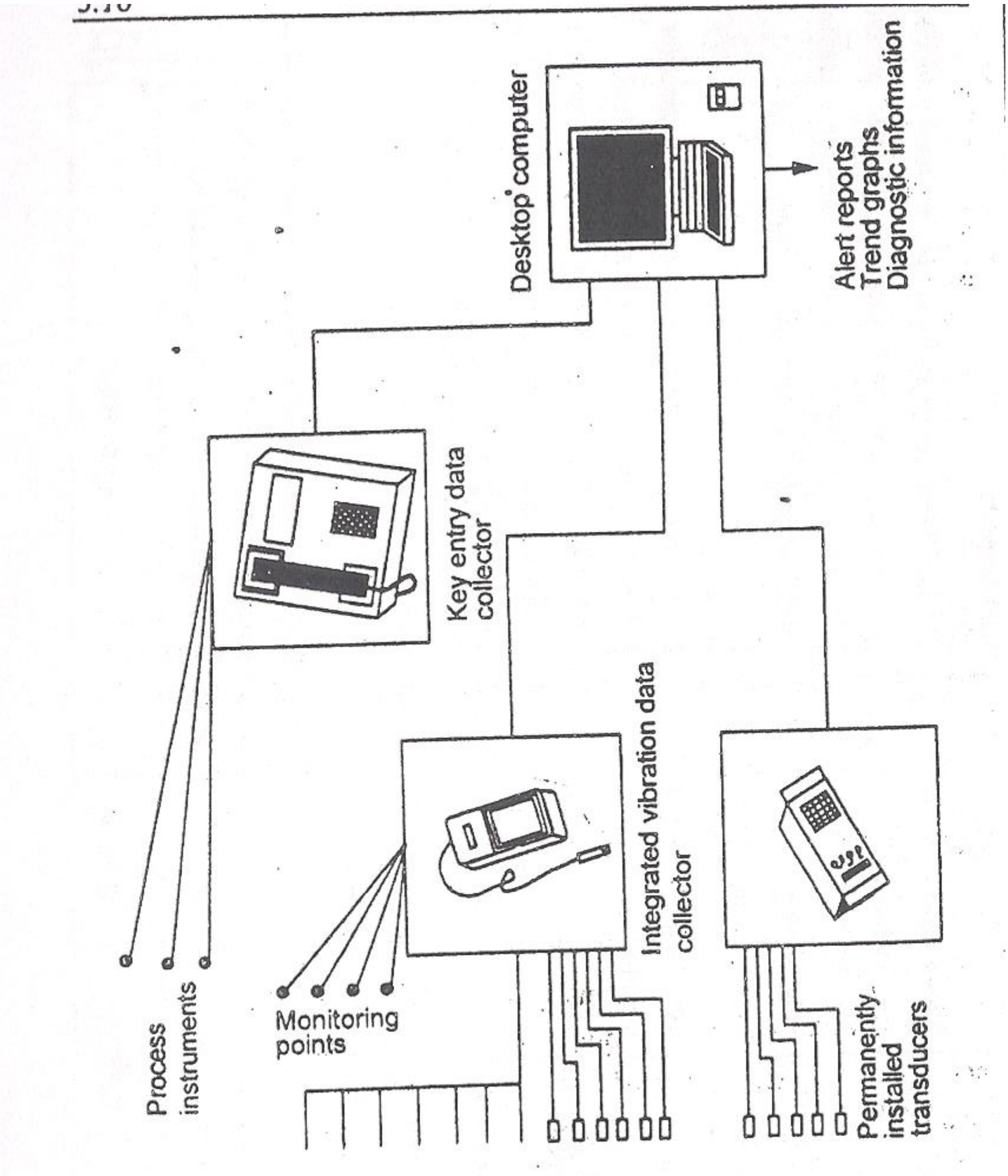
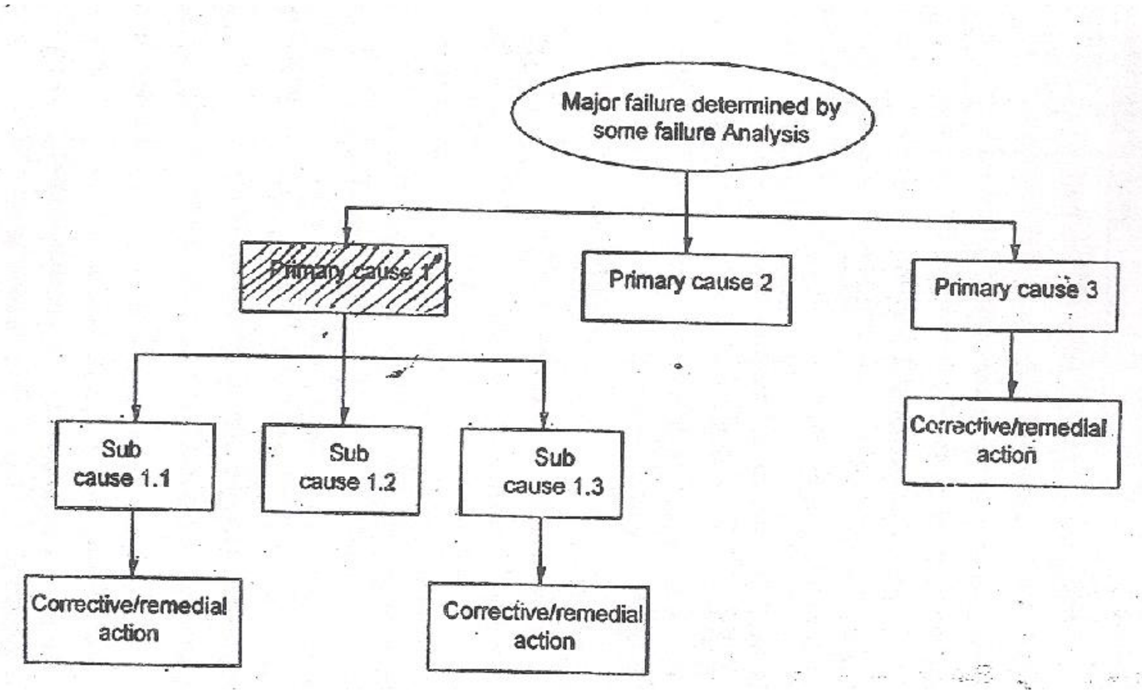


Figure 3.8 On-line condition monitoring system

On-line continuous monitoring techniques allow developing faults to be detected before they lead to a catastrophic failure. It allows the change in maintenance programs from 'periodic' to 'condition' based leading to be more effective and reduced maintenance costs. In this type of system, monitoring equipment are built in or installed in series with the running equipment.On-line monitoring system are generally continuous with provision to by pass.

Unit-
IV

11.Write short notes of fault fault tree diagram?



FTA is a graphical technique used to determine the various combinations of hardware (and software) failures and human errors, which can result in an undesirable outcome. The specified undesirable outcome is referred to as a 'top event', where the deductive analysis about the general conclusions and their causes is often described as a 'top down' approach. A Fault Tree Analysis begins with a construction of a fault tree, relating the sequences of events leading to the top event. This may be illustrated by considering the probabilities of events and by constructing a tree with AND and OR logicgates.

Basically, the steps involved in a fault tree analysis are:

1. Define the Top Event
2. Know the system
3. Construct the tree
4. Validate the tree
5. Evaluate the tree
6. Study tradeoffs
7. Consider alternatives and recommend actions

A fault tree analysis can also include human error contribution to the overallsystem,ifthe probabilities for human error are described in the same term as component and hardware failures.

Thus the main purpose of fault tree analysis is to evaluate the probability of the top event using analytical and statistical methods. By providing useful information concerning the likelihood of a failure and its means, efforts can be made to improve system safety and reliability. It also evaluates the effectiveness and the need for redundancy. Hence, the resulting benefits of fault tree analysis to project management are reduction of analysis time and precision in identifying and correcting deficiencies

Fault tree diagrams are logic block diagrams that display the state of a system in terms of the states of its components.

capabilities of Fault Tree Diagram.

- Fault tree analysis and failure modes and effects analysis,
- Design for reliability
- Design for safety

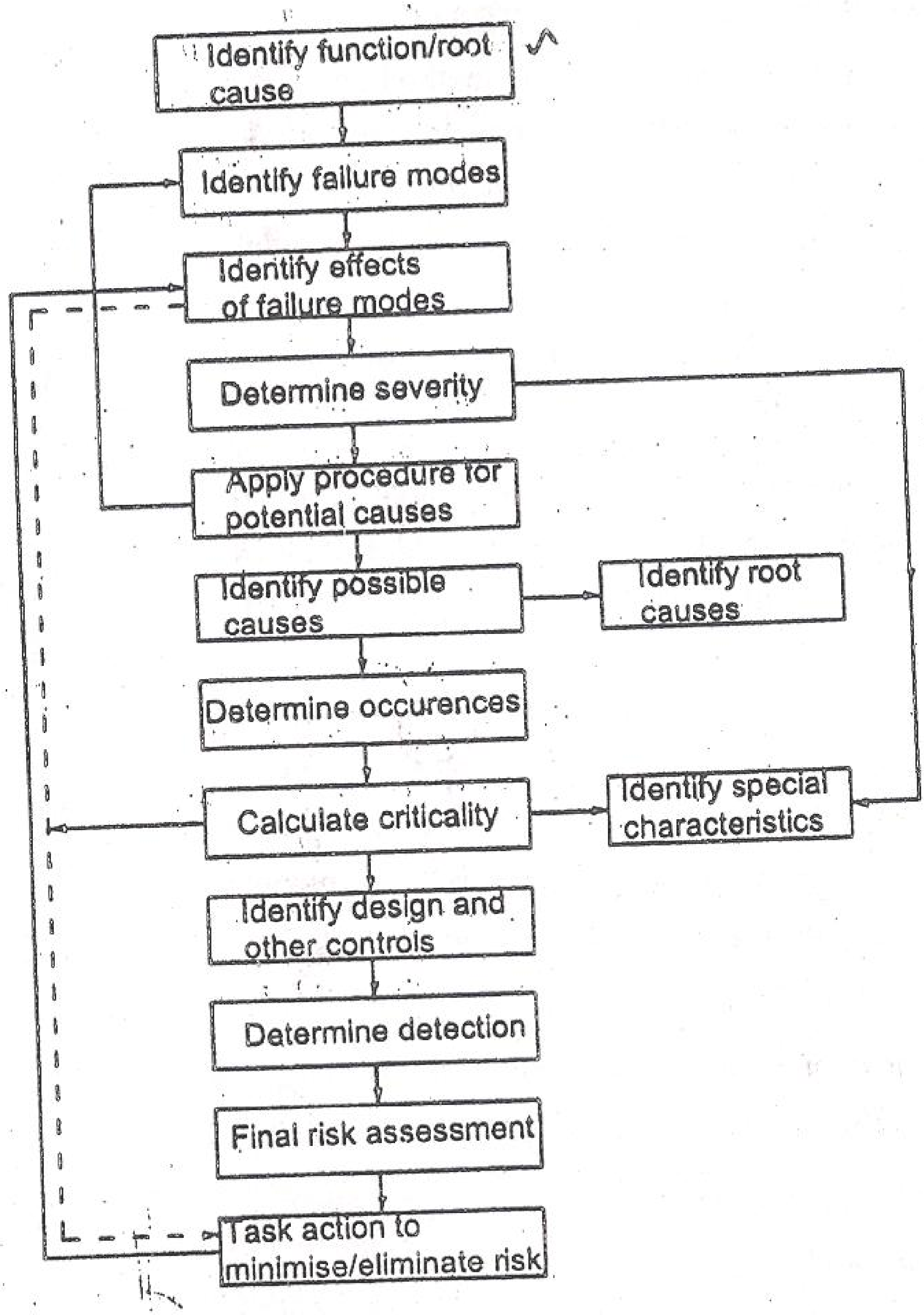
Benefits of fault tree diagram:

- Used to identify possible system reliability or safety problems at design time,
- Used to assess system reliability or safety during operation,
- Helps to improve understanding of the system,
- Can identify root cause of equipment failures.

12.Explain briefly with the help flow chart about FMEA?

FMEA is methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome the issues, thereby enhancing reliability through design

FMEA is a procedure in operations management for analysis of potential failure modes within a system for classification by severity or determination of the effect of failures on the system. It is widely used in manufacturing industries in various phases of the product life cycle and is now increasingly finding use in the service industry. *Failure modes* are any errors or defects in a process, design, or item, especially those that affect the customer, and can be potential or actual. *Effects analysis* refers to studying the consequences of those failures.


Identify function/root cause
Identify failure modes
Identify effects of failure modes
Determine severity
Apply procedure for potential causes
Identify possible causes
Identify root causes
Determine occurences
Calculate criticality
Identify special characteristics
Identify design and other controls
Determine detection
Final risk assessment
Task action to minimise/eliminate risk

FMEA cycle.

Failure mode: "The manner by which a failure is observed; it generally describes the way the failure occurs."
Failure effect: Immediate consequences of a failure on operation, function or functionality, or status of some item
Indenture levels: An identifier for item complexity. Complexity increases as levels are closer to one.
Local effect: The Failure effect as it applies to the item under analysis.
Next higher level effect: The Failure effect as it applies at the next higher indenture level.
End effect: The failure effect at the highest indenture level or total system.
Failure cause: Defects in design, process, quality, or part application, which are the underlying cause of the failure or which initiate a process which leads to failure.
Severity: "The consequences of a failure mode. Severity considers the worst potential consequence of a failure, determined by the degree of injury, property damage, or system damage that could ultimately

Advantages

- Improve the quality, reliability and safety of a product/process
- Improve company image and competitiveness
- Increase user satisfaction
- Reduce system development timing and cost
- Collect information to reduce future failures, capture engineering knowledge
- Reduce the potential for warranty concerns
- Early identification and elimination of potential failure modes
- Emphasize problem prevention
- Minimize late changes and associated cost
- Catalyst for teamwork and idea exchange between functions
- Reduce the possibility of same kind of failure in future

Limitations

FMEA is effectively dependent on the members of the committee which examines product failures, it is limited by their experience of previous failures. If a failure mode cannot be identified, then external help is needed from consultants who are aware of the many different types of product failure. FMEA is thus part of a larger system of quality control, where documentation is vital to implementation. General texts and detailed publications are available in forensic engineering and failure analysis. It is a general requirement of many specific national and international standards that FMEA is used in evaluating product integrity. If used as a top-down tool, FMEA may only identify major failure modes in a system. Fault tree analysis (FTA) is better suited for "top-down" analysis. When used as a "bottom-up" tool FMEA can augment or complement FTA and identify many more causes and failure modes resulting in top-level symptoms. It is not able to discover complex failure modes involving multiple failures within a subsystem, or to FaultTree+ is a fully interactive graphics and analysis program for performing probabilistic risk assessment using integrated fault tree, event tree and Markov analyses..

Unit-V

12. Explain the detail repair methods for material handling equipment?

The proper maintenance of material handling equipment is extremely essential for preventing the occurrence of bottlenecks or points of congestions. Production line flow can be maintained only if the material handling equipment is in proper working order. Out of many maintenance techniques available, preventive maintenance is the one of the best maintenance techniques suggested in case of material handling equipment.

These are three stages of preventive maintenance and they are

- Inspection
- Repair
- Overhauls

Maintenance strategies for hoists and cranes:

Portable crane:

- It is necessary to keep loads within design limits on portable cranes that are mounted on wheels platforms.
- Frequent inspection of brakes, load hoisting and lowering mechanism
- Inspection of boom, base and platform for any sign of stress

Eg: cracks, bends, breaks

Over head cranes:

- Keep the attachments in overhead cranes loaded within the rating capacity.
- Maintain safety factors for replacement parts according to manufacturer specifications
- Check welded connections for cracks, bends abrasion and corrosion

Maintenance strategies for conveyers:

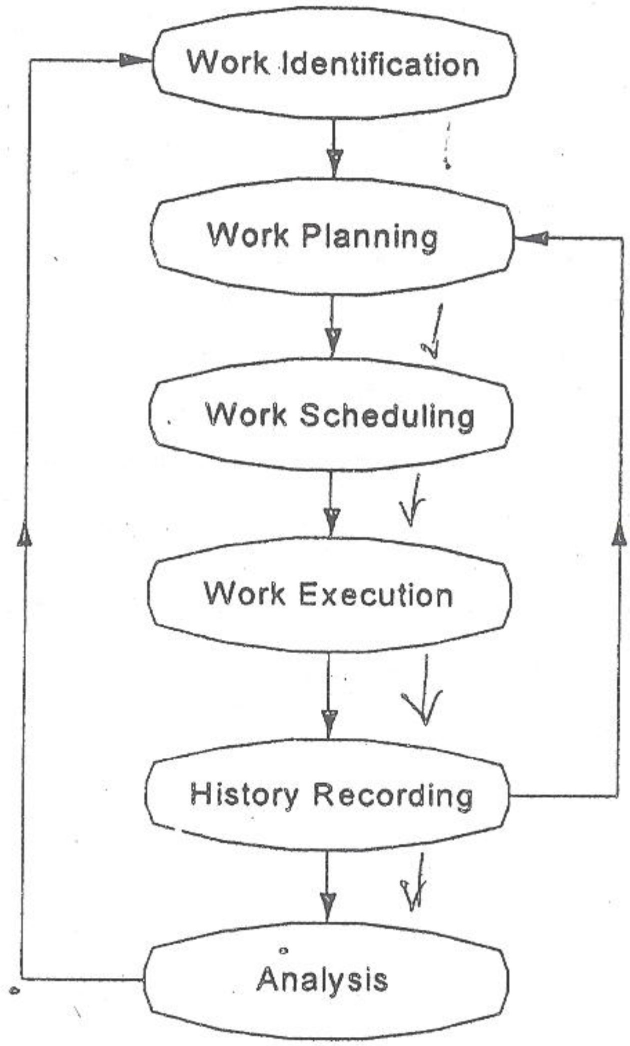
- Conveyer system need to be inspected on a regular basis. The important areas include rollers, bearings chains and belts. All of these moving parts are subjected to wear and tear
- Check conveyers to detect any bolt slippage, dragging or defective rollers.
- Moving equipment parts are subjected to breaks caused by metal fatigue, loose bearing and obstructions.

A typical scheduled conveyor maintenance plan:

- Check/lubricate all bearings, universal joints, and pulleys.

- Check chain tension, wear and lubricate
- Check sprocket alignment, wear and screw set.
- Check flat belt tension, wear and acing
- Check V-belt tension, wear and sheave alignment.
- Check general condition of system
- Operate entire system after service
- List any items requiring replacement or repair.

13.Explain the general structure of six phases of good maintenance management?



The proper operation of an industry requires appropriate strategies in maintenance management.This is ensured by the effective integration of various phases involved in management.A good maintenance management can be considered as having six phases as shown.

They are

- Work identification
- Planning
- Scheduling
- Execution
- Recording
- Analysis

The important steps in this system approach are

- Codification and cataloguing
- Preparation of history sheet
- Preparation of instruction and operating manual
- Preparation of maintenance manual
- Maintenance operation liaison
- Maintenance work order and permit system
- Job execution, monitoring, feedback and control

14. Explain the general structure of computerized maintenance management system?

Computerized maintenance management system is the application of computers in planning, scheduling, monitoring and control of maintenance activities.

A computerized maintanance management system includes the following aspects:

- Development of a database
- Analysis of available past records
- Development of maintenance schedules
- Availability of maintenance material
- Feedback control system
- Project management.

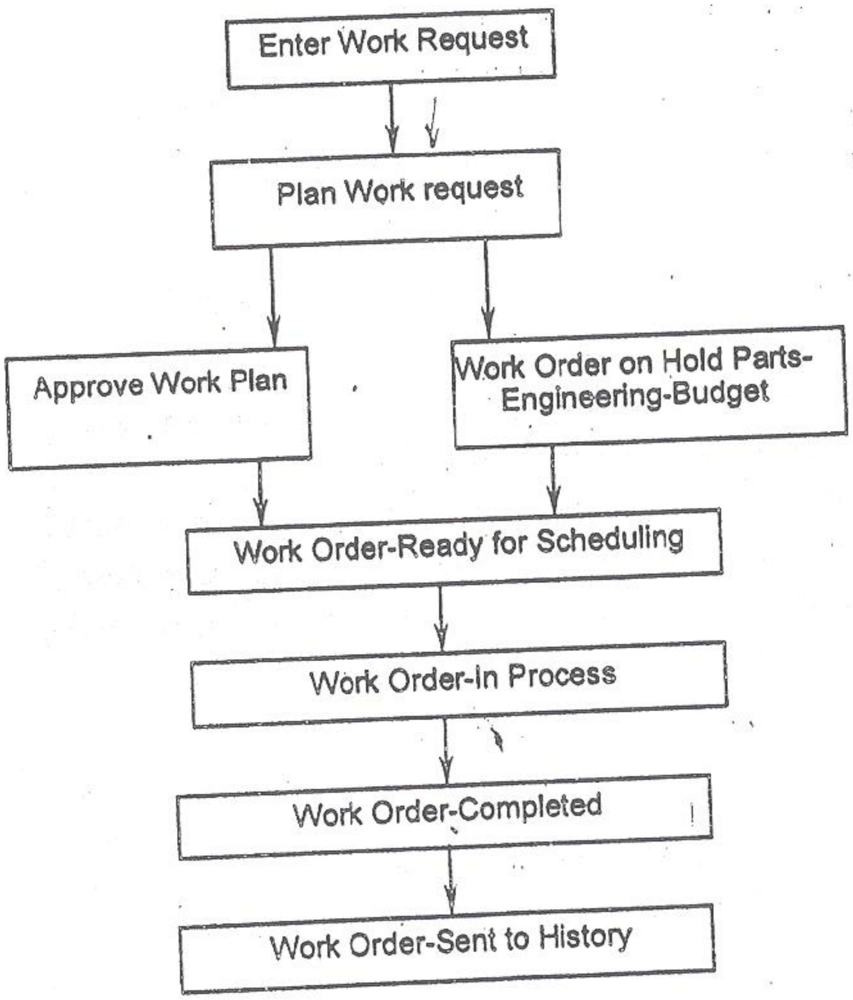
Te objectives of CMMS.

6. Maintenance of existing equipments
7. Inspection and service of the equipment
8. installation or revamping of the equipment
9. Maintenance storekeeping
10. craft administration
11.

Te advantages of CMMS.

1. Improve maintenance efficiency
2. Reduce maintenance costs
3. Reduce the equipment downtime by proper scheduling preventative maintenance.
4. provide maintenance reports in specific formats depending on the requirements.
5. Quicker access to plant maintenance statistics

Work order flow diagram



15.Explain the work order flow diagram?

Work order system is the information system used by the industry to keep track of its maintenance works. Work permits are components of work order. Maintenance department issues work permits to different executing agencies permitting them to start their work.

A maintenance work order are generally gives the following information:

- Work order number and code
- Departments address and code
- Date of issue
- Detail of approval

- Date of receipt of work order
- Priority
- Location
- Equipment details
- Nature of work
- Material requirement
- Completion data and report
- Special requirement

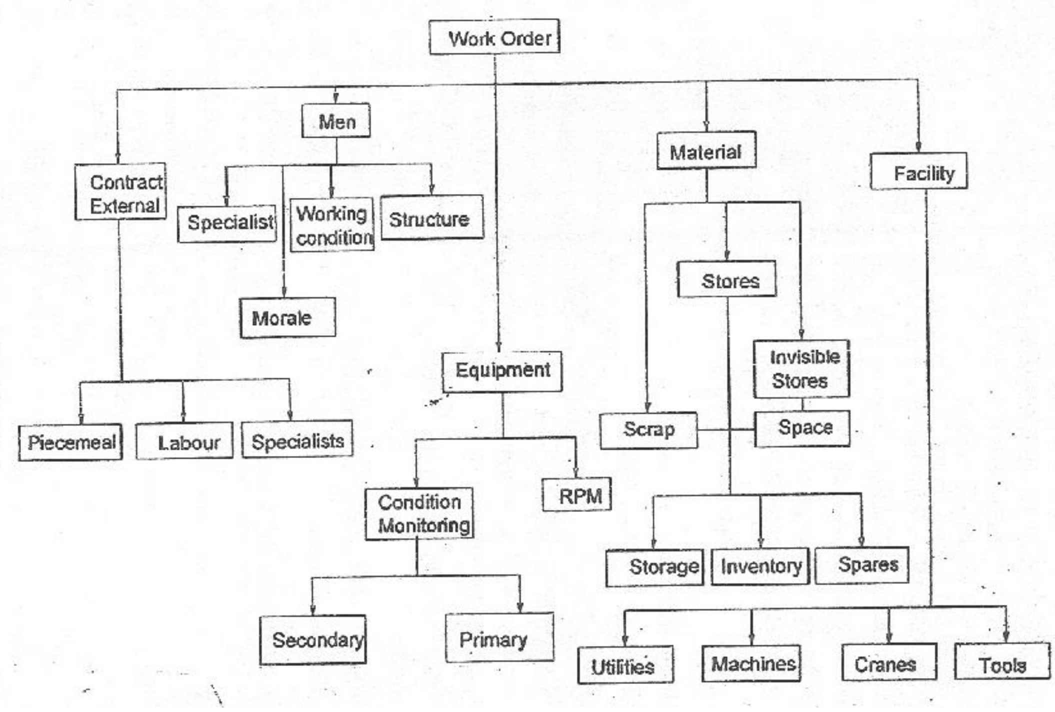
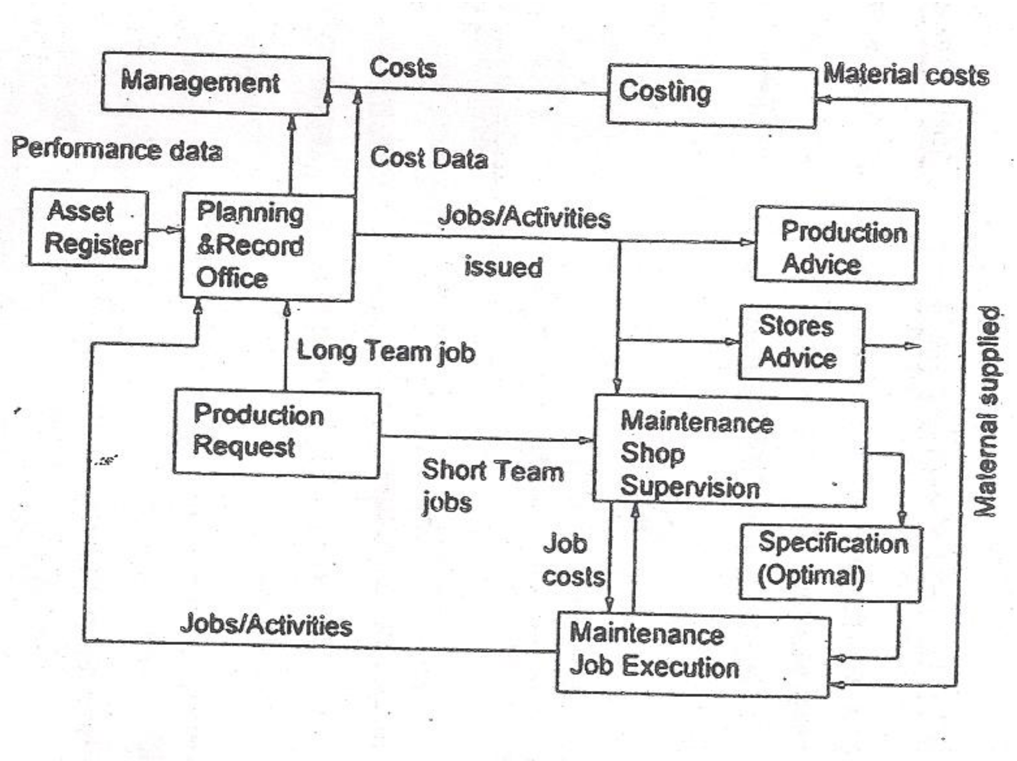


Figure 5.5 Work order tree

Work permit are components of work order. Maintenance department issues work permits to different executing agencies permitting them to start their work. A work permit mentions the work permit number ,work order number, section from which work originated and information as mentioned in work order.

16.Explain about maintenance monitoring, execution and control?

A well designed organization should have proper strategies to execute,monitor and control over the various maintenance tasks.



- Monitoring:

  a)Gather information about deviation and delay in execution of
  maintenance may provide idea about the need to add more resources to complete the maintenance task in scheduled time frame b)Communication of the changes in job content to the various follow up agencies
  c)ovide information about constraints in technical issues and necessary steps can be taken to improve the existing techniques

Method of monitoring: Feedback:

- Unscheduled / pending job
- Work status
- Suspended work
- Work completion
- Manpower requirements and actual utilization
- Cost of maintenance
- Technical difficulties

Control:

- Continuous or periodical monitoring
- Inspection of status
- Comparison of status with the predetermined standard and initiating corrective measures.

Reg. No. :

Question Paper Code : Q 2309

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2009.

Eighth Semester

(Regulation 2004)

Mechanical Engineering

ME 1019 — MAINTENANCE ENGINEERING

(Common to Production Engineering)

(Common to B.E. (Part-Time) Seventh Semester Regulation 2005)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Define reliability.

2. What is Mean time between failures (MTBF)?

3. List out the objectives of corrective maintenance.

4. What is meant by predictive maintenance?

5. What are the three types of condition monitoring?

6. State the various methods of corrosion monitoring techniques.

7. Differentiate between Fault tree diagrams and Reliability block diagrams.

8. List the design consideration of guide ways.

9. State the objectives of CMMS.

10. State the benefits of keeping equipment records.

PART B — (5 × 16 = 80 marks)

11. (a) (i) State the various objectives of maintenance planning. (8)

(ii) Derive an expression for determining the Mean time to failure (MTTF). (8)

Or

(b) (i) State the benefits of a sound maintenance management system. (8)

(ii) State the steps necessary to reduce the maintenance cost in an industry. (8)

12. (a) (i) Compare TQM and TPM. (4)

(ii) Discuss the various stages involved in implementation of TPM. (12)

Or

(b) (i) With a suitable example, illustrate repair cycle. (8)

(ii) Explain the importance of lubricating of moving parts of industrial machineries. (8)

13. (a) (i) Explain how cost comparison is done in condition monitoring. (8)

(ii) Explain on-load and off-load testing used in condition monitoring with its flow diagram. (8)

Or

(b) (i) Discuss how infrared thermo grapy inspection is more advantages over other temperature monitoring techniques. (8)

(ii) How the monitoring of wear-debris analysis in the lube oil is achieved? (8)

14. (a) (i) List the possible causes of failure of bearings and explain how to overcome them. (6)

(ii) With the aid of suitable sketches, describe the method of repairing cracks in Machine bed by

(1) Riveting

(2) Hot clamping. (10)

Or

(b) Briefly discuss on following as regard to bearings

(i) Failures

(ii) Characterization of failures

(iii) Causes

(iv) Solutions. (4 × 4 = 16)

15. (a) (i) Explain the work order flow diagram. (8)

(ii) What is job card system? State its benefits. (8)

Or

(b) (i) Explain the preventive maintenance strategies for cranes. (8)

(ii) Explain about maintenance monitoring, execution and control. (8)

Reg. No. :

Question Paper Code : 21553

B.E. /B.Tech. DEGREE EXAMINATION, MAY/JUNE 2013.

Eighth Semester

Mechanical Engineering

ME 2037/ME 803 – MAINTENANCE ENGINEERING

(Common to Production Engineering)

(Regulation 2008)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. Write the use of computer based maintenance system.
2. What is maintenance?
3. Write the types of maintenance system?
4. Define environmental impact.
5. Write the use of condition based maintenance.
6. What is shock pulse meter?
7. Write short note about Ferrograph.
8. What is the role of FMECA in system analysis?
9. What is meant by central workshop organization?
10. Why lubricants are required?

PART B — (5 × 16 = 80 marks)

11. (a) (i) Explain productivity and maintenance. (8)

(ii) Describe the various levels of maintenance functions. (8)

Or

(b) Discuss the roll of R & D in maintenance organization. (16)

12. (a) Explain the planned maintenance. (16)

Or

(b) Discuss about preventive maintenance. (16)

13. (a) How system approach to condition monitoring can be useful? Explain. (16)

Or

(b) Discuss the benefits from condition based maintenance. (16)

14. (a) Discuss about the types of failure mechanisms. (16)

Or

(b) Describe the fault tree method. (16)

15. (a) (i) Discuss about store layout design. (8)

(ii) Discuss the role of lubricants for maintenance. (8)

Or

(b) How can computers be useful in maintenance planning? Explain it briefly. (16)

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12. (a) Discuss about the Repairable and repair cycle in Tools Management. (16)

Or

(b) Explain the methods of lubrication. (16)

13. (a) Describe Standard hourly cost estimation and Manpower repair cost estimation. (16)

Or

(b) How do we estimate repair, removal, or capital improvement costs? Discuss. (16)

14. (a) How do we monitor and report maintenance and capital improvement accomplishments? (16)

Or

(b) Describe the load testing. (16)

15. (a) Explain the maintenance work quality. (16)

Or

(b) Discuss about Software maintenance and their distribution (16)

Reg. No. :

Question Paper Code: J7682

M.E. DEGREE EXAMINATION, JUNE 2010

Elective

Product Design and Development

ED9266 — MAINTENANCE ENGINEERING

(Regulation 2009)

Time : Three hours | Maximum : 100 Marks

Answer ALL Questions

PART A — (10 × 2 = 20 Marks)

1. State the purpose of the maintenance function with an organization.
2. Distinguish between preventive maintenance and breakdown maintenance.
3. Enumerate the benefits of vibration monitoring.
4. What is the importance of condition based maintenance?
5. What do you understand the term "Reliability"?
6. What is the importance of TPM?
7. What do you understand the term "EOQ"?
8. List the critical aspects of both routine and shut down maintenance.
9. What is Weibull Distribution?
10. List the importance of safety engineering.

PART B — (5 × 16 = 80 Marks)

11. (a) (i) Discuss maintenance as business. (8)

(ii) Discuss the differences between reactive and proactive maintenance system. (8)

Or

(b) Explain the following in detail :

(i) Design for maintenance (8)

(ii) Design for reliability. (8)

12. (a) (i) Discuss the benefits of condition based monitoring. (8)

(ii) Explain the basic principles underlying condition based monitoring. (8)

Or

(b) Describe the following in detail :

(i) Vibration analysis for maintenance (8)

(ii) Application of Thermography with an example. (8)

13. (a) Briefly explain :

(i) FMEA with an example (8)

(ii) Logic tree analysis with a case study. (8)

Or

(b) Discuss relationship between OEE and world-class maintenance in detail. (16)

14. (a) Explain the different aspects of planning and scheduling of maintenance in detail. (16)

Or

(b) Briefly describe the following :

(i) Application of Bar charts in maintenance (8)

(ii) Utilization of skilled manpower in maintenance. (8)

15. (a) Explain the general rules and guidelines in safety and hazard prevention in detail. (16)

Or

(b) Discuss the following :

(i) Fault tree analysis with an example (8)

(ii) Sneak circuit analysis with an example. (8)

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