Basic Maintenance techniques

for

Wind Energy technicians

Heetech Consulting AB 2011 / Hans-Erik Emanuelsson

European Union
The European Regional Development Fund

The development of Maintenance

Technological developments and demands for increased production have led to the increase in the complexity of components and the refining of the technology (designs). The requirement for reliable equipment has become a concept and the work associated with this is known as *reliability engineering*.

In around 1950, the first civilian operational reliability applications were introduced in the fields of communication and transport. It was primarily the very rapid growth in electronics and control engineering (automation) that drove this development.

In electronics and digital technology in particular, *operational reliability* is now thoroughly established, and well-developed systems are in place for function check-out and monitoring of operational reliability. Components are tested in laboratories on a large scale with respect to *functional reliability* under a range of operating conditions (temperature, pressure, vibration, fatigue, etc.). The same trend is true in mechanical design/functionality, albeit slightly slower.

Where we have several components (both “electric” and “mechanical”), then these have to interact (be assembled) in the majority of cases to ensure the required equipment functionality. For example>

- Function: I/O - card Components: transistors, resistors, relays etc.
- Function: Gearbox Components: Gear wheels, bearings, lub. pump etc.

It is in this interaction that often the root of the problems arising to get functional reliability, as the majority of the components' failure probability relates to this interaction. At the same time we affect the functionality (I/O - card, gearbox), for example, through the method of operation or maintenance work. *Operational reliability* is also dependent on *maintenance supportability.*

As you would expect, the mathematical calculation methods have also been refined. Improved numerical methods, empirical relationships and the increased capacity of computers to speed up and increase the number of calculations have produced better and more reliable results.

This in turn means that the refinement of the design of components and equipment can be optimized, such as material selection (quantity, type), for a given performance (strength). The driving force is of course to produce the necessary functionality (performance) as cost effectively as possible. This will give that we must be very careful and aware of more “slimmed” designs when carrying out maintenance.

For example:

- Screws/bolts must be tightening according to recommended torque for good strength.
- Transducers must be adjusted/calibrated to achieve the right signals to a control system, for proper controlling.

It is therefore of great importance for today's maintenance technicians to follow the specified documentation/instructions, and where these are not available, creating them. This “Paperwork”, which is very often perceived as not a real “job”, is vital, even more in future. One way to do this is to use the company's business system and/or certification system.

The basis for operational reliability work (functional reliability) is the use and processing of the collected data (results from trials and tests), which is then processed mathematically in the fields of statistics and probability theory. For the area of operational reliability that can be affected by operation and maintenance, various types of monitoring in the event of production downtime and breakdowns are often used.

Today, advanced development in operational reliability technology is applied not only in the aerospace industry, but other areas have also seen significant benefits from using some form of operational reliability technology. There are a number of approaches from both a practical and theoretical point of view (for example, downtime monitoring or RCM (Reliability Centred Maintenance).

Mechanical designs are not standardised in the same way as electrical or electronic designs, and their functionality is dependent on several factors. It has therefore been difficult to produce functional reliability data in many cases. But new calculation methods and approaches have been developed since the 1950/60s

First Generation	*Second Generation*	*Third Generation*
Fix it when it broke	Higher plant availability Longer equipment life Lower costs Introduction of MMS Planning & Scheduling	Higher plant availability and reliability Greater safety Higher environment awareness Longer equipment life Computerized CMMS RCM

1940	1950	1960	1970	1980	1990	2000	2010

Figure 1.1: How maintenance has changed focus over time.

The focus of maintenance activities has also changed during the last six decades. From being repairers (repairing faults that arise) in different work fields, work tasks are now increasingly geared towards preventing and anticipating the emergence of faults. We have moved from what we call *reactive maintenance* to *proactive maintenance*. This means that a Maintenance Technician today is not only a “professional repairman” in a specific area of equipment or a specific area of work, but also has sound knowledge in how to carry out maintenance prediction and work in a safe way for the human and the equipment. (Think first then act).

Introduction

All equipment needs different levels of maintenance (even the human). The term maintenance-free has been coined from the equipment having a technical service life, and that maintenance is not necessary over this period. But the fact remains that equipment is affected over its life by its particular environment and how it is “handled” during operation and maintenance. Many of the failures may originate from handling errors or incorrectly applied maintenance methods. It is therefore important that the machine is run and maintained properly at determined intervals to avoid serious and costly breakdowns.

Figure 1.2: What went wrong?

There are several aspects to consider for the maintenance of plant and machinery. General aspects or objectives include always striving to create plant or machinery that is safe to use and maintain for people who work with it or are in its vicinity. This is partly due to the introduction of CE marking, and that particular designs and maintenance activities are carried out in line with legislation.

Moreover, the plant must be safe when in operation so that nothing unexpected happens that could harm the environment in or around the machinery and plant.

We can then define the main objectives for maintenance activities as:

- **Personal safety**
- **Environmental safety.**
- **Operational reliability**.

Figure 1.3: Work safe to avoid accidents

You could say that the requirement for operational reliability for the machine or equipment must be that

"It must run when intended"

What should we then set as requirements for a function/equipment/machine? Here we will discuss some of them.

Figure 1.4: What are functional requirements: safety, environment, reliability?

It must be *available* for production and fulfil our *requirements*. Besides the equipment being available, it must meet the requirement for the *rate* or *capacity* it is built for, and provide the correct *quality* of the product produced**.** Moreover, financial aspects should be included such as *operating and maintenance costs*. The equipment must be *safe* for operation and maintenance work, and it must not impact on its surroundings by transgressing the set *environmental demands.*

A plant that is well maintained, creates the ideal conditions for staff to perform their goal of producing, instead of dealing with disturbances and problems.
In addition, it creates the conditions for maintenance technicians to work proactively.
This means anticipating problems before they happen in different ways, and thus be able to address them in a planned way.

This, in turn, minimizes the costs of operating losses during downtime, while maintenance costs are kept low. We also know from studies that staffs are more motivated in clean and tidy surroundings, and where small problems do not occur all the time.

In order to produce figures of equipment performance, the monitoring of conditions (values) of the above parameters must be calculated and monitored over the useful life of the equipment. This monitoring with calculated values is called Key Performance Indicators (KPI). Furthermore, it is more than likely that a number of disturbances and breakdowns have occurred over its lifespan. It is essential that these are monitored and documented. The documentation is called Equipment History.

Today the calculation of Key Performance Indicators is often done by computer online, and the Equipment History is stored in a database (CMMS). Computer aids used include maintenance systems. How do we set these basic KPI:s and what are their mutual relationships?

The concept of operational reliability

As already mentioned, the term *reliability engineering* is used as a generic term for the activities for a machines in that it “must run when intended” at the optimum cost. *Reliability engineering* is to systematically address the problems which occur or may occur during a given operation of a part of equipment or function of an individual component.

Operational reliability is by definition according to EN 13 306 as follows:

“The ability of an item to perform a required function under given conditions for a given time interval, provided that the necessary support functions are on hand”

If, for example, we have a wind turbine of 2 MW, it will not be enough to set the requirement of 2 MW as a measure of operational reliability. We must also specify the conditions for the turbine to deliver 2 MW. That is, in our case: Is there an outlet for the energy produced, and what are the optimal wind conditions?

What is it that affects operational reliability? One factor is of course the functional reliability of the installed components. How good are the quality of the maintenance work that we carry out, and how the accessibility of the equipment is during maintenance? Operational reliability therefore depends on:

- Functional reliability (installed components)
- Maintainability (access for Maintenance)
- Maintenance supportability (maintenance organization, maintenance efficiency, quality, competence.)

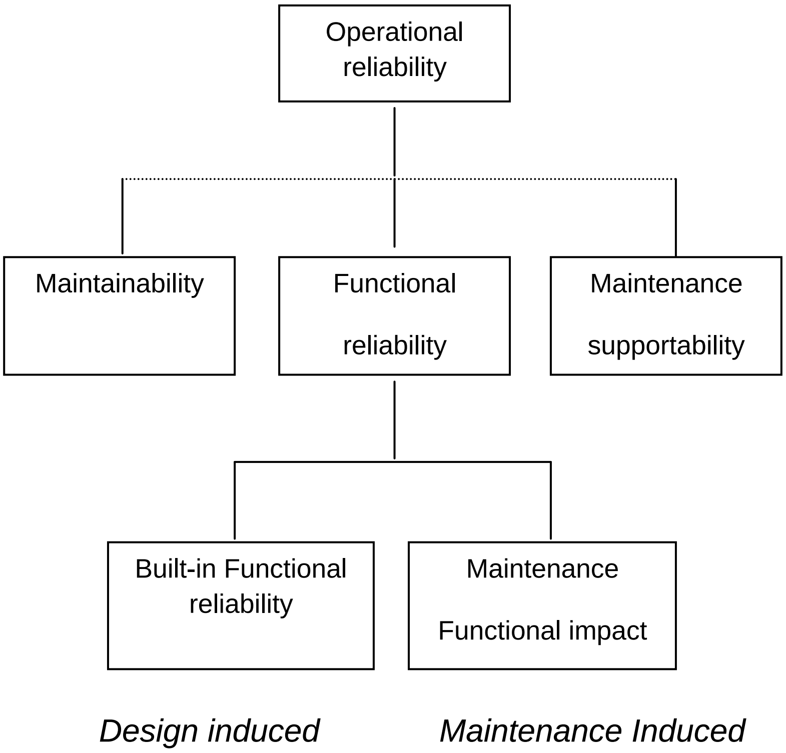


Figure 1.5 Operational reliability parameters

Maintainability

This is a factor that indicates how equipment or a machine is adapted to facilitate maintenance and service. It will include physical location, resource requirements, need for lifting equipment, special tools requirement or selection of standard components. Maintainability must start on the drawing board and during the design period.

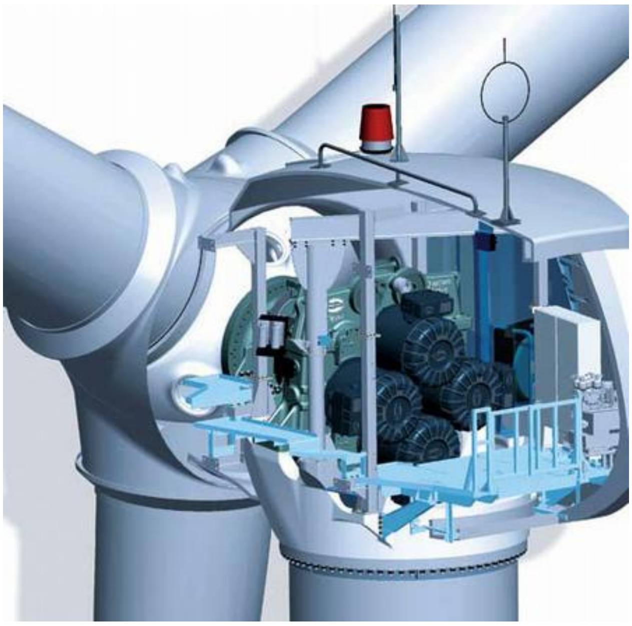


Figure 1.6 Are the design of the Nacelle and equipment placement maintainable?

Functional reliability

This factor is the ability of equipment or component to operate as intended under the given operating conditions (environmental, raw material, etc.) for the specified time. The Swedish Standard defines functional reliability as a synonym for the concept of functional probability

Figure 1.7 Are the right components selected for the designed load?

Maintenance supportability

This factor specifies in a quantitative manner the possibility of utilising spare parts, tools, aids and resources for a maintenance operation at the right time and at the right cost.

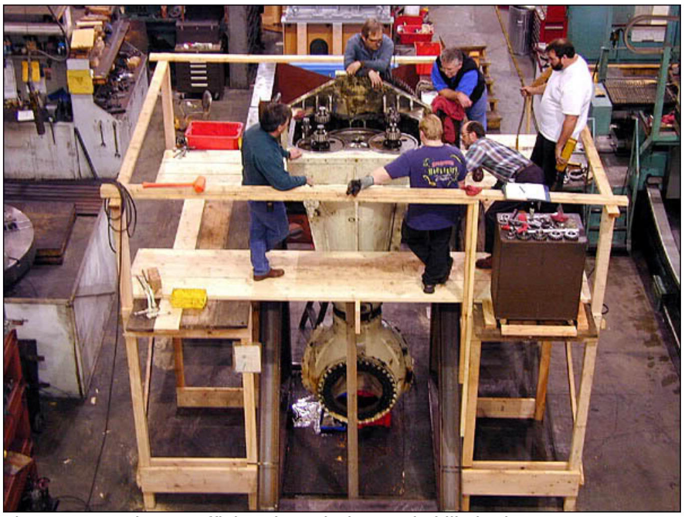


Figure 1.8 Is there sufficient knowledge and skills in the team?

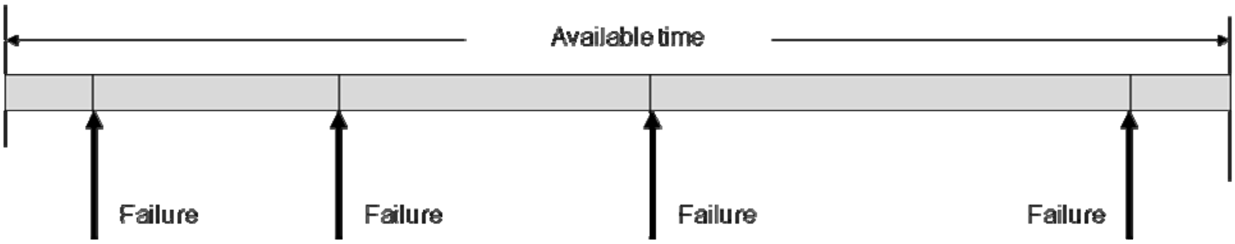
Measure of Operational Reliability

Operational reliability can be quantified (empirically developed) and compared to, for example, mass, volume, power efficiency, etc. This value is of course calculated from other parameters. In Figure 1.5 above, we have described the parameters that affect operational reliability. We will now see how to calculate operational reliability. This gives us a quantitative measure of how operational reliability (performance) varies over time (days, weeks, months ...), and how it can be an important aid, for example, in improvement/implement of new maintenance methods.

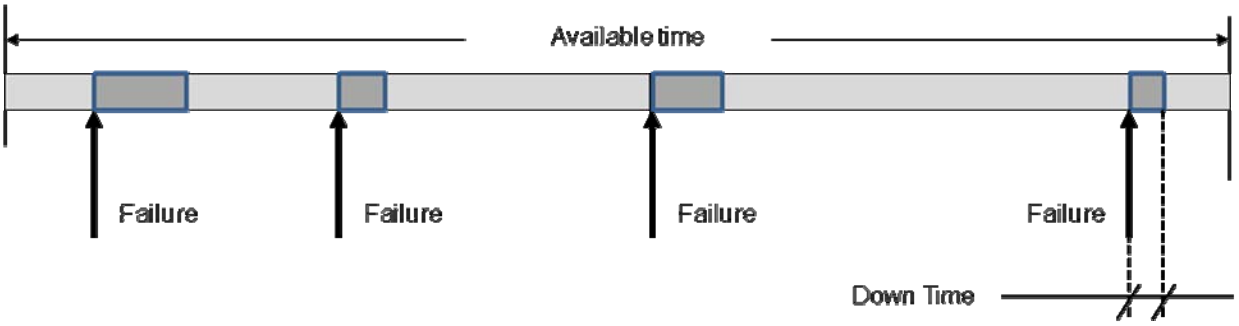
Availability

To calculate Availability, we need to measure the time between the occurrences of failures. This is known as

Mean Time To Failure = MTTF



the Mean Down Time (MDT) resulting from failures occurred



The Mean Down Time consists as the sum of the two parts Mean Waiting Time (MWT) and Mean Time To Repair (MTTR).

MDT = MWT + MTTR

The Up Time (UT), running time is then defined as Mean Time Between Failures (MTBF).

MTBF = MUT = MTTF – MDT = MTTF – MWT - MTTR

The basic relationship according to the model we have used gives the following relationship for *Availability A, which is an operational reliability numerical value*:

If we use the above designations we get

$$A = \frac{\text{Up time}}{\text{Available time*}} = \frac{\text{MTBF}}{\text{MTBF + MWT+ MTTR}}$$

* Available time here means the time that the machine/equipment is ready for production. Note that this may vary due to, for example, different shifts, or in a wind turbine 24 hours per day. Mark that it is independent if it windy or not.

In summary:

Quantity	*Abbreviation*	*Measure/Unit*
Operational reliability	A	Availability
Up Time	MTBF	Mean Up Time
Down Time	MDT	Mean Down Time
Functional reliability***	MTTF	Mean Time To Failure
Maintainability	MTTR	Mean Time To Repair
Maintenance supportability	MWT	Mean Waiting Time

*** A parameter in functional reliability is the dependability which is determined empirically (by testing).

<u>Example</u>

We have a wind turbine with the following data:

Installed maximum capacity	2 MW
Available time for production	8,760h
Down time over the year due to breakdowns	120h
Down time due to preventive maintenance/service	150h
Production over the year	4,850 MWh

Availability is calculated as:

$$T = \frac{8{,}760-(250+150)^*}{8{,}760} = 0.954 \quad (= 95.4\ \%)$$

* Here we have to use the total downtime resulting from failures and preventive maintenance to calculate a mean time between failures (= Up Time).

Note that this does not take into account the conditions for supplying energy (if it is windy or not), it is only an estimate of the turbine's technical condition (possibility of delivering energy during 1 year).

Plant Performance or Gain

With an investment in the form of a production process, it is essential that the production capacity is at, where necessary, the installed capacity and is sustainable at this level over time.

Perceptible situations include when you “reach the production ceiling” primarily during boom periods when the demand for the product is high. At such times, the question will always arise if it is not possible to “increase capacity”. Can´t we do any modifications to increase capacity?

In fact, if you are producing around the clock (as in a wind turbine), you cannot increase the number of production hours. The next question is then whether to invest in new machines or equipment to increase capacity or try to do “debottlenecking”.
However, the first question, to ask, is: “Do we really run the maximum installed capacity, or is it merely illusory”?

In a similar way as we determined the Availability, we can also determine the performance of the plant, The Gain.

From the operational reliability method, we have arrived a measure of Availability (the time *we are able* to produce = uptime). However, Availability *only indicates* the time the machine is “running” of the total time. It gives no information on how much is being produced.
Under the concept of Availability, the machine can therefore be running in idle without producing anything at all.

In our Example above, a turbine of 2 MW was installed, and the energy produced over 1 year was reportedly 4,850 MWh. How high is plant performance (or Gain)?

Possible time for production (=Up Time)

8,760h – 250h - 150h = 8,360h

Installed output of 2 MW then gives maximum production during this Up Time

2MW x 8,360h = 16,720 MWh

This will now give the Plant performance

$$\text{Gain} = \frac{\text{4,850 MWh (produced)}}{\text{16,720 MWh (maximum production)}} = 0.29\ (= 29\ \%)$$

What happens to plant performance if we install a larger/smaller wind turbine at the same annual production?

The product of Availability and Plant performance is often referred to as the AP factor.

AP = Availability x Plant performance (A x P)

For our turbine, the AP factor

AP = 0.954 x 0.29 = 0.276 (= 27.6 %)

Quality rate

When producing a product or goods, we want the customer to be satisfied, and that the product meets the customer's requirements. Therefore, production follows a certain specification (function, appearance, quantity, etc.). The product is said to fulfil a certain quality. The level of quality is monitored, usually ongoing, during the current production.

All products that do not meet the set quality requirements are rejected or reworked so that the requirements (specification) are met.

We must add an additional parameter to see how effective our plant is as a “quality machine”. Quality Rate is defined by

$$Q = \frac{\text{Products “passed”}}{\text{Products produced}}\ (=\%)$$

Overall Equipment Efficiency

The three parameters give us complete information in how effective our manufacturing/production is. This is called OEE (Overall Equipment Efficiency).

- OEE* = Availability x Performance x Quality Rate

*In windturbine production there is no need to talk about quality of the product. Why?

To summarise, we have the following:

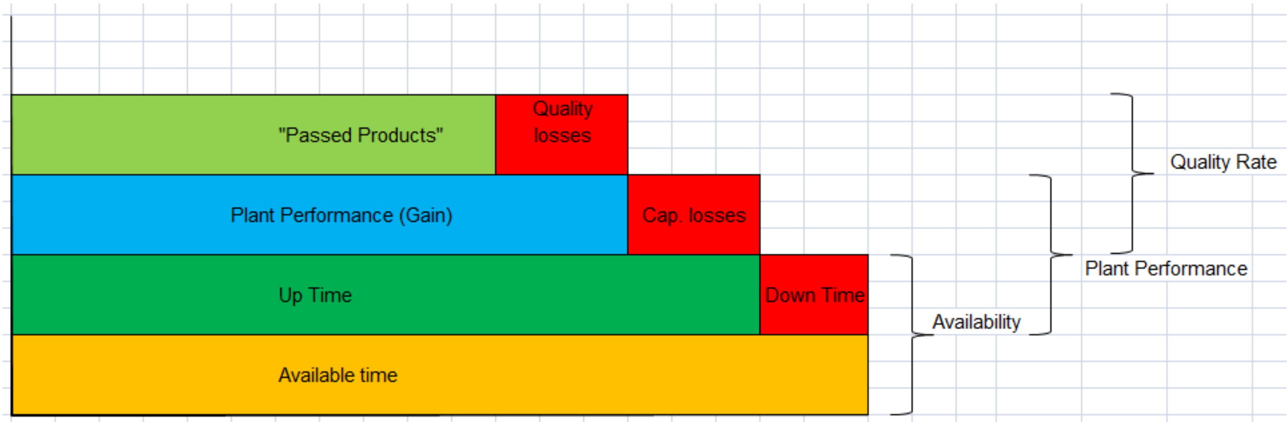


Fig 1.9 OEE- factor parameters

The following is a guide to how to sort the different sub-parameters. It is important, before calculating and monitoring the operational reliability in a company, to agree on “definitions”. The target is to always have a measurable degree of operational reliability so that improvements can be made. (Try to use above definitions. It is an international standard). If you use other definitions, it´s get difficult to do benchmarking.

List of sub-parameters

Availability	*Functional reliability*	Design	Materials
			Dimensioning
			Design principle
		Reserve capacity	Operative
			Stand by
			Selecting
			With repair
		Maintenance intensity	Preventive maintenance
			Maintenance execution
		Operator ability	Physical
			Psychological
			Trainability
	Maintainability	Failure detection	Failure indication options
			Test connections
			Test apparatus
			Condition monitoring
		Ability to supply	Standardisation
			Modularisation
			Transport and storage
		Repairability	Failure modes, consequences
			Standard tools
			Reworking, marking
			Accessibility

		Mounting, dismantling
		Work sites, environment
		Security, Protection
Maintenance supportability	Maintenance staff ability	Quantity
		Competence
		Stationing
		Personal data
	Rep. Eqmt, opportunities	Machines
		Tools
		Specialty eq.
		Utilities
	Reserve materials	Replaceables
		Spare parts
		Supplies
		Data
	Technical data	Maintenance instr.
		Operating instructions
		Drawings
	Administration	Organisation
		Control systems
		IT

Dependability (Functional reliability)

The dependability is a parameter in functional reliability that has its origin in the mathematical probability theory, and is described/reported frequently as a statistical outcome with an expected value for failure intensity. A measure of failure intensity can be the “Number of failures that have occurred per 1 million operating hours”. In specific terms (when calculating dependability) functional probability are used.

The failure intensity can be calculated for individual components or the entire machine system. The way in which the calculation is made depends on the need for accuracy in the results.

To increase dependability, redundant systems (dual systems) can be used. This is primarily for systems with high demands of availability and/or safety and cost critical operations. The investment costs to “double” the equipment are often expensive.

The way in which the dependability of the entire system is dependent on the dependability of each sub-system when these are connected in series is shown below. (Each sub-system is then dependent on the dependability of the individual components in each sub-system.)

In the example below, each component has the functional probability R_x

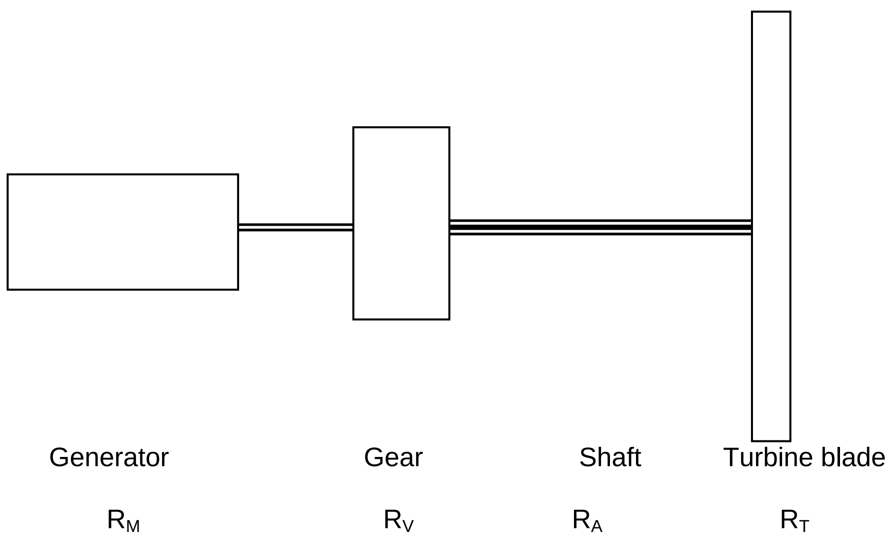


Image 1:10 Dependability, series connection

The dependability (functional probability) is

$R_{\text{wind turbine}} = R_M \times R_V \times R_A \times R_T$

For a redundant system (parallel connection) the following is obtained:

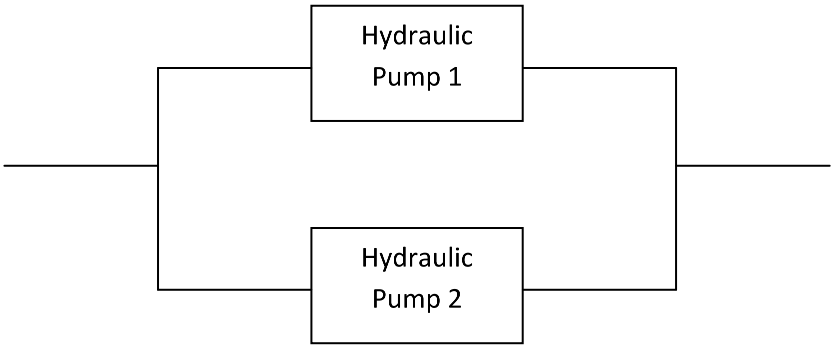


Image 1:10 Dependability, parallel connection

The function probability for the pump system above is:

$R_{Pump\ system}$ = 1 - both pumps out of service

$F_{Pump\ 1} = 1 - R_{Pump\ 1}$ (pump 1 out of service)

$R_{Pump\ system} = 1 - (1-R_{Pump\ 1})(1 - R_{Pump\ 2})$

Failure intensity - contra component

Figure 1:12 Crestfallen, what went wrong?

To develop the functional probability of a component, you have to study how often the component loses its functionality (failure intensity) over its pre-determined lifetime. This varies from component to component, and from type to type.

However, work has been carried out in line with the hypothesis that there are three parts or areas that are characteristic for most components.

- Infant Mortality Period
- Useful Life Period
- Wear Out Period

The three phases put together is what we call the “Bathtub Curve” which is frequently used in maintenance to make predictions when activities would be carried out..

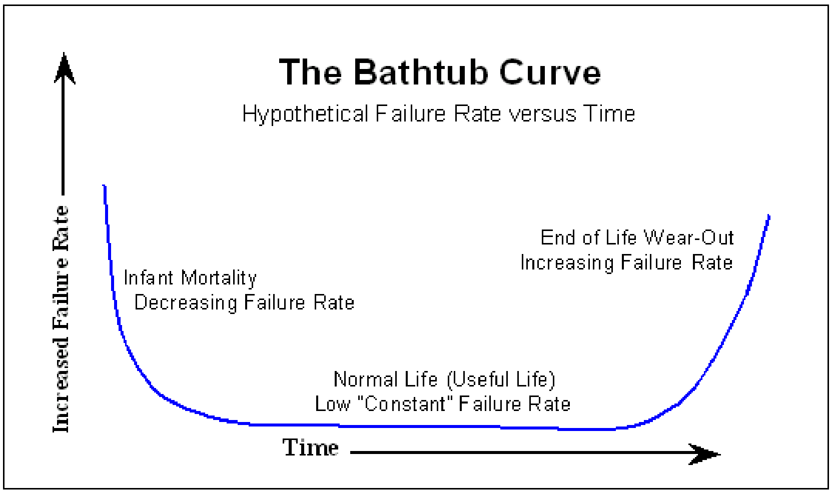


Figure 1:13 Bathtub curve

This has from time to time been questioned. This is because the design, development and reliability of new component do not produce the distinct states mentioned above. However, it is the general view among operating and maintenance staff to “view the world in this manner”. The approach is totally wrong. It is in most cases we humans that under this influence “reliability.”

Development in terms of the appearance of the failure intensity curves and the percentage to which curves most of the components relate to is shown below.

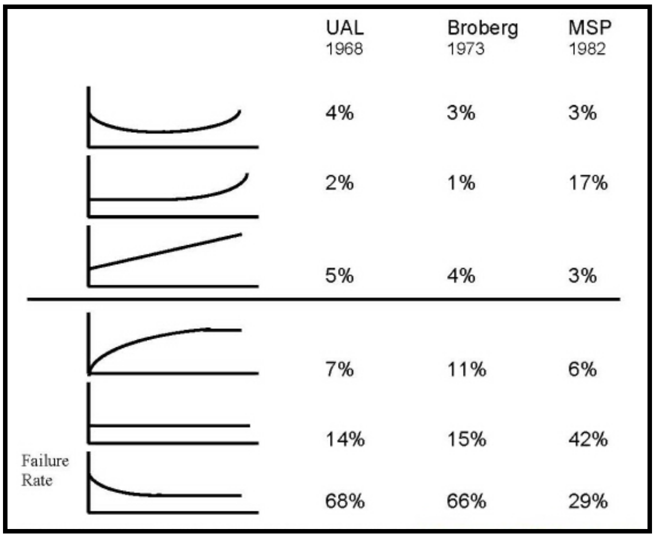


Figure 1:14 The six failure intensity curves

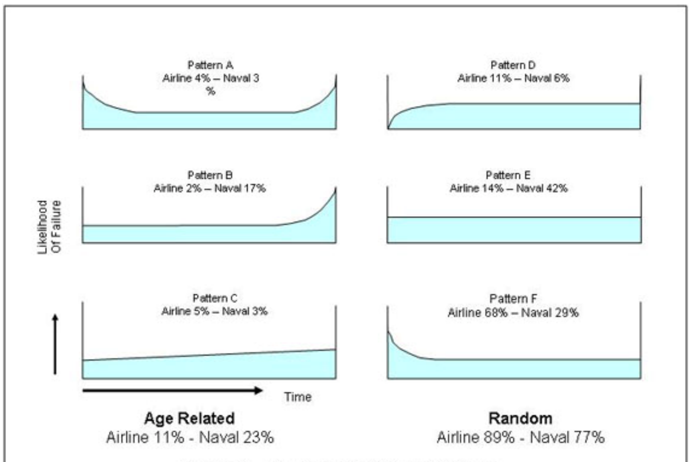


Figure 1 – Equipment Failure Patterns

Figure 1:15 Age-related and random failure intensity 6 curves

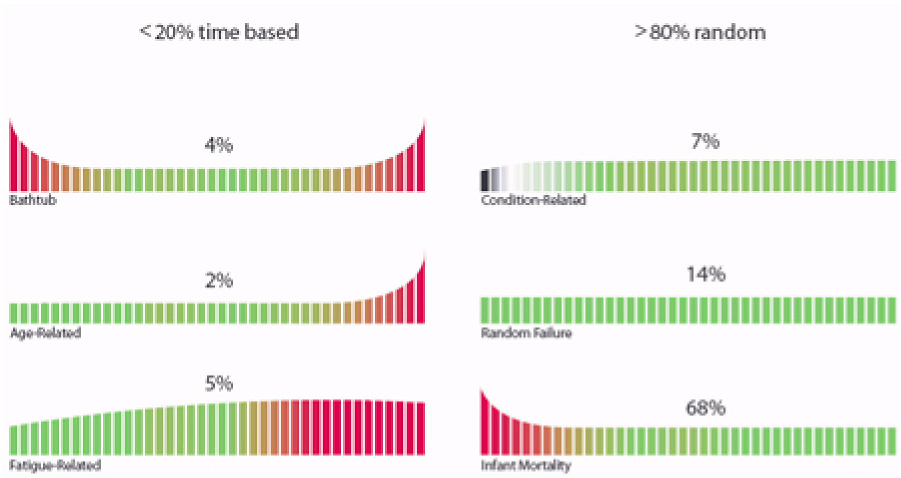


Figure 1:16 68% of random failures are infant mortality. Why?

Survey Says 60% of US Wind Turbines May Be Behind in Maintenance

Frontier Pro Services has released the results of an informal survey of approximately 75 wind farm operators in the United States. Designed to assess the specific operation and maintenance service needs of wind energy operators, the survey reveals what could be serious threats to wind farms largely because of the industry-wide shortage of qualified turbine technicians, Frontier said.

According to the findings, many wind farm operations and maintenance teams are so resource constrained that they are barely able to keep up with the unscheduled maintenance repairs their wind turbines require to continue generating electricity. Even regular, scheduled preventative-maintenance like oil changes and gearbox lubrication (services that are often still under warranty) are falling behind as manufacturers face similar resource struggles related to the shortage of qualified technicians.

Gearbox failures account for the largest amount of downtime, maintenance, and loss of power production. These costly failures can total 15-20 % of the price of the turbine itself, making wind turbine and gearbox maintenance a high priority.

“Most gearbox failures are preventable,” said Jack Wallace, lead technical advisor for Frontier Pro Services. “Most gearboxes fail as a direct result of improper lubrication and lack of routine maintenance. With so many turbines behind on inspections and regular service, there is real cause for concern here,” Mr. Wallace continued.

If oil is not properly monitored and replaced as needed, bearing and gear wear will lead to more serious and costly damage to the drive train. According to Frontier, when a US $1,500 bearing failure is unnoticed, it can lead to production loss and revenue loss including an unscheduled replacement of a US $100,000 gearbox and an unscheduled crane cost of up to US $70,000 to access the failed components.

The Frontier Pro Services Operations & Maintenance survey was conducted through a combination of informal phone interviews and in-person meetings with operations and maintenance technicians, wind farm operators, and wind farm owners during the first six months of 2008.

The results of this survey come as earlier this year a 200-foot Vestas wind turbine near the city of Århus in Denmark disintegrated in high winds when a blade came loose and hit the central tower, causing the whole structure to collapse. Two days later a blade broke off of a turbine near Sidinge, Denmark.

MAINTENANCE

"Are all activities that are undertaken designed to maintain and restore a piece of equipment to such a condition that all scheduled operations can be carried out

MAINTENANCE OBJECTIVE

"Ensuring a given production capacity within specified quality limits for staff, the environment and equipment at an optimised direct and indirect maintenance cost"

Maintenance

Maintenance, depending on the type of activity, is classified in general into the concepts listed on page 4. See the European standard EN 13 306 for the correct definitions. However, some of these are used sporadically. In addition to the definitions, another group has been added known as improvement maintenance.

Maintenance of equipment must be considered, not only during the production part of its service life but also throughout its technical life. This can be calculated in line with a philosophy/working method called Life Cycle Costs. More on this in Chapter 6. The phases are usually called:

- Project
- Development
- Manufacturing
- Performance
- Scrapping

The later in a life cycle that maintenance is taken into account the greater the costs of the execution of maintenance and down time.

With regard to the financial and cost aspects, costs are classified related to maintenance activities in two groups:

- Indirect maintenance costs - loss of production
- Direct maintenance costs - the cost of the maintenance operation

Costs related to a maintenance context are often showed with an iceberg. The visible part is the direct maintenance cost, while the bulk of the iceberg under water is usually considered as the indirect maintenance cost. This means that we have a relationship between indirect costs and direct costs 10 to 1.

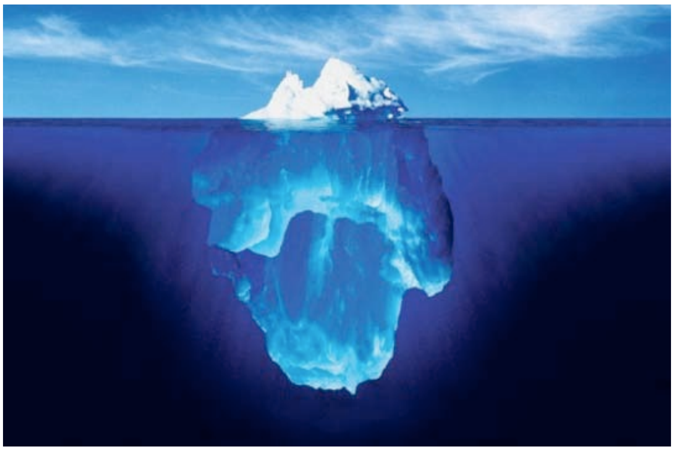


Figure 2.1 One tenth of the iceberg is visible above the water surface

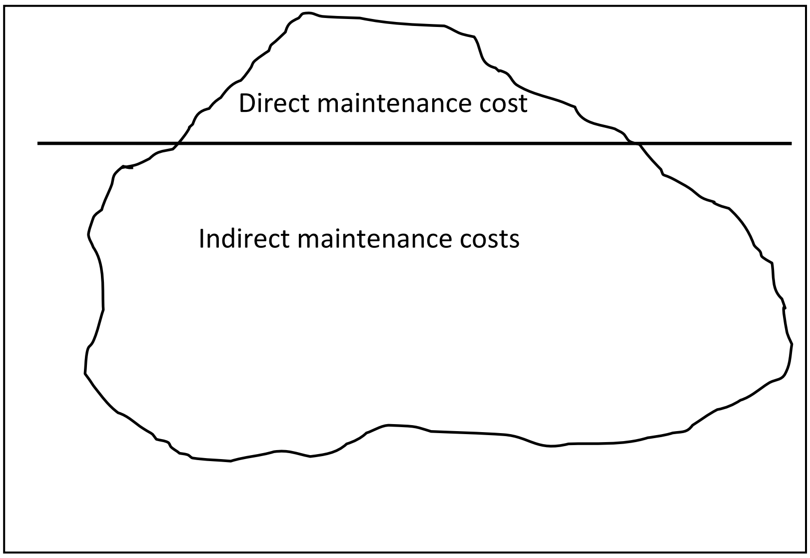


Figure 2.2: The indirect maintenance costs are usually much larger than the direct costs

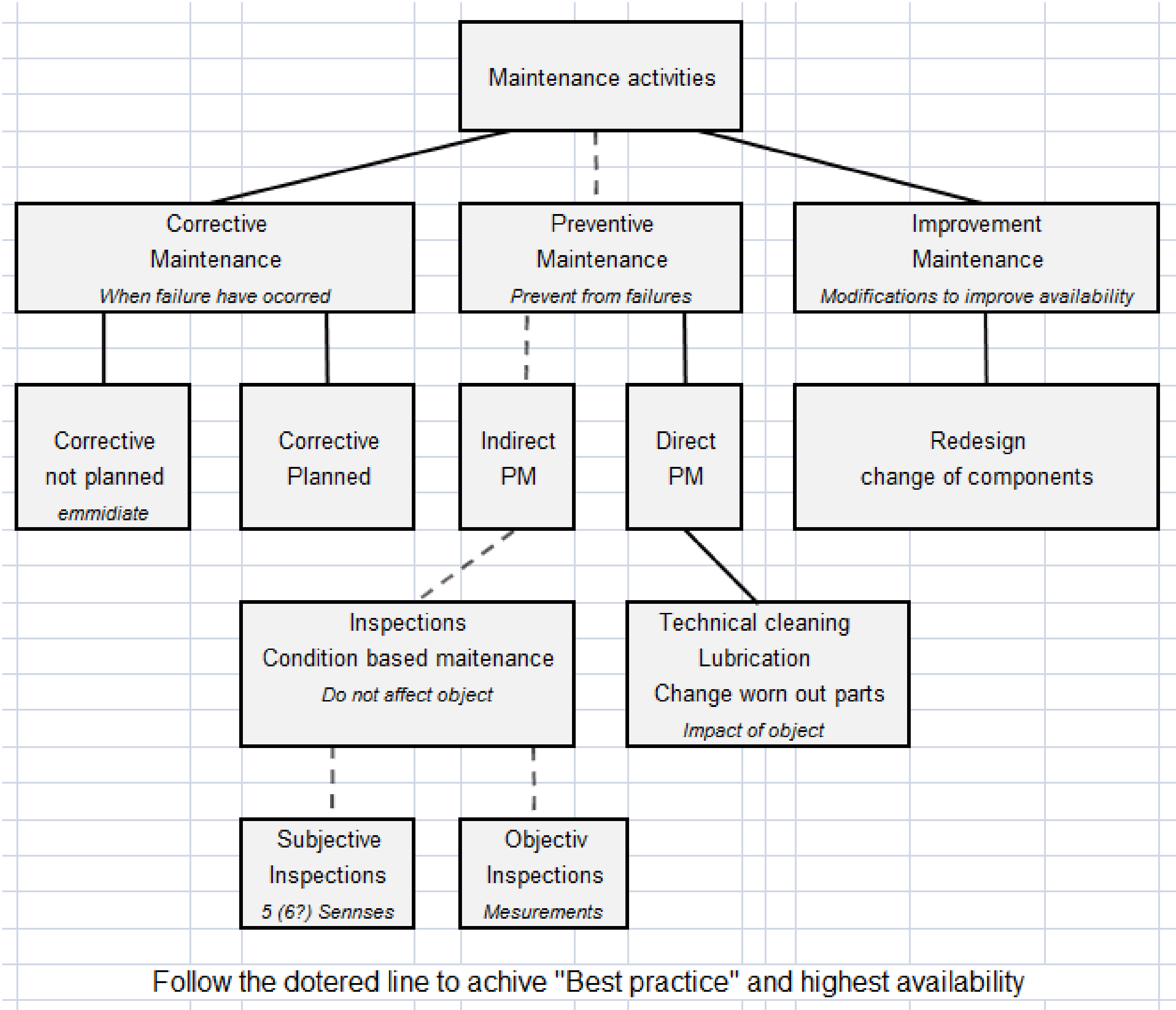


Figure 2.3: Breakdown structure of maintenance activities

Maintenance activities can be executed in different ways and have different objectives. The classification above is common in Sweden and is used in a maintenance context in maintenance departments at most companies.

Maintenance is divided into what is called *Corrective maintenance* and *Preventive maintenance*. In addition, there is the Swedish speciality called *Improvement maintenance*. Corrective maintenance means an operation (activity) carried out *after* a failure has occurred. This means in most cases that production cannot be maintained and that *repairs* are usually made during *unscheduled down time* (Emmidiate response). Obviously this means a loss of revenue for the company and corrective maintenance should be avoided wherever possible.

However, it may be the case that not all identified failures mean that you have to shut down equipment for repair, but we can schedule the operation (activity) at an appropriate time. A failure has occurred, therefore corrective maintenance is necessary, but it can *be scheduled*.

One variant of corrective maintenance is known as “Temporary”*.* In the heat of the battle when you want to get started as quickly as possible, inventiveness becomes your ally. Here are all the permissible means for a quick restart. “We'll fix it properly later” is the most common comment. Unfortunately, “later” seldom comes around. Temporary repairs have always a tendency of becoming permanent repairs. Therefore it´s very important for a Technician to report any temporary repairs carried out.

Figure 2.4: Temporary repair of coupling. How long will it work? (Source: SPM)

Preventive maintenance means, as the name suggests, that we must *prevent* the occurrence of failures and thus avoid unscheduled and costly down time. Preventive maintenance can be divided into two categories: *indirect preventive maintenance* and *direct preventive maintenance*.

Indirect preventive maintenance means activities that can be executed during operation and that will not affect the object (component, equipment). This type of activity is in the nature of an inspection. There are two types of inspections

- Subjective inspection
- Objective inspection

Subjective inspection means we use our senses (which vary from person to person), we have five senses and then a sixth, “intuition”. The sixth sense can be said to be the experience that we develop and that gives a person the sense that “something is afoot”.

It is quite clear that a subjective inspection provides a mixed picture of what the failure could be. The experienced maintenance technician should, for example, always be aware of signals coming from subjective inspections from operational staff and not ignore them.

Objective inspection means that we inspect objectively, i.e. we measure in some way to verify a deviation from the norm. This is today by far the most widely used method for critical equipment that in the event of failure could lead to lengthy down time and a major loss of income. For example:

- Vibration measurement (electrical & mechanical)
- Temperature measurement
- Calibration on-line
- Current and voltage monitoring

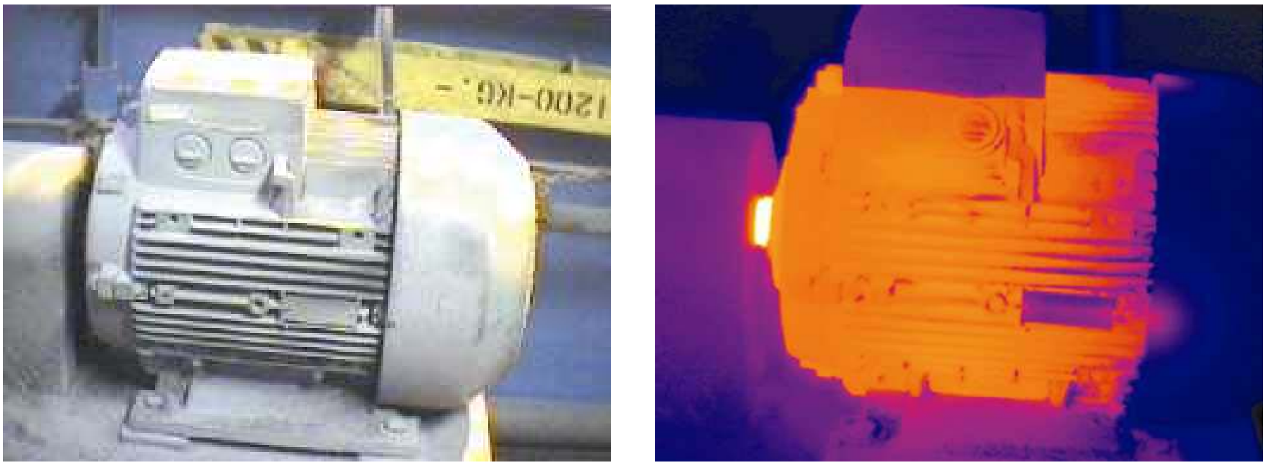


Figure 2.5 Thermographs (Source: FLIR Instruments)

Direct preventive maintenance means a direct action taken on the object (equipment). The most important preventive measure is *technical cleaning*. A large proportion of breakdowns that occur and shorten lifetime result from “dirty machines”, which increase wear. Here it is not the outside of the machine we are referring to, but the inside. (What happens if we do not change the lubricating oil on time? What happens if we do not keep an electric motor clean?) Abnormal wear and overheating due to dirt is very common.

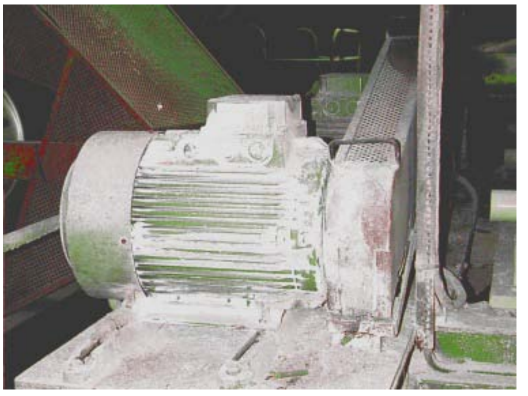


Figure 2.6 Cleaning needs? Why?

Lubrication as everyone knows is a necessity to keep friction low. Another purpose of lubrication is to cool and clean at lubrication points (e.g. a roller bearing or a crank bearing in a motor). It is essential that lubrication is carried out correctly. You can actually over lubricate a ball or roller bearing. More on lubrication in Chapter 7.

Figure 2.7 Satisfactory automatic lubrication?

Replacement of wear parts also belongs to the category of direct preventive maintenance that affects the object. Here you need to be extremely vigilant, and perform the work operations as specified in the instruction manual. Most of the failures are the result of improper dismantling/assembly. By nature man is lazy, and likes taking short cuts. For instance, “There were a few washers left, but OK,” “Why should I squeeze the pipe, the coupling is holding it in place after all” or “Tighten as much as you can - that will keep it tight”.

Keep in mind that today's designs are carefully calculated in terms of strength and performance, which means that we must observe the specified instructions when repairing/replacing to ensure satisfactory results so as not to “overload” the machine parts.

Improvement maintenance is the program of initiatives we take to improve operational reliability from a maintenance aspect. Reconditioning of equipment to increase capacity is not improvement maintenance. However, replacing a constant malfunctioning hydraulic directional control valve with a different type which has a higher functional reliability belongs to this maintenance activity.

Below is the list of the most common definitions of maintenance.

Maintenance

Combination of all technical, administrative and managerial measures taken during the life cycle of a unit designed to retain it in, or restore it to, a state in which it can perform the required function.

Management of maintenance

All managerial measures for the determination of the objectives, strategies and responsibilities of the maintenance and the implementation of this by means of planning, monitoring and inspection of the maintenance activity, and improvements thereto, including financial aspects.

Maintenance objectives

Objectives that are specified and accepted for the maintenance activity.

Maintenance strategy

The focus set by management to achieve the objectives of the maintenance activity.

Maintenance plan

Structured grouping of tasks that includes activities, processes, resources and the time-scale necessary to perform maintenance.

Required functionality

A function or combination of functions in one unit that is deemed necessary to achieve the required performance.

Dependability

A generic term to describe the characteristics of operational reliability and the characteristics that affect this: functional reliability, maintainability and maintenance reliability.

Maintenance reliability

The ability of the maintenance organisation to provide the proper maintenance resources at the required place to perform the required maintenance measures on a unit at a specified time or during a specified time interval.

Unit

Every detail, component, piece of equipment, subsystem, functional part, plant or system that can be considered separately.

Plant access

A formally reportable unit

Repairable unit

Unit that after a failure and under the specific conditions can be restored to a condition in which it can perform the required functionality.

Repaired unit

Repairable unit that after repair does not malfunction.

Consumable

Unit or material that is not specific to a particular unit and is considered to be spent following use.

Spare part

Unit designed to replace a similar unit with the intention of restoring it back to its originally required functionality.

Operational reliability

The ability of a unit to perform a required function under given conditions for a given time interval, provided that the necessary support functions are on hand.

Functional reliability

The ability of a unit to perform the required functionality under given conditions over a specified time interval.

Maintainability

The ability of a unit that is used under given conditions, to be maintained at, or restored to, a state in which it can perform the required function, when maintenance is performed under the specified conditions and while using established procedures and resources.

Redundancy

The incidence of more than one option, at a specific time, to perform the required functionality of a unit.

Active redundancy

Redundancy in which all options to perform the required functionality are considered to function simultaneously.

Reserve redundancy

Redundancy which to some extent has the possibility to perform the required functionality which can start to work when other options fail.

Useful life

Under specified conditions, the time interval that begins at a specified time and ends when the failure intensity becomes unacceptable, or when a functional fault in a unit cannot be repaired, or because of other relevant factors.

Failure intensity

The number of failures for a unit during a specified time interval, divided by the time interval.

Failure

The end of a unit's ability to perform the required functionality.

Cause of failure

Circumstances that led to the failure.

Wear failure

Failure where the probability of incidence increases with operating time or the number of completed work cycles or the load a unit is subjected to.

Ageing failure

Failures where the probability of incidence increases with operating time. This time is independent of the unit's operating time.

Degradation

Of time, use or external causes leading to the irrevocable gradual deterioration of one or more of a unit's properties.

Primary failure

A failure of a unit that is not caused directly or indirectly by a failure or malfunction of another unit.

Secondary failure

A failure of a unit that is caused directly or indirectly by a failure or malfunction of another unit.

Sudden failure

A failure that cannot be predicted using previous investigations or observations.

Malfunction

The condition of a unit characterised by its inability to perform a required function, excluding any inability that may occur when preventive maintenance or other scheduled activities are being carried out or a lack of support functions.

Hazardous state

The condition of a unit that is feared could cause personal injury, substantial material damages or unacceptable consequences.

Preventive maintenance

Maintenance carried out at predetermined intervals or according to predetermined criteria, and with the purpose of reducing the likelihood of failure to, or degradation of, the unit's function.

Scheduled maintenance

Preventive maintenance carried out in accordance with an established schedule or after a specified application.

Predefined maintenance

Preventive maintenance carried out according to specified intervals or after a specified application, without prior condition monitoring.

Condition based maintenance

Preventive maintenance consists of inspection and monitoring of a unit's condition with respect to its functionality and properties, and the resulting measures to take.

Predictive maintenance

Condition based maintenance measures implemented as a result of a prediction of a unit's deteriorating functionality based on an analysis and evaluation of key characteristics.

Corrective maintenance

Maintenance carried out after a malfunction is detected and with the intent to get the unit in a condition that allows it to perform the required functionality.

Deferred maintenance

Corrective maintenance that is not carried out immediately after a malfunction is detected but is postponed in accordance with the specified maintenance directives.

Emergency maintenance

Maintenance carried out immediately after a malfunction is detected in order to avoid unacceptable consequences.

Operator maintenance

Maintenance performed by the unit's user or operator.

Inspection

Verification of conformity through measuring, observation, testing or assessment including the unit's properties. The inspection can be carried out before, in connection with, or after other maintenance activities.

Monitoring

Activities carried out either manually or automatically, with the intention of noting a device's current condition. Monitoring is different to inspection in that monitoring is used to evaluate the changes to a unit's properties over time. Monitoring can be continuous or after a certain time interval or a number of operating cycles.

Function check-out

Measures implemented following maintenance operations to verify the unit's ability to perform the required functionality.

Routine maintenance

Regular or periodic basic maintenance activities which usually do not require any special expertise, authorisation or special tools. Routine maintenance can include such things as cleaning, check tightening of connections, inspection of fluid levels, lubrication, etc.

Overhaul

Comprehensive examinations and measures to maintain the required level of operational reliability and the safety of the unit. The overhaul can be performed at set time intervals or for a number of operating cycles. The overhaul may require complete or partial dismantling of the unit.

Renovation

Measures carried out on a dismantled unit to repair or replace the sub-units which are nearing the end of their useful life and/or are to be routinely replaced. Renovating is different from overhaul as renovation can include modifications and improvements. The objective of the renovation is usually to give a unit a service life that is longer than the original.

Repair

Physical activity for restoring a unit with a malfunction to such a condition that it can carry out the required functionality.

Temporary repairs

Physical activity to ensure a unit can temporarily perform the required functionality for a limited time, until repairs can be carried out.

Improvement

Combination of all technical, administrative and managerial measures, designed to improve a device's dependability, without changing its required functionality.

Modification

Combination of all technical, administrative and managerial measures, designed to modify a device's functionality. Modification does not mean replacing with an equivalent unit. Modification is not a maintenance measure but refers to the change of a unit's required functionality to a new functionality. The changes may have an impact on the dependability of the unit or the unit's performance, or both.

Available time

Time interval during which a unit is in an operational condition.

Uptime

Time interval during which a unit performs its required functionality.

Time for maintenance

Time interval during which maintenance measures are carried out on a unit, either manually or automatically, including the technical and logistical delay.

Time to repair

The proportion of active time for corrective maintenance during which repairs are performed on a unit.

Time to failure

The total uptime of a unit from the time when it is in an operational condition to the time it fails.

Time between failures

The time between two consecutive failures for a unit.

End period

The period at the end of a unit's lifetime under which the unit's failure intensity is significantly higher than during the earlier period.

Best period

The period of a unit's lifetime under which the failure intensity is approximately constant.

Life cycle

The time interval that begins with an idea for a unit and ends with the scrapping of the unit.

Maintenance support functions

Resources, administration and managerial measures necessary to carry out maintenance. A support function can include, for example, personnel, test equipment, facilities, spare parts, documentation, tools, etc.

Failure analysis

Logical, systematic examination of a unit in which failures have occurred for identifying and analysing the failure sequence, failure cause and the resulting future consequences.

Maintenance documentation

Written or electronic information needed for maintenance implementation. This information can consist of technical, managerial, administrative and other documentation.

Unit records

Records that identify each individual unit and its location.

Maintenance records

Part of the maintenance documentation that contains all failures and malfunctions, as well as information associated with the maintenance measures for a unit. These records may also include the costs of maintenance, the unit's operational reliability or available time or other relevant data.

Lifetime cost

All costs incurred by a unit during its lifetime. For a user or owner, the total lifetime cost could include the cost of the unit in terms of its purchase, operation, maintenance and scrapping.

Condition based maintenance (CBM)

Virtually all components and equipment will within a certain period of time exhibit some form of defect or failure. Measures designed to identify these failures, and prevent unnecessary down time and other disruption to production in good time, are called, as mentioned earlier, indirect preventive maintenance. The generic term for this type of maintenance is also called condition monitoring.

Condition based maintenance makes it possible to schedule maintenance more effectively, and identify the deviations and failures before the deviation/failure affects production or becomes so great that a costly breakdown occurs.
There are several advantages to using condition based maintenance. When condition based maintenance is used you utilise the lifespan of the various components of a machine in a better way as they are only replaced when the need arises.

Condition monitoring is divided into three groups.

- Subjective inspection
- Objective inspection
- Condition monitoring using continuous monitoring.

Subjective condition monitoring (Inspections)

Subjective inspection refers to inspections that have our senses as a reference. Examples of what we can detect with our senses are:

What can you see?

Leaks
Damaged components
Loose components
Oil and water levels
Cleaning requirements
Temporary repairs
Broken knob lights

Figure 3.1 Subjective inspection, sight

What can we feel?

Vibrations
Temperature levels, changes
Damaged surfaces
Knocks, impacts
Unevenness
Loose components

Figure 3.2 Subjective inspection, sensory

What can we hear?

Grinding noises
Buzzing sounds such as electrical coils
Rattling of loose parts
Cavitation
Uneven running
Air leaks

Figure 3.3 Subjective inspection, hearing

What can we taste?

Acid/sweet
Content of different substances

Figure 3.4 Subjective inspection, taste

What can we smell?

Smell from high temperatures
Smoke
Gas leaks
Leaks of different substances
Dust particles

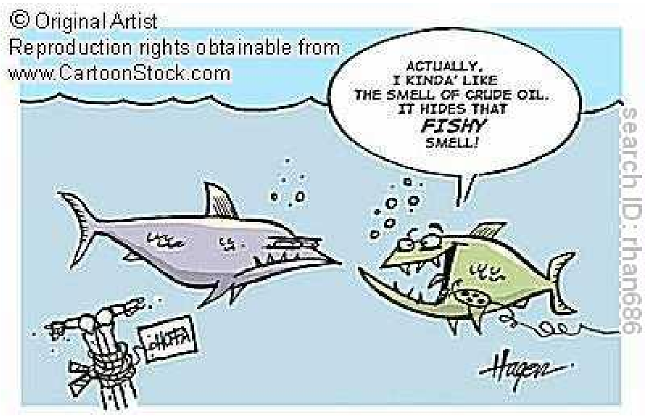


Figure 3.5 Subjective inspection, smell

Given that two people may have quite different perceptions of what a sound from a machine could mean, it is important that the people performing the inspection have sound knowledge of the machine's “signals” and that the condition monitoring is performed in such a way so as to ensure that the *same* “measuring point” is inspected during routine inspections.
This type of inspection is simple to carry out, and any specific skills/professional knowledge is not required. However, it is important that the inspector performing the inspection has been trained/informed on what a deviation/failure means when they occur.

Objective condition monitoring (Inspections)

When objective condition monitoring is performed, a *reference* is used to determine, for example, a temperature or pressure level. This reference is often a measuring instrument of some kind.
Here it is very important to have supporting data from commissioning or design data to help determine the condition of the equipment or a component in a machine. It is the deviation from this basic data that reveals the scope of a failure.
Just as with subjective inspections, the objective inspections are carried out using the same "measuring point" and at a predetermined regularity. This is to ensure the comparability of measured/recorded values.
As a measurement/reading of a specific value is made, this must be noted if possible so that any failure trend can be identified. It is this trend or mal-development that is the basis for any decisions on the replacement of a component.

There are many different types of objective condition monitoring with varying degrees of complexity and measuring equipment/reference equipment. The choice of the reference equipment is related to how accurate and how important the inspection is in avoiding disruption to production or quality discrepancies.

Calibration, alignment and adjustment of machinery to specific measurements are often linked to the outcome of a manufactured product. The product must have a certain specification. Many companies today have been certified in order to be able to demonstrate traceability (uniform "product quality" for mass production). Certification of this type could be according to ISO 9000 family.

Continuous Condition based monitoring (CBM)

When continuous monitoring is carried out, a sensor for "online" measurement is placed on a piece of equipment. These sensors can measure factors like power consumption, speed, temperature or vibration. The signal from the sensors goes to a control and monitoring system (SCADA = Supervising Control and Data Acquisition), or to a local monitoring safety system
The signal is processed (filtered, amplified, processed mathematically, etc.) and then presented on a trend chart or log and may give an alarm, and possibly influence a "Shut Down" function.

Selecting method

When it comes to choosing the most suitable CBM method, a number of different assessments need to be made.
At first you must rank all the machines at a production plant from a criticality point (Criticality ranking) of view (important machines, red-line machines), and then based on this decide whether there is a need for CBM that is continuous (with a possible "alarm / shut down" function), or if routine inspection is sufficient (subjective or objective). Note that criticality ranking is not only aiming at availability, but also to subjects as HSE, costs etc.

For equipment that has a minor impact on production performance, it is perhaps unnecessary to apply the most expensive and/or most time-consuming methods.

Furthermore, you should consider when selecting the method whether in the event of a breakdown or a disturbance there is a risk of personal injury or significant environmental impact.

There may be a number of factors that make it difficult to carry out subjective inspections. This may, for example, be due to heat, cold, radiation or the location of equipment. Is it manned or not? The parameters help you to evaluate if you must go for CBM or objective inspections (like function tests).

A balance between the benefits and the financial aspects must always be made regardless of whether you choose a subjective, objective inspection or CBM.

Generally, it is always monitoring and continuous measurement of a machine that is the most expensive inspection method. Note that it is not just equipment and installation that costs money, but also the routine function tests (inspections) that confirm that the monitoring function is working properly. Moreover, objective inspections require trained personnel and that there is investment in calibration/test instruments.

Subjective inspections require no major investment, but still require that the personnel undertaking an inspection are capable of detecting errors using their senses which means this method is limited.

We must remember that these inspections are categorised as preventive maintenance, and that the objective of a maintenance activity is to avoid corrective maintenance. Below is a graph of the cost of balancing corrective and preventive maintenance. The amount of preventive maintenance has no intrinsic value, but must provide a “benefit”. Today too much preventive maintenance is carried out on the wrong equipment and at the wrong frequency due to old customary practices. This costs money.

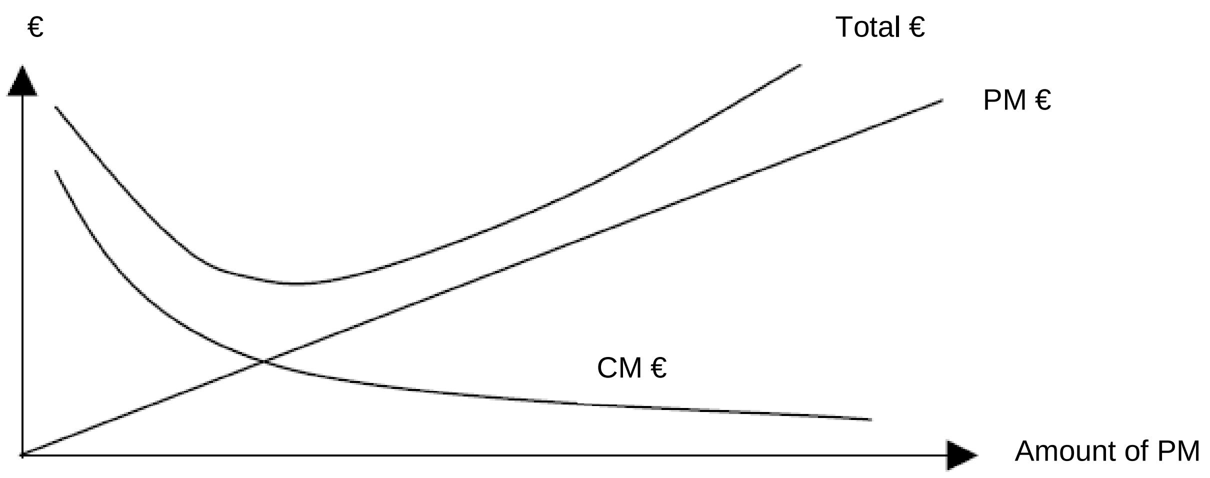


Figure 3.6 Direct maintenance costs

How to determind ”The red line of machines” depends of the business. Below you will find an example

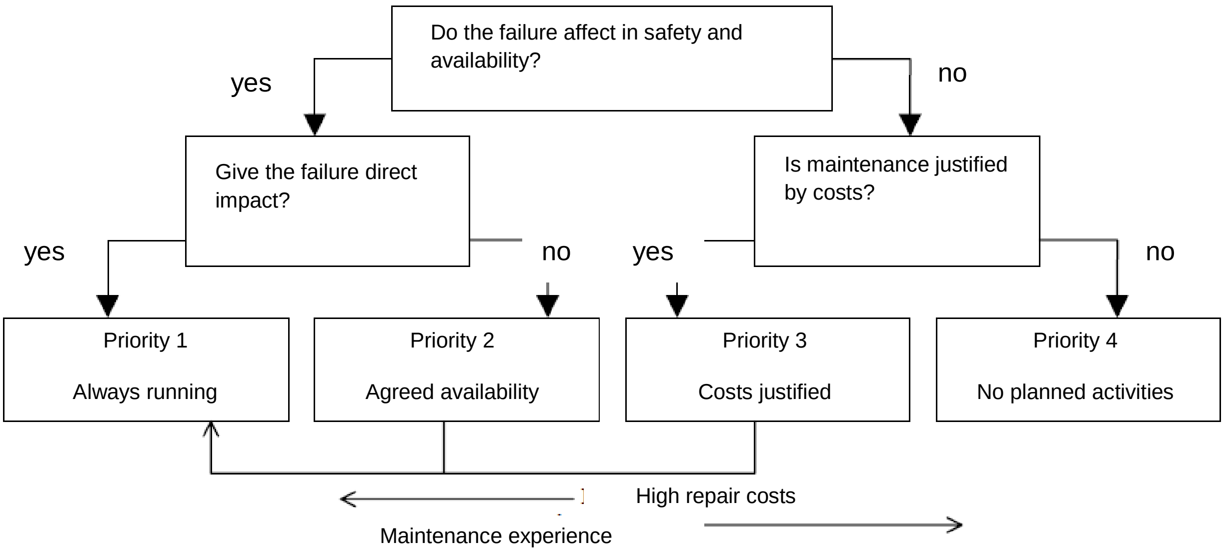


Figure 3.7 Identification of Equipment criticality

Inspection methods

In order to select a method you should have first scanned the market and identified the methods that are suitable for your particular machine in its environment. It is not always certain that the same measurement method can be used on the same machines in different environments. The impact on special sensors can be very different (temperature, water, vibration, impacts, shocks, etc.). What inspection methods are available? Information about the most common and most prevalent methods is listed below.

Reading deviations display instruments

There are usually a number of display instruments in a piece of equipment or a plant. The reason for this is to be able to see the levels for pressures, temperatures, flow rates, etc. But what is the normal pressure or temperature, and when do we have a deviation? What value is the process to assume? This is difficult to assess and be subjective in many instances. One way is to define a more precise value or range. This makes the subjective “operational” inspection objective.

Fig. 3.8 Modified thermometer and pressure gauge readings for more objective readings

Temperature measurement

A temperature change in a component often indicates that a change in condition has occurred. These include bearings where the wear and improper lubrication cause rises in temperature. Other reasons could include the contamination of heat exchangers, or poorly cleaned cooling fins in an electric motor. The temperature can of course be a part of the process's characteristics. Increased load - increased temperature. Remember that intrinsic conducting in semiconductors increase with temperature.

Contact thermometers

It is very common to measure the surface temperature. There is a wide selection of contact thermometers on the market for both fixed installation and mobile use.

For hand-held (portable) models, there are a number of failure sources that have an influence such as, for example, poor heat transfer, various plant pressure and surfaces, angle fluctuations and drafts.

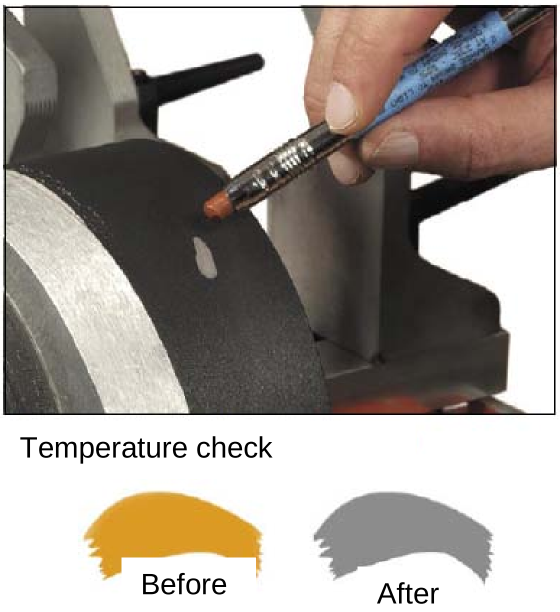
For permanent installation, this is avoided by the same “failure” always being present and by having repeatability in the readings. Contact thermometers react relatively slowly which means rapid temperature changes cannot be recorded.

Figure 3.9 Contact Thermometer

Temperature indicating tape
Temperature indicating tape is an inexpensive way of indicating temperature changes.
There are two types of temperature tape; reversible and irreversible.
Tapes are available for different temperature ranges, and there is a tape that can withstand attacks from moisture, oil, grease,
fuels, solvents, water and steam.

Figure 3:10 Temperature tapes

Temperature indicating chalks and paint
In order to determine the temperature of a surface in an easy way, you can use temperature indicating chalks or paint.
A line must be drawn and the paint checked. If the paint changes within 1-2 seconds
the surface has the temperature that is indicated by the chalk. If this happens more rapidly, the temperature is higher and if it is slower, the temperature is lower.



3.11 Temperature chalk

Temperature measurements with sensors

To measure the temperature “Online” you can use different types of temperature sensors. The most common is based on the principle that a measuring body changes its resistance following a change in temperature. For temperatures in the range of -50 degrees to +300 degrees, a Pt-100 sensor is normally used witch increase resistance with temperature. Semiconductor sensors are inexpensive and their applicability is on the rise. For measuring higher temperatures a thermocouple is frequently used where the output voltage (in mV) from the sensor increase with the temperature.

Thermography

Thermography is an inspection method for temperatures where cameras that work with Infrared light are used.
The camera generates an image of the component's radiated heat energy. Heat energy is emitted from all objects which have temperatures above absolute zero.

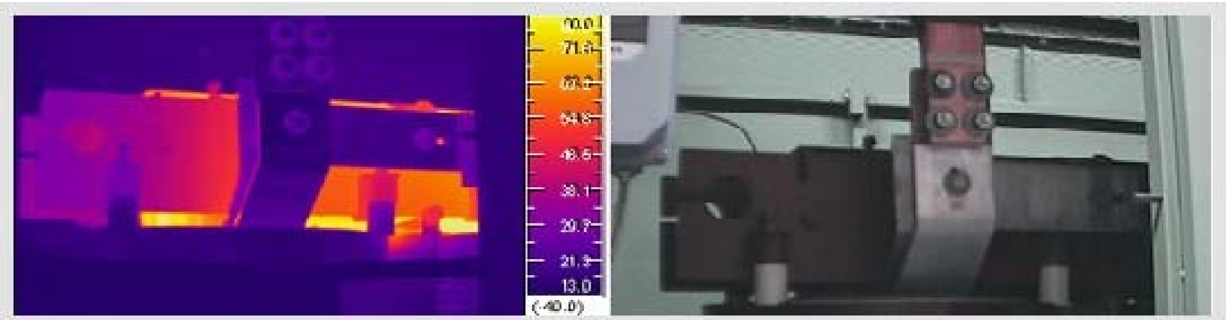


Figure 3.12 Temperature inspection busbars (Source: Flir Instruments)

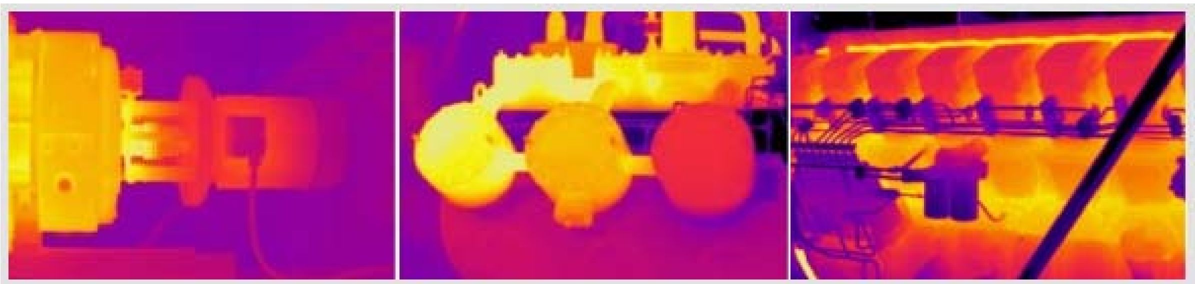


Figure 3.13 Temperature inspection combustion engines (Source: Flir Instruments)

Some applikations for IR measurements

- Rotation drives (unalignment)
- Electrical equipment during operation
- Heat exchangers
- Heat conduction through insulation
- Detection of hotspots
- Electric motors (motor and windings temperature)
- Switchgear busbars
- Contact/distribution cabinets
- Materials with very high temperatures, such as molten metal.
- Large areas where temperature differences are found, such as stoves and pipes.
- Objects with sudden temperature changes.
- Objects requiring a safe protection distance.

Visual inspections

Boroscope (endoscope)

A boroscope (endoscope) is a simple inspection method. What you need is a separate light source and light conductors to get light to the object you wish to inspect. You then simply inspect with the eye using the eyepiece.

It is increasingly common to use a boroscope where a camcorder is connected to the light-guide. You can then see the object on a display. Images/film footage can also be stored.

Figure 3.14 Boroscope with rod and light fibre


Figure 3.15 Inspection of a tank

Stroboscopes

A stroboscope is used to inspect rotating equipment or components/parts that vibrate.
By setting the stroboscope's flashing frequency to match the measuring object speed or vibration frequency, you create a visual image of the component when it is still, and you can then see any defects. From a safety aspect, it is important to understand that the object is rotating, which fools the eye.


Figure 3:16 Stroboscope

High speed video

In order to inspect the rapid sequences or movements in which the eye cannot cope with, you can use a high-speed video. There are cameras that can take 100,000 images/s
with an exposure time of 1/1,000,000/s

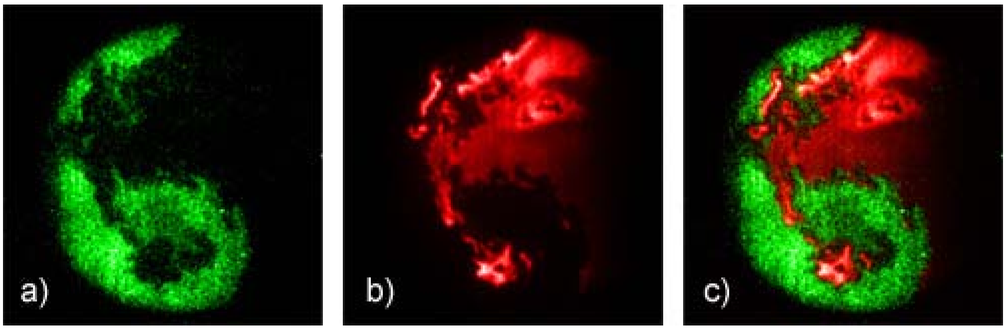


Figure 3:17 Fuel-air mixture from combustion with high speed camera.

Vibration measurement

Changes to vibration levels in a machine are often a sign of an incipient failure. For instance, when the vibration noise in a bearing increases, the temperature also rises (increased friction), resulting in the lifetime being shortened and the bearing prematurely failing.
The strength of welds and bolted joints is also affected by vibrations. Material is fatigued.

In many cases you can detect incipient failures by measuring the vibration levels, and in so doing schedule the correct maintenance operation at the right time.
Both electrical and mechanical vibrations can be measured. A poorly aligned machine (pump - electrical motor) gives rise to mechanical vibrations and changes to power consumption (electrical vibrations). Vibration measurements are a highly effective way of detecting the most common machine failures such as imbalance, structural weakness and loose components.

The developed methods are easy to apply, and you need a negligible amount of basic data. Interpreting the results can be difficult, however, which is why knowledge of the frequency patterns that occur is important.
By regularly measuring and analysing differences to the frequency pattern, you get information on the status at an early stage.

The selection of the type of vibration measurement instrument depends on the complexity of the machine, and how high the frequency measurement interval should be. There are both portable vibration meters and fixed systems for vibration measurements.

The theory behind vibration measurement is based on the principle that a vibration is *composed of a number* of different fluctuations caused by “vibration generators” inside the machine. These each generate a specific oscillation with a specific frequency (often sinusoidal).

Through mathematical treatment (Fourier analysis) the combined oscillation is divided into the various “generator frequencies”. Each “generator frequency” originates from equipment parameters such as speed, number of gear teeth in a gear wheel, rollers in a bearing and the rods in a rotor of an electric motor.

Three different failures could be found

- Equipment not static or dynamic balanced
- Defects in rotating surfaces (like cracks in bearings)
- Harmonics

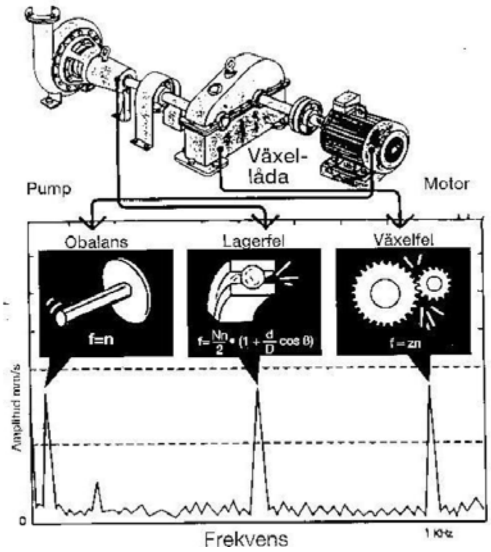


Figure 3:18 The principle for vibration measurement (Source SPM)

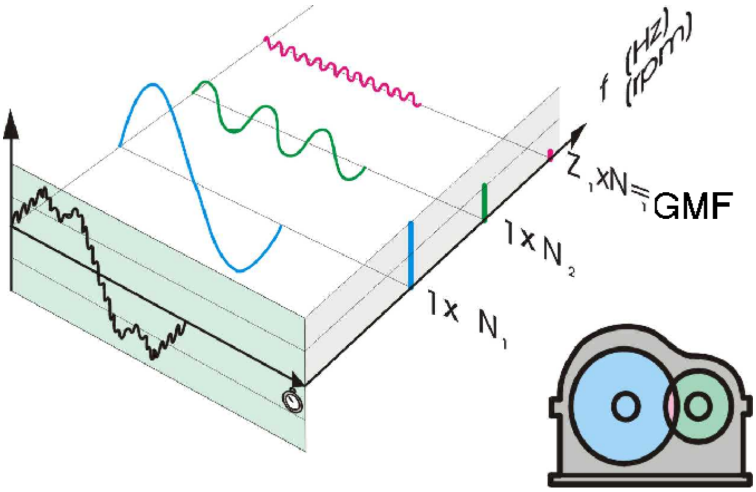


Figure 3:19 Classification of the different “generator” oscillations (Source SKF)

The classification of the complex oscillation is insufficient to be able to easily build a perception of which sub-component is the “generator”. Therefore the oscillation (y-axis = amplitude, x-axis = time) must be recalculated in a mathematical way (Fourier analysis) into something that provides more information. Following mathematical treatment you obtain the amplitude on the y-axis (as before), but the x-axis is given the unit's frequency.

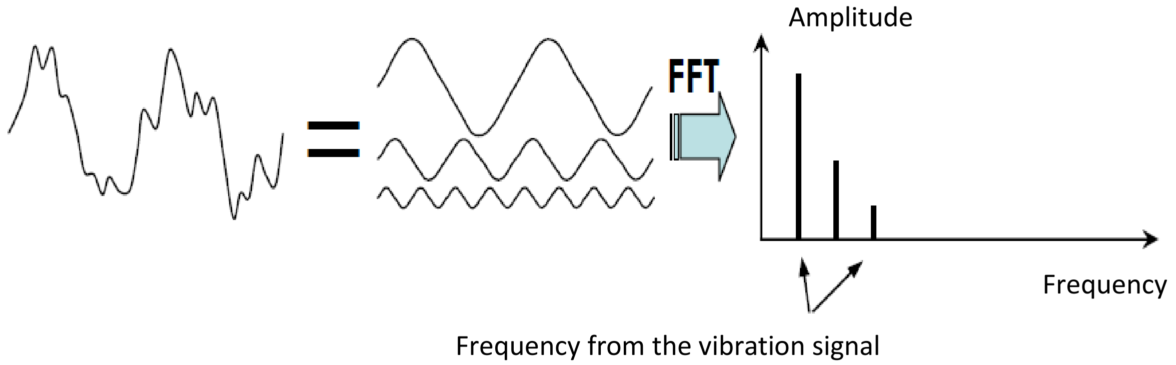


Figure 3:20 Development of a frequency curve (Source SKF)

Figure 3:21 Measuring equipment electrical vibrations (Source NEA)

A defect in a rotating system powered by electricity gives a variation in the voltages and currents that the rotating system is powered by. For a misalignment, for example, the current will then vary during a rotation (more friction/resistance to rolling). This then becomes an “electric vibration generator” that is detectable. The current/voltage is measured for these electrical vibrations on incoming cables for the operation to be inspected.

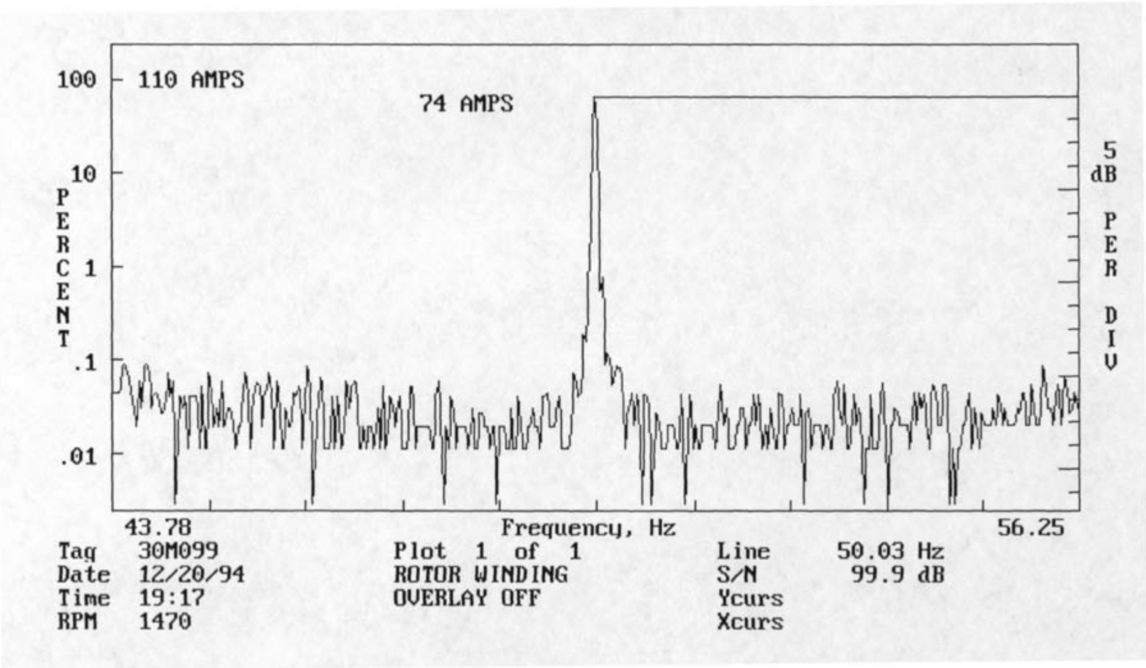


Figure 3:22 frequency curve electrical vibrations (Source NEA)

Shock pulse meters

Shock pulse meters measure the mechanical shock generated by defects such as roller bearings. These measurements provide good information about the condition of the bearing. By measuring the bearing using the shock pulse method, you can also detect common machine malfunctions. For example, a poor shaft alignment will increase the shock values for bearings. Pump cavitation causes a clear signal, as do loose parts and scrap. There are handy, portable SPM instruments available. However, it is important that you measure at the same measuring point for repeated measurements in order to ensure reproducibility. It is often the case that special measuring points are marked or indicated.

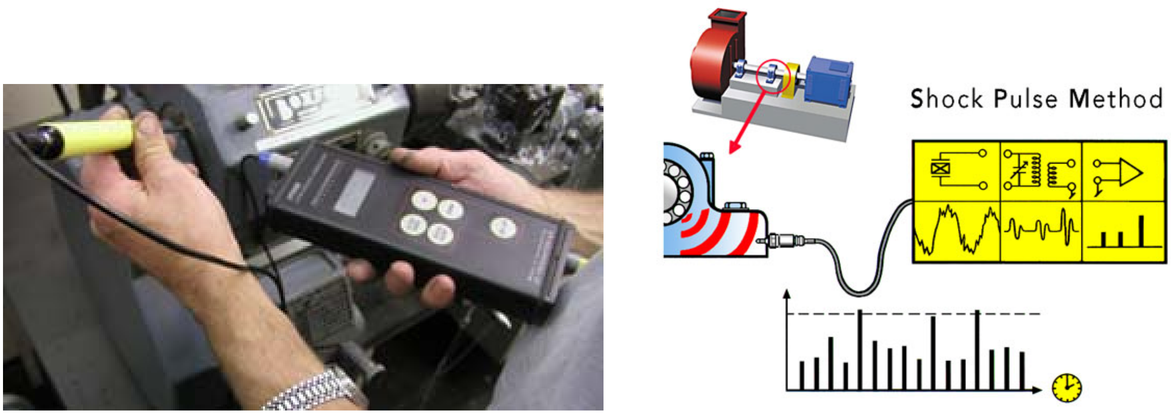


Figure 3:23 The principle for shock pulse measurement (Source SPM)

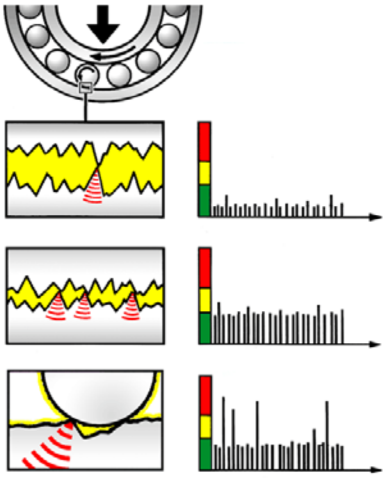


Figure 3.24 Frequency spectra following bearing damage (Source SPM)

Vibration levels

ISO 10816 specifies the recommended limits for vibration values for vibration measurements for different machine classes.
These recommendations are divided into three classes, acceptable, questionable and too high Vibration level.

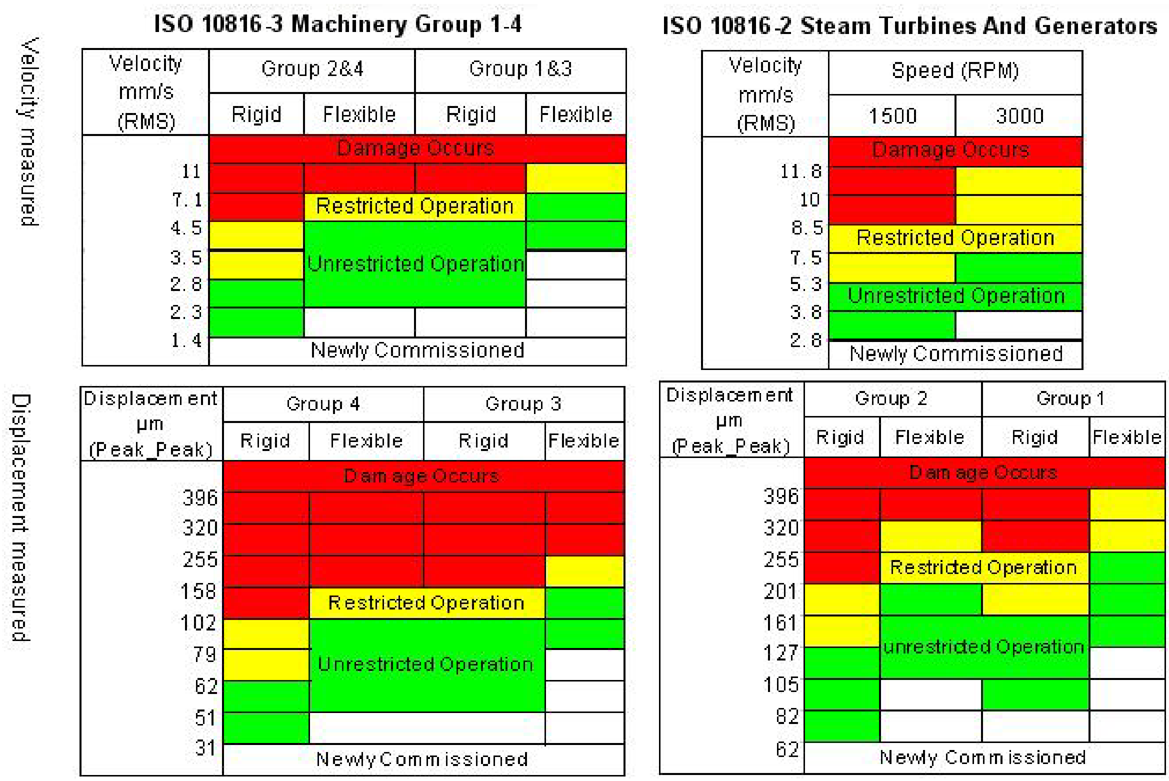


Figure 3:25 Vibration speed and vibration amplitude

.

Figure 3:26 Trend curve vibration development bearing damage

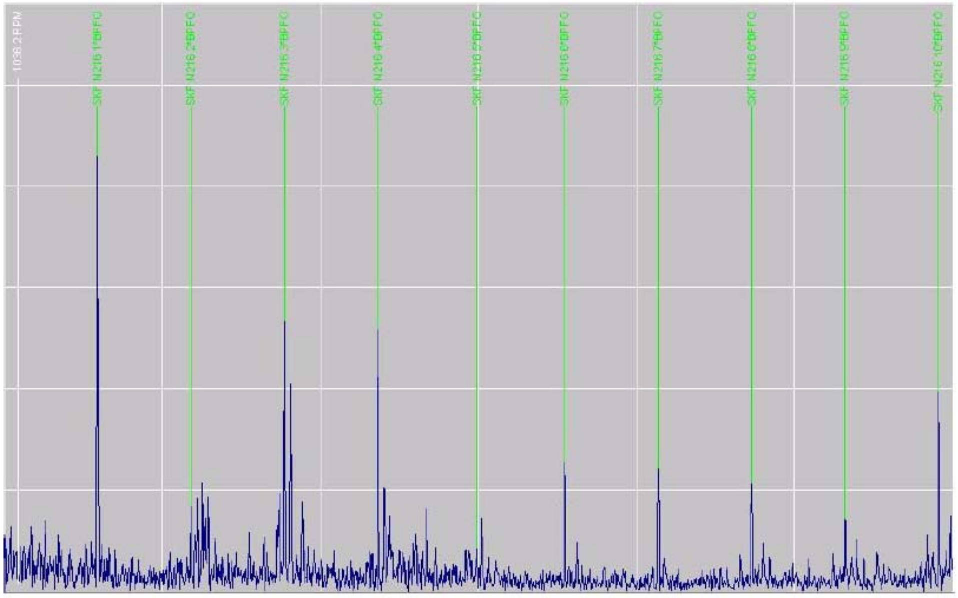


Figure 3:27 Vibration analysis

Alignment

There are four variables that are inspected for the alignment:

- Parallel failure horizontally,
- Parallel failure vertically,
- Angular displacement horizontally
- Angular displacement vertically

The challenge is to carry out alignment inspections periodically to see if any changes have occurred. Changes may be due to a bearing becoming worn or that the attachment bolts in the foundation have worked loose. If a change is detected in the vibration levels, these can often be attributed to the changes in the alignment. Previously, “clocks” were used to measure angular deviation, but today we almost exclusively use laser light for all alignment. A transmitter located on the driving unit sends a very straight and precise beam of light to a transmitter on the driven unit. Deviations in the light provide a measure of alignment.

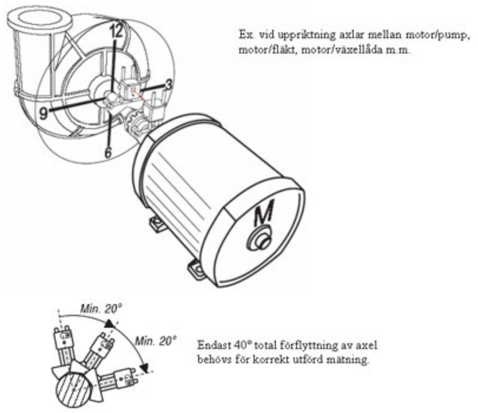


Figure 3:28 The principle for alignment

Figure 3:29 Flatness measurement of towers in a wind turbine and alignment of generator/gearbox (Source Damalini)

Figure 3:30 Location of transmitter and receiver on motor - pump unit (Source Damalini)

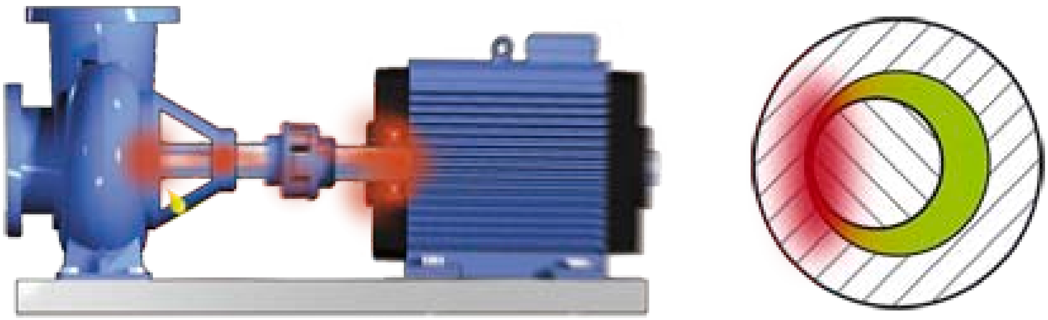


Figure 3.31 Load points at the misalignment of pump - electrical motor (Source Damalini)

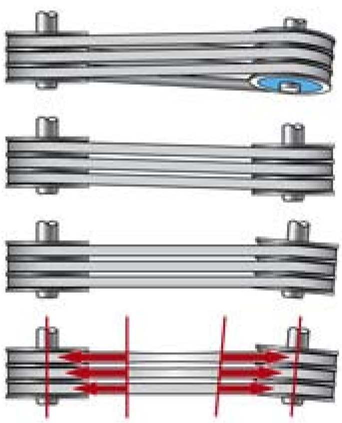


Figure 3.32 Misalignment of the belt transmission (Source Damalini)

Non-destructive testing

These are the most common testing methods:

- X-ray radiography
- Gamma radiography
- Accelerator - high energy X-ray
- Ultrasonic testing
- Eddy current testing
- Testing with penetrant
- Magnetic powder testing
- Visual inspection
- Leak detection/leak testing

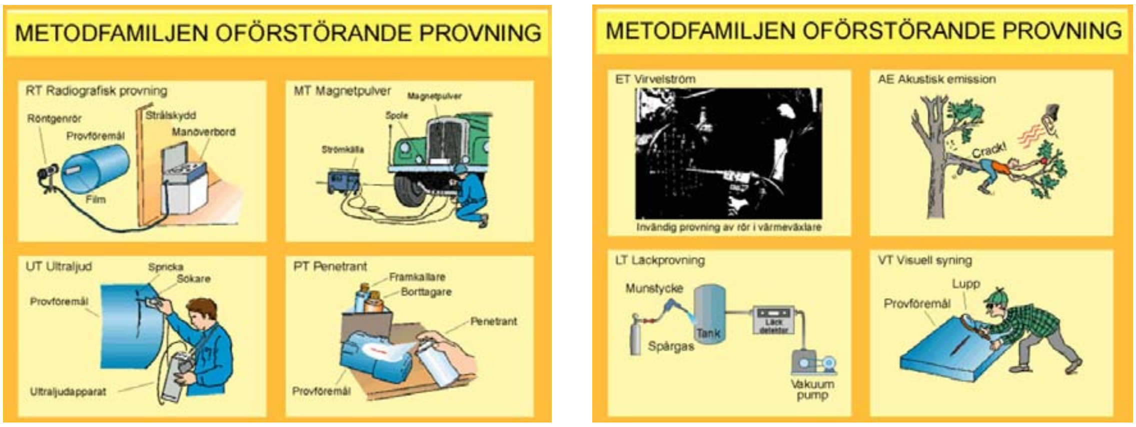


Figure 3:33 Non-destructive testing methods

X-ray radiography

For checking the welding joints and material in up to about 90 mm thick steel goods in and about 1 meter in
concrete. After passing through the object, the X-ray radiation is recorded on film. Defects
in the material appear as variations in film density and can be evaluated against the set requirements. Even
equipment for film-less (digital) technology is available.

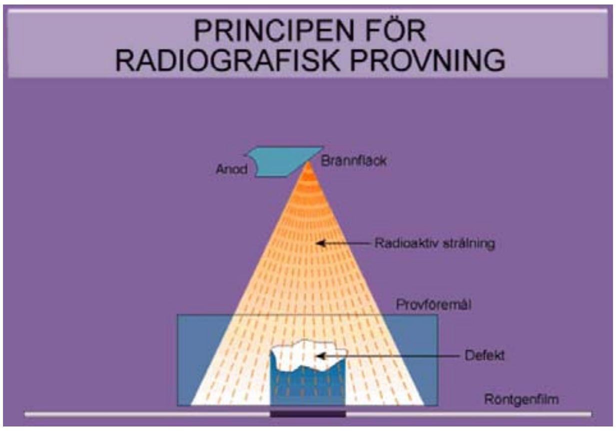


Figure 3:34 Radiographic testing

Gamma radiography

This source of radiation is radioactive isotope. The same general principle as X-ray radiography applies, but
the radiation has a shorter wavelength, resulting in a greater penetration capability. The method can therefore be used for heavier goods, up to 180 mm in steel.

Radiation source Half-life Material thickness, steel
Cobalt 60 5.3 years 40-200 mm
Iridium 192 74 days 20-100 mm
Ytterbium 169 32 days 1-20 mm

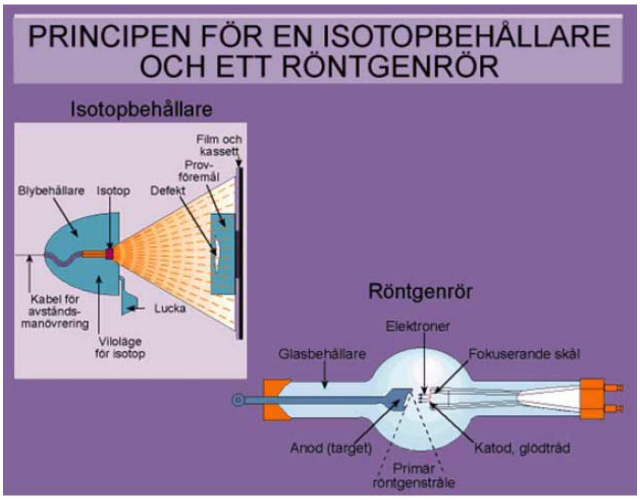


Figure 3:35 X-ray tube and isotopic source

Ultrasonic testing

A method for detection of cracks, lack of fusion and inclusions, etc., preferably in steel. The methodis based on the reflection of high frequency sound waves, much like sonar. The method is also used in thickness measurement.

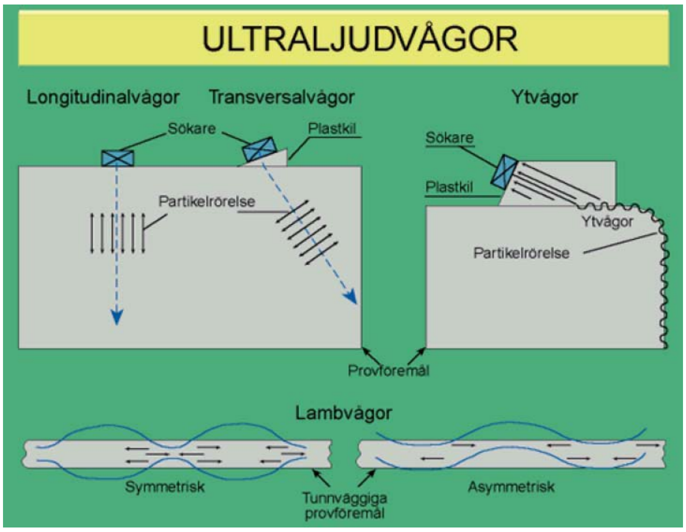


Figure 3:36 Thickness measurement with ultrasound

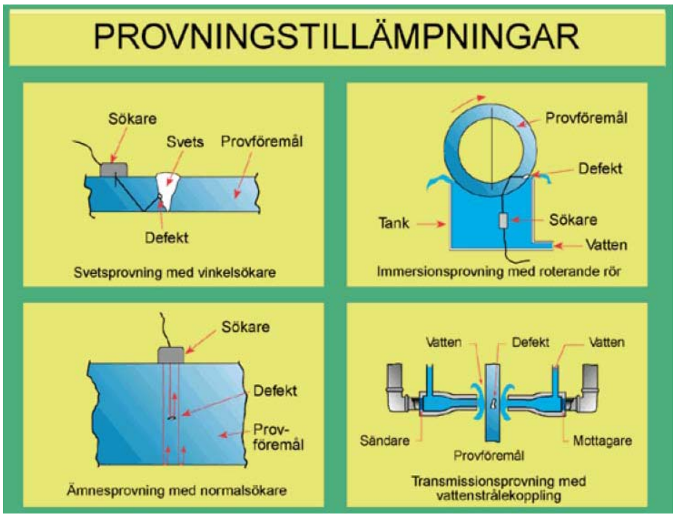


Figure 3:38 Applications ultrasound

Visual inspection

One of our most important methods when inspecting is to check that the object or component meets the set
requirements in terms of welding geometry, for example. Sometimes technicians must use aids such as different types of television cameras or mirrors to access confined spaces.

Eddy current testing

The method is based on the generation of eddy currents in a conductive material with a high frequency
current through a coil. Defects in or under the surface disturb the eddy currents, and these variations can
be measured and recorded using an instrument. The method is used for operations like surface inspection of the welds and the inspection of heat exchanger tubes with respect to erosion and corrosion damage and cracks, voids and thickness.

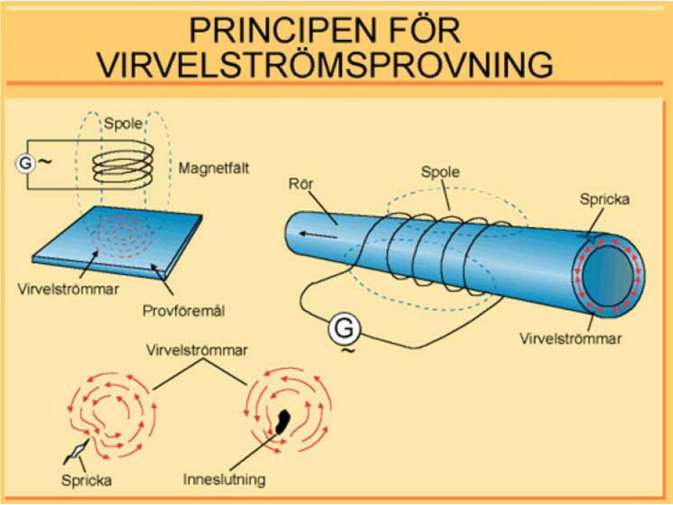


Figure 3:39 Eddy current testing

Testing with penetrant

Surface cracks can also be detected with indicating fluid, known as penetrant. The liquid is sprayed on the surface and then penetrates into any cracks. You wipe off any excess fluid and a special developer makes the cracks appear.

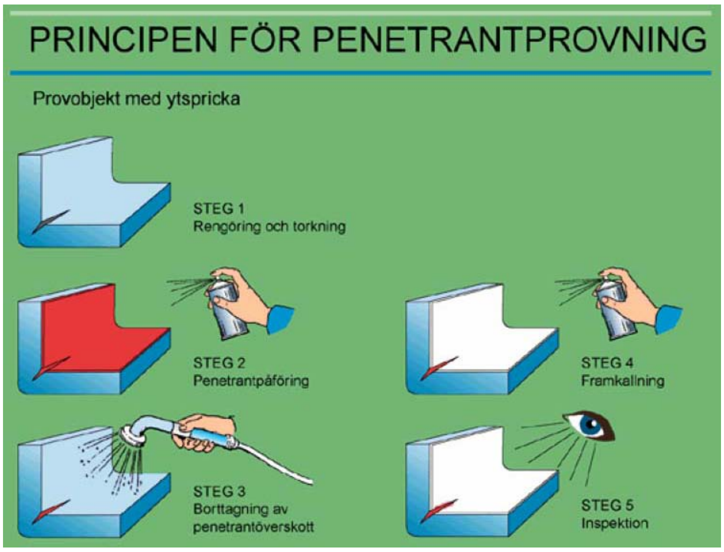


Figure 3:40 The principle for penetrant

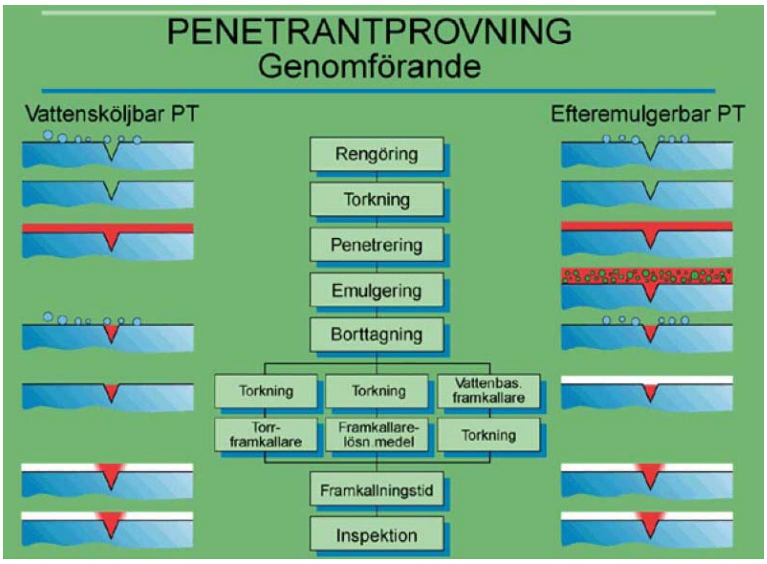


Figure 3:41 Implementation

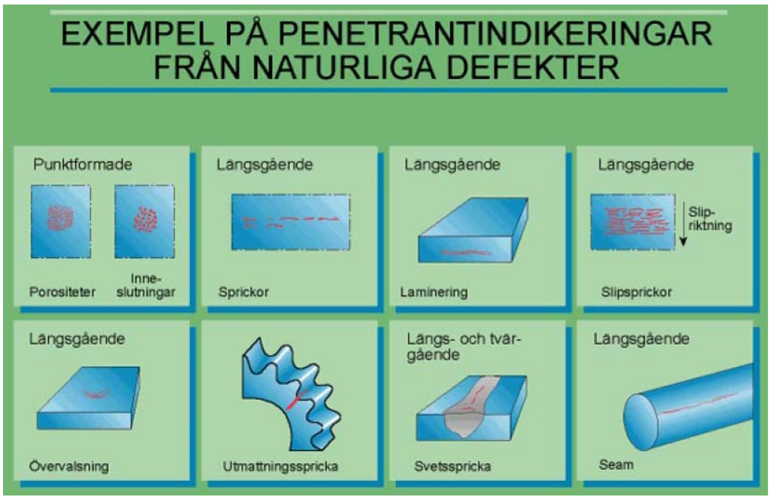


Figure 3:42 Detected defects

Leak detection/leak testing

Test with a vacuum box: Suitable for relatively large leaks. Leak detection fluid is applied to the suspected area. Via a vacuum pump, the bulk of the air is sucked out creating a pressure difference,
which can be indicated by the testing technician. In order to detect minor leaks, the object is pressurised with
an excess of helium or such like and then scanned with a sniffer-probe connected to a mass spectrometer. Leak tests are used when checking the object's total leakage. This usually answers the question whether the object is leaking by more or less than the calculated and established leak specification.

Magnetic powder testing

Used to check the surface of magnetic materials. The subject-matter is magnetised and magnetic powder spread over the surface. The powder collects in cracks and other surface defects because the magnetic field is disturbed in these places. The method detects even very small cracks.

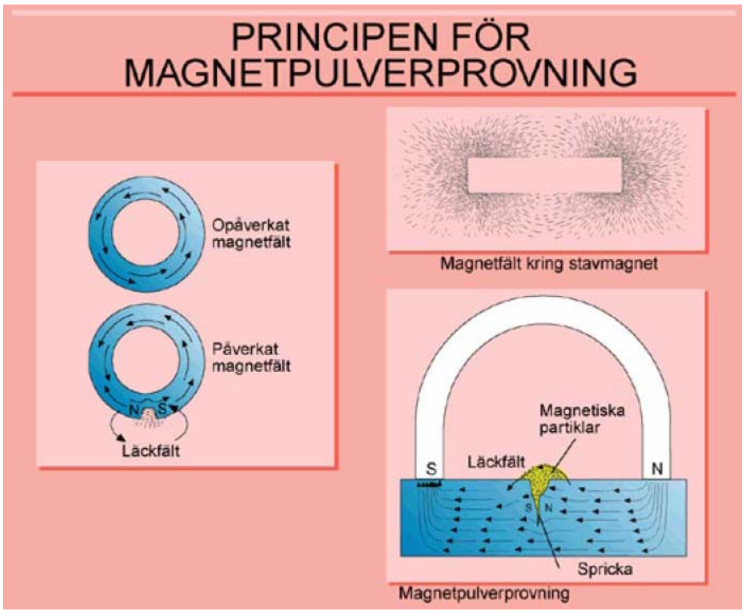


Figure 3:42 Magnetic powder testing

Failures and how failures occur.

Consider the content of the following story

Once upon a time there was a baker who baked buns. “100-gram buns cheap” said the sign in the window of his shop, for this was a clever baker who knew how to market things. His buns quickly became very popular.

One day the king himself came to the shop.
“I want one hundred buns every day,” said the King.
“Of course,” said the baker with an ingratiating grin. “They will be delivered tomorrow.”
When the buns arrived, however, the king thought they seemed unusually small to weigh 100 grams each. Has the baker sold him buns that weighed too little?

To find out, the King went to his court mathematician and wondered what he should do.
“Simple,” said the mathematician. “We put all one hundred buns on a scale, and divide the result by one hundred. Then we find out what an average bun weighs.”

No sooner said than done. The buns were weighed, and it was concluded that, on average, they weighed only 95 grams.
This made the king very angry. He went to the baker and said that unless the buns that came to the castle the next day weighed 100 grams, the dragon in the moat would eat the baker for dinner.

The baker blamed the problem on his scale, but promised solemnly that henceforth the buns would be weigh the correct amount.
When the next day's rations were collected, the king once again weighed the buns. The weight was now correct. One hundred buns together weighed 10 kg, i.e. one bun weighed on average 100 grams.

But the king was still concerned. He suspected that the baker had tried to fool him. However, the question was how.
The king went back to court mathematician and asked for advice.
“Let us do a new test,” replied the mathematician. “When you bake large quantities of buns, the sizes can vary. Some weigh 102 grams. Others 95. And some even up to 110 grams. Let us weigh each bun and display the results in a bar chart.”

The whole court spent the morning weighing buns and plotting the results on a large board.
“Aha!” exclaimed the court mathematician. “The baker has fooled us. He still bakes buns that are too small, but he picks out the biggest ones to sell to the court. Other customers buy buns that are too small.”

“How do you know this?” asked the king.

“Simple”. “The natural variation in weight between the buns should have given a normal distribution, a bell-shaped curve. But here we see only the upper part of the curve. All values less than 100 grams are missing. The shape of the curve shows that the buns average weight was only 95 grams. The buns the baker has sold to customers other than the court are too small.”

How can the above story help us understand the functional reliability of equipment and components? The baker baked buns. You could say that he engaged in mass production. Although he wanted all buns to weigh 100 grams, there was some variation in weight.

The same applies when we manufacture equipment, components and machine parts. We always try to observe a certain specification in order to have a predetermined life time but there is natural variation in life expectancy (the time when a failure occurs). This is called normal distribution.

Based on the formulated failure intensity (indicating the number of failures per unit of time) we can treat the results statistically. The outcome is usually defined in terms of a function (normal distribution function) Gauss - function or Gauss - graph.

This function specifies how an outcome of measurement points (in our case the number of failures) can be interpreted as an expected value (in our case when the failure has the highest probability of occurring). It is specified in the function below with μ.

σ in the function specifies how the spread is from the expected value, and is called the standard deviation.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

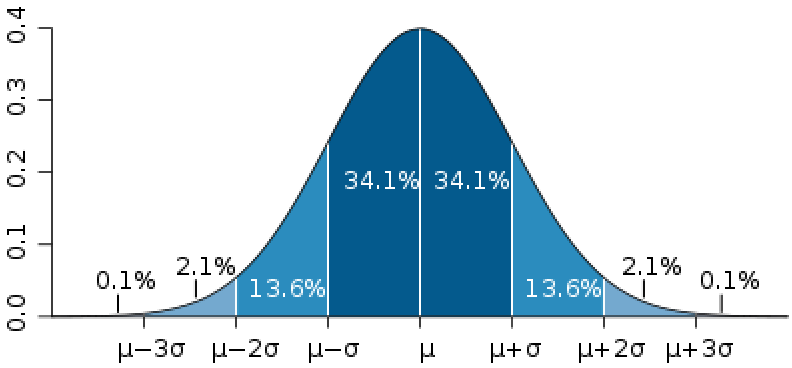


Figure 4.1: Normal distribution curve

Returning to the story of the baker, we now understand that he delivered buns “to the right” of the chart (over 100 grams)

All components, depending on how they are structured (mechanical or electrical) always have an expected value, and a standard deviation in their function during their lifetime before they breakdown (failure occurs). This in turn means that the shape of the curves varies and may look different for different components. How does our maintenance work affect the results in the chart?

For some, we can almost certainly determine the expected value, while for others it is more difficult. The Gauss curves below show the outcome for different components.

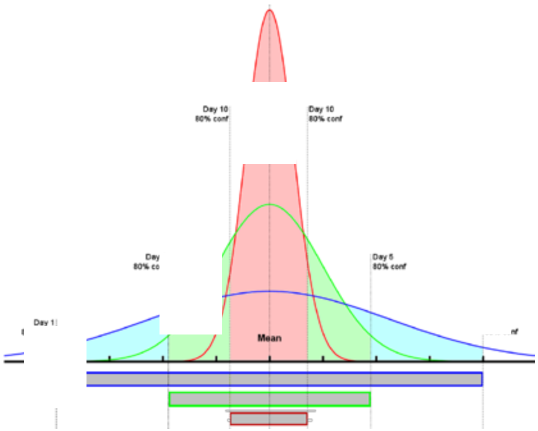


Figure 4.2: Gauss - curve for different components

If the X-axis now represents time, and the Y-axis the probability that a failure will occur, we can see that for some components the “lifetime” is well-defined (the pointed curve). This component is expected fail after a “predetermined” time. These failures are referred to as *regular* as we know they will occur with some regularity at a predetermined time.

For other components we see that the corresponding expected “lifetime” is not as well defined (flat curves). They could occur at any time. We call these failures *random or temporary failures.*

How does a failure appear when it occurs? Does it come as a bolt from the blue, or after a gradual deterioration in functionality so that the component finally fails. There is a distinction here for us to be able to easily determine the method of the failure.

A failure without warning is called *a failure without a development time*, and a failure with a warning (gradual worsening) is called *failure with development time.*

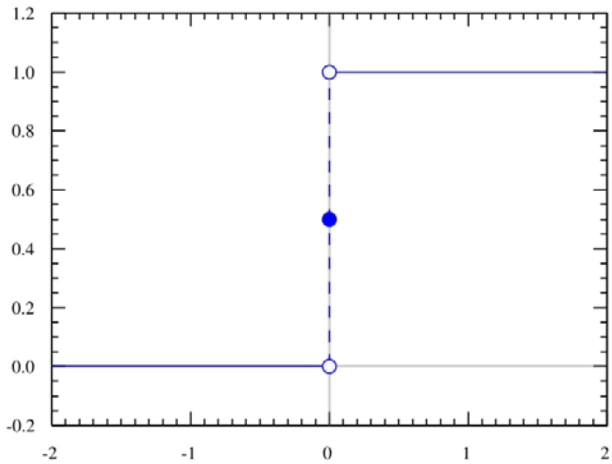


Figure 4.3 Failure without development time - step function

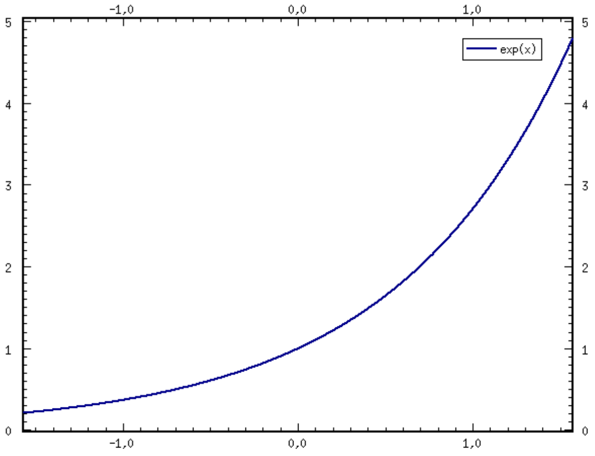


Figure 4.4 Failure with development time - exponential

The purpose of maintenance is to prevent the failure from arising and ensure that the failure does not happen again. Either through preventive maintenance and/or through modification (improvement maintenance) of the equipment (component). We have now come to the conclusion that there are two different types of failures and that they can develop in two different ways. We therefore have four variants of how a failure occurs.

1. Random failure without development
2. Random failure with development
3. Regular failure without development
4. Regular failure with development

If we now go back and reconsider the maintenance task and what tools are available to prevent the failure from occurring, we will have the tools:

A Inspection and Condition Monitoring

B Regular replacement

This now gives us the four failure cases:

- Random failure without failure development - no tools
- Random failure with failure development - inspection and condition monitoring
- Routine failure without failure development - regular replacement
- Routine failure with failure development - inspection and condition monitoring

It is essential that we do not build equipment that is part of the “red-line machinery” with components that produce random failures without failure development. Then it could be a great difficulty to maintain high operational reliability.

If it is necessary to do this, redundant systems should be installed, particularly with respect to HSE and safety systems. Various agencies such as the Work Environment Authority work on verifying that safety systems meet the demands set for high functionality.

We have previously also studied how maintenance impact on functional reliability. Each action (both in operation and maintenance) on a piece of equipment has an impact. In most cases of a component's early demise (shortened life time), the origin is “human error”.

To achieve high operational reliability, it is important to choose the right maintenance practices (best practice), i.e. those that do not affect the equipment or components. Select inspection and condition monitoring wherever possible. Do this, if possible in real time (uptime) and make no routine replacements in advance to be in the safe side.

How this pan out in reality? Is our discussion right? Below are the various failures distributed in a SCADA - system. Which of these failures are random and regular with and without development time?

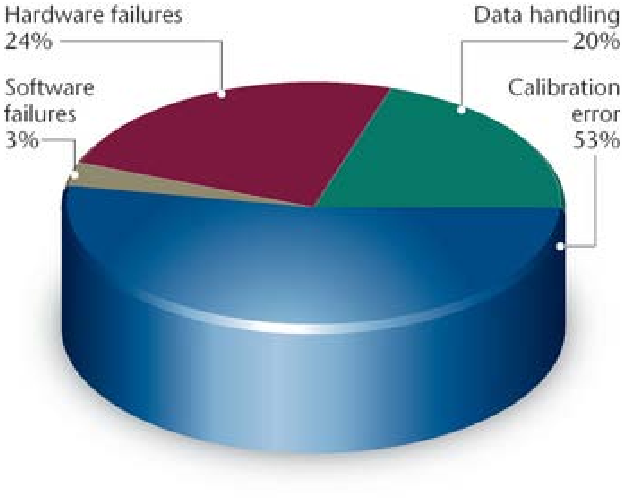


Figure 4.5 Failure distribution - SCADA - System

Figure 4.6 Failure types?

If we look at roller and ball bearings, the life time is specific to a time interval where 90 % of all bearings of a certain type and a given load “survive”. The figure below shows a very different picture of reality. Only 9 % of the mounted bearings achieve their predicted lifetime. How can we improve the statistics/results, so that more bearings “live longer”?

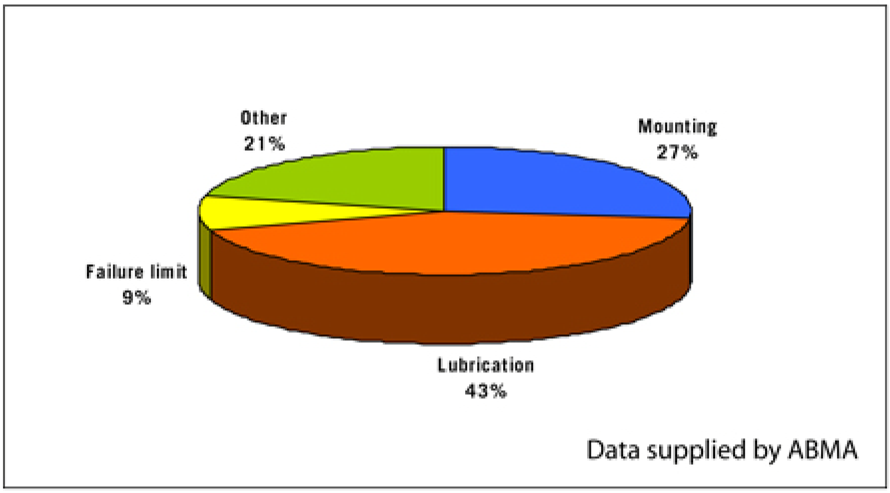


Figure 4.7 Failure distribution, bearings

When performing maintenance work properly and with quality it´s a must to ensure the various components are able to live their expected lives. Failures are frequently blamed on overloading, overheating, bad designs, etc. But if you think this is true, study the statistics below taken from a manufacturing company.

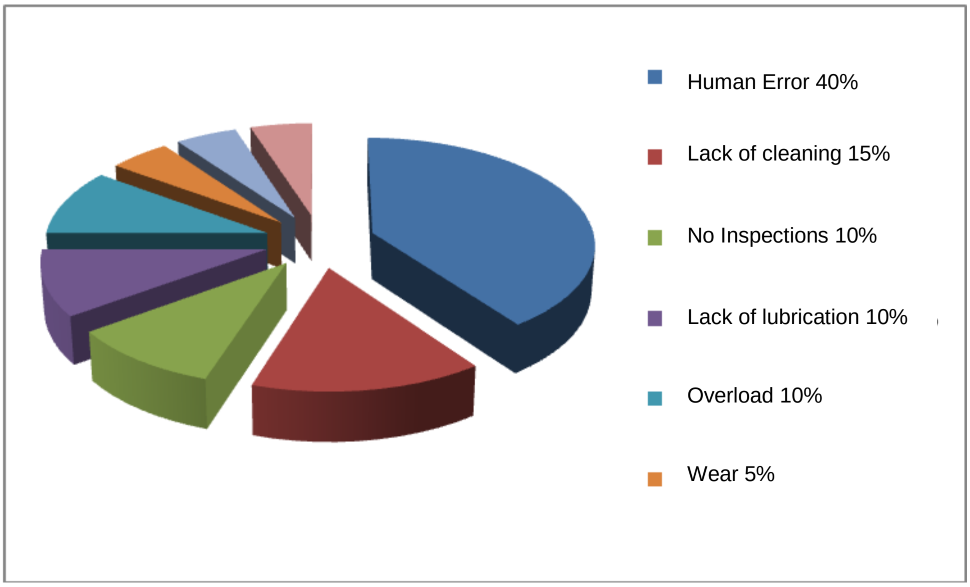


Figure 4.8 Implemented failures

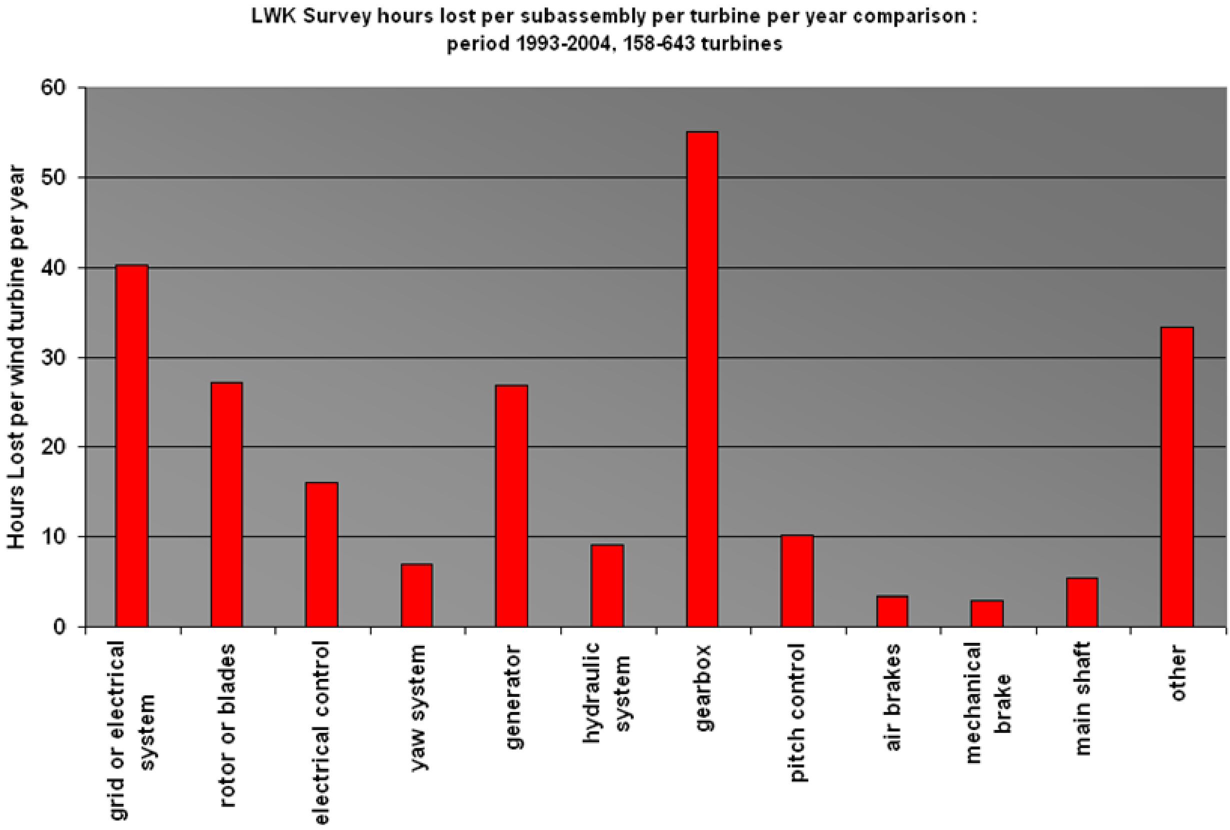


Figure 4.9 Malfunctions or implemented failures - that is the question

How do we react in order to avoid implementing failures during operation and maintenance work? We use condition monitoring of course, but for repairs and regular replacements we have to dismantle and reassemble. Then you have to think before you act, and study the workshop or repair manual.

Think beyond Repairs (TBR)

Prevent problems -think before you act. Analysing potential problems is a good way of avoiding future operational disturbances. This analysis can be used to plan the day to day work in a systematic way to find and fix recurring problems and above all, improve safety before, during and after maintenance work.

You can use the following steps in an analysis, regardless of area:

- What are the possible problems? What can go wrong?
- What are the possible causes?
- What can I do to prevent this problem?
- If the problem occurs, what can I do to mitigate the consequences?
- Revise working method/plan

It is often worthwhile to prepare a schedule to prevent the problem.

Possible problems	Possible causes	Measures to prevent problems	Measures to mitigate the consequences

In addition to the above analysis of the possible problems that can often be complex, a fault tracing schedule is used. Here we work gradually towards finding the cause of the problem. This fault tracing schedule has its origin in a failure tree analysis.

Failure analysis

TBR is a simplified version of a method known as “fishbone” (the Ishikawa - method). A tool that helps you to understand the reasons that affect a particular issue or a problem.

Possible applikations

- Clarifies the factors influencing a problem.
- Creates a snapshot of the collective knowledge and consensus in a team regarding a problem.
- Displays the root causes, not the symptoms, and is thus an excellent basis for resolving the problem.
- Characterises different cause types.
- Clarifies the data that must be collected to show the root cause of the problem.

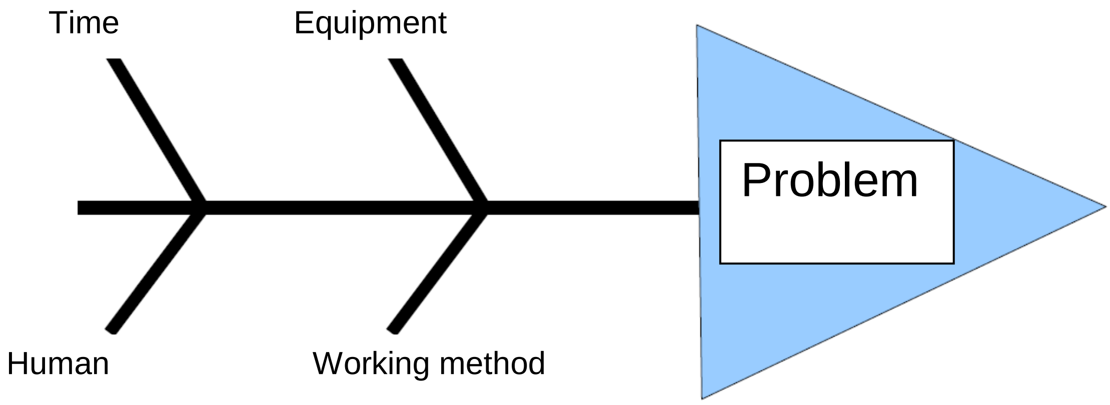


Figure 4:10 The Ishikawa - method

Procedure

- Write down the problem description to the right of the diagram.
- Specify the main groups that you think are the cause of the problem. Label the major bones of the fish with these groups. Examples of these main groups can be: methodology, equipment, human, organisational, environmental, personnel, modes of operation, training, equipment, facilities, etc. This categorisation will be an aid to use in the current situation.
- For example, use brainstorming to identify possible causes. Remember to look for causes not solutions!
- Put ideas in the appropriate main group, either directly when they are mentioned or only when the full list has been agreed. Think about whether you have chosen the right main groups for the problem?
- Ask the question “Why?” for each cause, in order to progressively identify the root causes.
- Search for the root causes of the problem by looking for causes that appear repeatedly in different main categories. There may be multiple root causes to a problem.
- Collect and analyse data so that you can decide how much this affects the various causes. Enlist the help of other tools to determine if you have found the right cause to the problem.

Mechanical components and systems work under different physical conditions. Some parts of a company's equipment require a dry environment, for example, while others must be carefully designed to satisfy strength requirements.

Each system can be considered as individual. Different types of systems have different operational reliability problems and, consequently, different functional reliability depending on system solutions and component selection. In addition, location is an important factor for the various operating times, weather conditions and climate.

Operational reliability measures must therefore be customised. These measures can often be implemented without prior analysis. In some cases, however, an analysis of operational reliability problems is necessary before any concrete actions can be specified. This applies to both design and construction as well as for improvement maintenance.

When systematising the methods for improving operational reliability you also standardise the failure causes and failure types. We have identified the seven simple and practical standard areas for improving operational reliability below.

Seven standard measures for improving operational reliability:

- System design
- Monitoring
- Component design
- Environmental improvement
- Quality control
- Maintenance
- Instructions for handling

Failure Mode and Effect Analysis

FMEA, Failure Mode and Effect Analysis, is a useful tool for design work and the systematic and detailed approach to preventive maintenance. Note that we will have also taken into account here what the effect of failure may be on the process/plant.

The analysis aims at identifying key failure sources through the systematic review of possible failure modes at a component level and detail level. These sources may have an engineering origin or be a handling fault during regular operation or maintenance work.

Using FMEA you can assess a design from a functionality reliability aspect more easily and also prioritise possible actions to reduce the impact of failures and/or the likelihood of their occurrence.

The Failure Mode and Effect Analysis is partly qualitative without any kind of quantification, i.e. numerical information, of the degree of severity of failure probability and therefore serves, among other things, as a check to ensure the design does not contain any unexpected possibility of failure.

The analysis method is well tested and has a major benefit in that you are forced to deal with the idea that failures will occur. Below is an example of the analysis framework.

SYSTEM SAMPLE
SUBSYSTEM
SUBSYSTEM ELEMENT
PREPARED BY
APPROVED BY
DATE
REVISION
PAGE 1 OF 1

Item Identification	Function	Failure Mode	Failure Cause	Failure Effect on: Component or Functional Assembly	Failure Effect on: Next Higher Assembly	Failure Effect on: System	Failure Detection Method	Remarks
Switch	Initiates Motor Power Function	Fails to Open	Release Spring Failure Contacts Fused	None	Maintains Energy to Circuit Relay	Maintains Energy to Pwr Circuit Through Relay	Motor Continues to Run Smoke-Visual When Pwr Circuit Wire Overheats	
Battery #2 (Relay Circuit)	Provides Relay Voltage	Fails to Provide Adequate Power	Depleted Battery Plates Shorted	None Battery Gets Hot and Depletes	Fails to Operate Relay Circuit	Systems Fails to Operate	Motor Not Running	
Relay Relay Coil	Closes Relay Contacts When Energized	Coil Fails to Produce EMF	Coil Shorted or Open	Does Not Close Relay Contacts	Does Not Energize Pwr Circuit	System Fails to Operate	Motor Not Running	
Relay Contacts	Energizes and De-Energizes Pwr Circuit	Fails to Open	Contacts Fused	None	Maintains Energy to Motor	Overheated Pwr Circuit Wire if Motor is Shorted and Circuit Breaker Fails to Open	Motor Continues to Run Smoke-Visual	
Motor	Provides Desired Mechanical Event	Fails to Operate	Motor Shorted	Motor Overheats	High Current in Pwr Circuit	Overheated Pwr Circuit Wire if Circuit Breaker Fails to Open and Switch or Relay Fails	Smoke-Visual	
Circuit Breaker	Provides Pwr Circuit Fusing	Fails to Open	Contacts Fused Spring Failure	None	Maintains Pwr to Motor if Relay Contacts are Closed	Maintains Energy to Motor	Motor Continues to Run Smoke-Visual	
Battery #1 (Pwr Circuit)	Provides Motor Voltage	Fails to Provide Adequate Power	Depleted Battery Plates Shorted	None Battery Gets Hot and Depletes	None	System Fails to Operate	Motor Not Running	

Figure 4.11

Fault tree analysis (a variation of the fishbone method)

A Fault Tree Analysis (FTA), is an analytical method, where a failure of a component or system is examined in stages to identify subordinate events, or combinations thereof, which may cause failures in the overall system.

In order to make the method systematic and visual, you use a logical technique chart with symbols for “AND” (all input events required for superordinate event to occur) and “OR” (one of several events required for a superordinate event to occur).

If a risk of failure of the input components is known or can be estimated, the overall risk of system failure is calculated using logical algebra (Boolean) .

A qualitative fault tree analysis should be used in cases where you suspect a combination of a number of base failures and any external influences that might cause a system failure with serious consequences. The development work should thereby be given enough time to ensure the system or design drawings have been prepared, while the product or system's immediate environment is known.

Metallic materials

What are metallic materials? The “Periodic system” includes a number of substances known as metals. There are different components or systems herein that are called metallic materials.

Each single application places different demands on the material used. It has therefore been considered appropriate to divide the materials into different groups according to their use.

The development of the Swedish metal standards was undertaken by the *Swedish Metal Standards Centre* (MNC), which is connected to the Swedish Standards Institute (SIS). The number of standard grades of steel has increased over the years. Qualities belonging to the same group have been combined.

It is important to know that for each product/quality there is a standard sheet listing the set requirements together with specific information about heat treatment, welding, etc.

Steel is an atomic compound basically between iron (Fe) and carbon (C).

Different types and grades of steel products are available through “beta” steel with compounds such as chromium (Cr).

Steel

The element iron (Fe) is the main ingredient in steel. In normal structural steel, the carbon content is at most 0.20-0.25 %. One of the reasons is that the steel must conform to normal welding requirements.

Steels used for tool usually has a carbon content between 0.7 and 1.2 %. Pig iron, which the steel is produced from, has a carbon content of between 3 and 5 % which means that it is brittle and cannot be forged. Therefore normally there is a need to reduce the carbon content by means of different refining processes in furnaces where a number of contaminants are also expelled through oxidisation.

The steel is produced in blast furnaces with temperatures exceeding 1500 ^{O}C, and by exposing the produced steel to a range of thermal processes, its properties can changed.

By heating the steel to a temperature that is above the *recrystallisation* limit for 15-20 minutes, and then allowing it to cool in air there will be produced steel with a fine grain structure and with a greater resistance to brittle fracture.

There will be a steel with a high hardness, if you heat it up to a *conversion temperature* which varies depending on the carbon content (900-750 ^{O}C) for a carbon content of between 0.15 and 0.9 % and then rapidly cool it in water or oil.

This process is called *hardening*. After this process, stresses may arise in the material but you remove these by *oxidising* or *tempering* the steel in a temperature up to 700 ^{O}C.

Other tensions, residual stresses, which may arise from uneven heating or welding are minimised by using *thermal stress relief* to 500-600 ^{O}C. At high operating temperatures, the steel's properties reduce dramatically, at 500 ^{O}C a halving of the tensile strength occurs so for example a steel structure fails relatively quickly in a fire after just a few minutes.

Steel alloys

Sulphur and *phosphorus* are regarded as steel contaminants. *Sulphur* increases the risk of disintegration when welding and *phosphorus* makes the steel brittle.

Silicon is recognised as a deoxidant, i.e. it binds oxygen during production. *Manganese* determines together with the *carbon content* the weldability of the steel, but where *Manganese* increases the steel's toughness, *carbon* increases the material's hardness.

Generally the greater the presence of *manganese* and *carbon* the higher the strength but the lower the weldability.

Both alloy and non alloy steel is classified in the material tables in different terms, such as density, Poisson's ratio, and elasticity module. Steel stress and strain relationships are often interesting topics, and as early as the 17th century these were classified by R. Hooke (1635-1703) in the Hooke Law, “Out Tensio Sic Vis” as he put it in Latin, “As the tension, so the force” (1). With these words you actually describe a material's elastic properties. When tensioning, the linear range corresponds to up to R_p (σ_P), proportionality limit, see figure 5:1.

$$\sigma = E\varepsilon \qquad (1)$$

Soft steel

A material stress-strain curves contain a wealth of information. Tension is expressed as (2) and strain as (3). The tensile yield limit for soft steel with low carbon content is typically, σ_s, which is the tension at which the material begins to flow; the material undergoes plastic deformation. You usually divide the tensile yield limit to upper, R_{eH} (σ_{yu}), and lower yield limit, R_{eL} (σ_{yl}), see figure 5:1.

Load speed is crucial for the upper yield limit which is why the lower yield limit, which is more representative, is determinative in Sweden. Floating strain takes place during the floating stage, ε_f, which is also recorded as somewhat dependent on the strain speed. If the steel is under further stress, it eventually reaches breaking point which is the greatest load that the test piece can absorb.

A distinction is made between true breaking stress, R_m (σ_B) (4) and technical breaking stress, f_{st} (5). Breaks occur during breaking strain, ε_B. For circular cylindrical test pieces with a diameter *d* are used according to practices for measuring lengths *L=5d* and *L=10d*. The corresponding breaking strain or break elongation is then noted as A_5 (δ_5) and A_{10} (δ_{10})respectively. Breaks occurs if the material's internal forces are not able to maintain equilibrium in a section.

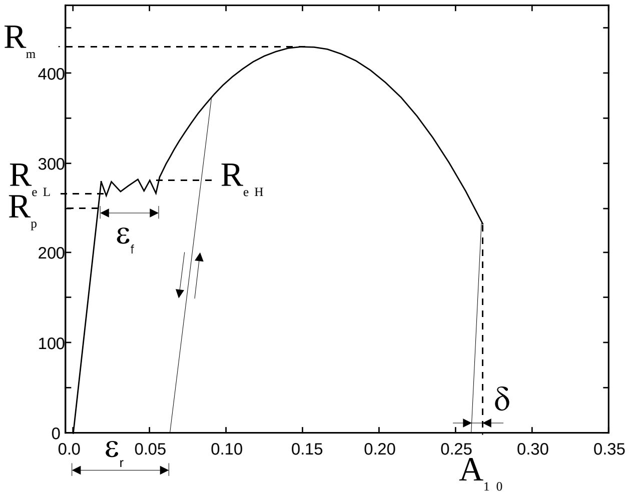


Figure 5:1 Stress - strain curve for hot-rolled steel

After the breaking stress is reached, the cross-sectional area decreases so sharply that for continued strain the load can drop and deformation has therefore begun and cannot stop before breaking. A_0 is the initial cross-sectional area and A_B is the break area. δ is the elastic springback after the break.

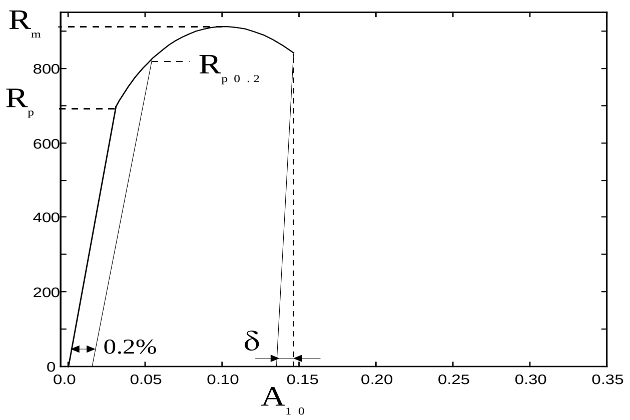


Figure 5.2 Stress - strain curve for cold finished steel

$$\sigma = \frac{F(\varepsilon)}{A(\varepsilon)} \tag{2}$$

$$\varepsilon = \frac{L - L_0}{L_0} \tag{3}$$

$$R_m = \frac{F}{A_B} \tag{4}$$

$$f_{st} = \frac{F_{\max}}{A_0} \tag{5}$$

The ratio between area change and the original area is known as break contraction, *Z* (ψ).

$$Z = \frac{A_0 - A_B}{A_0} \tag{6}$$

Cold finished steel

Immediately next to the proportionality limit is the elasticity limit. If this stress is exceeded, the material undergoes plastic deformation and during relief the material will not fully return to its previous length. The return has, however, an almost completely elastic appearance despite the remaining offset yield stress, ε_R. When stress is added, the stress-deflection curve follows its previous path, the steel will remember its history and follows the curve that would have occurred if no relief had taken place.

Cold-processed materials can be loaded so that the floating strain is exceeded and then the steel is relieved. The material that is now created has different properties and, according to earlier reasoning. completely lacks a tensile yield limit and floating area, but you still tend to characterise a tensile yield strength, offset yield stress limit that normally corresponds to a strain of 0.2 % (7).

$$0.2\% = \frac{\Delta L}{L} \tag{7}$$

The offset yield stress is usually known as $R_{p0.2}$ ($\sigma_{0.2}$), see figure 5:2. The advantage of cold finishing is that both the tensile yield strength and breaking point are increased, but the breaking strain reduces which means that the steel can be considered as brittle.

Material

The nature of the break depends on a number of material parameters such as external circumstances. External circumstances include load type, which determines the stress state and load rate. The tensile test has a relatively low strain speed, <100 MPa/sec, which does not have any significant impact on the results. At higher speeds the tensile yield strength is significantly affected, which increases, but the breaking point is about the same. Other factors include the material's production and post production and the presence of cracks. Parameters are usually given in the collection of statistical tables as *characteristic strength* and must be converted into *dimensioning strength* using a number of safety factors that depend on the application.

Material data

For example,a test piece as shown in figure 5.3 are tensioned to breaking point in a tensioner figure 5:4. Material data is given in the table.

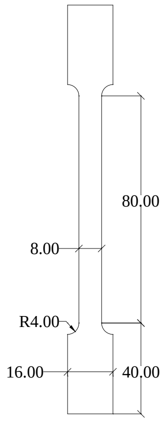


Figure 5.3 Test piece dimensions

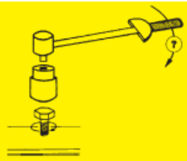
Figure 5.4 Tensile test piece equipment

Designation	C (%)	Si (%)	Mn (%)	R_{eL}	$R_{p0.2}$	R_m (MPa)	E (GP)	ν	ρ (kg/m^3)	A_{10} (%)	Z (%)
SS 1312-00	0.12	0.2	0.5	210	-	360-460	206	0.3	7850	>25	70
SS 14312-06	0.12	0.2	0.5	-	>290	630-730	206	0.3	7850	>7	46

By using tensioning and the materials memory there is a way to make stronger attachments fastens with screws and bolts. This is well known by using a torque spanner. Figure 5:5 shows the recommended torque for a certain bolt diameter.

Åtdragningsmoment för skruvar i olika hållfasthetsklasser.

Uppgifterna är endast riktvärden för val av momentnycklar, (För att fastställa exakt åtdragningsmoment krävs även uppgifter om friktionsförhållanden, anläggningsplan, förspänning, ytbehandling, smörjtillstånd etc,



Millimeter-skruvar. Åtdragningsmoment i Nm

Gänga M	Nyckelvidd mm	Hållfasthetsklass 4.6	5.8	8.8	10.9	12.9
1,6	3,2	0,065	0,10	0,17	0,24	0,29
1,8	3,2	0,096	0,16	0,25	0,36	0,43
2	4	0,13	0,22	0,35	0,49	0,58
2,2	4	0,17	0,29	0,46	0,64	0,77
2,5	5	0,26	0,44	0,70	0,98	1,2
3	5,5	0,46	0,77	1,2	1,7	2,1
3,5	5,5	0,73	1,2	1,9	2,7	3,3
4	7	1,1	1,8	2,9	4,0	4,9
4,5	7	1,6	2,6	4,1	5,8	7,0
5	8	2,2	3,6	5,7	8,1	9,7
6	10	3,7	6,1	9,8	14	17
8	13	8,9	15	24	33	40
10	16	17	29	47	65	79
12	18	30	61	81	114	136
14	21	48	80	128	181	217
16	24	74	123	197	277	333
18	27	103	172	275	386	463
20	30	144	240	385	641	649
22	34	194	324	618	728	874
24	36	249	416	665	935	1120
27	41	360	600	961	1350	1620
30	46	492	819	1310	1840	2210
33	50	663	1100	1770	2480	2980
36	55	855	1420	2280	3210	3850
39	60	1100	1830	2930	4120	4940
42	65	1860	2270	3640	5110	6140
45	70	1690	2820	4510	6340	7610
48	75	2040	3400	5450	7660	9190
52	80	2620	4370	6990	9830	11800
56	85	3270	5440	8710	12200	14700
60	90	4050	6750	10800	15200	18200
64	95	4900	8170	13100	18400	22000
68	100	5910	9860	15800	22200	26600
72	105	7060	11800	18800	26500	31800
76	110	8340	13900	22200	31300	37500
80	115	9770	16800	26100	36600	44000
85	120	11800	19600	31400	44200	53000
90	130	14000	23400	37400	52700	63200
95	135	16600	27600	44200	62200	74600
100	145	19400	32300	51700	72700	87300

Figure 5.5 Recommended torque

In figure 5:5 there is a column giving the bolt quality (strength class). For example a bolt with class 10.9 means:

σ_B = 10 x 100 N/mm^2 = (stress at break) = 1000 N/mm^2

σ_s = 0.8 x 1000 N/mm^2 = (floating stress point) = 800 N/mm^2

When tightening a bolt with a torque spanner, the stress in the bolt is depended of the friction in the threads and underneath the head. This means that there will be a difference in stress regarding using lubrication or not.

To get a more precise stress (and elongation) in the bolt a hydraulic tensioner (figure 5:6) can be used instead.

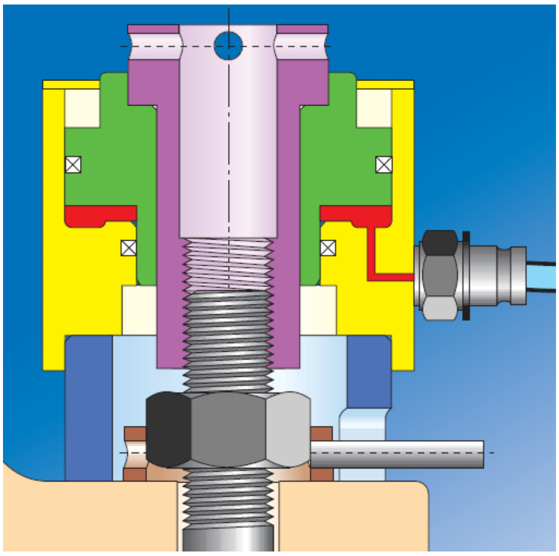


Figure 5:6 Hydraulic tensioner

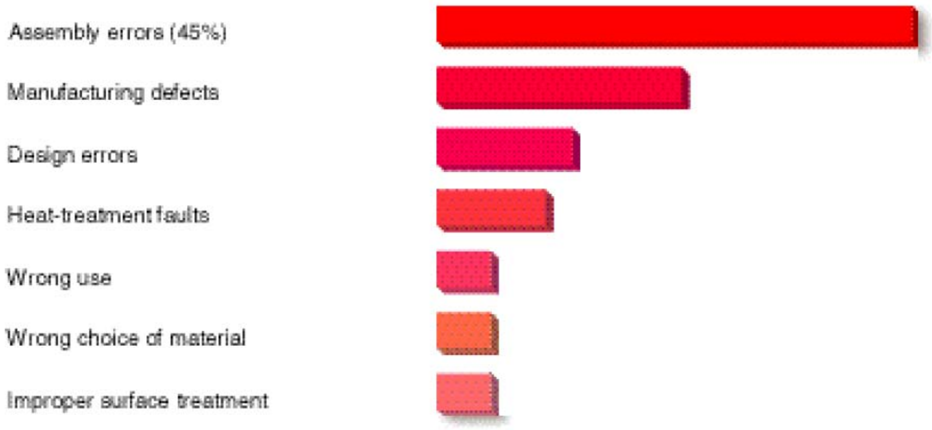


Figure 5:7 Errors in bolt stress

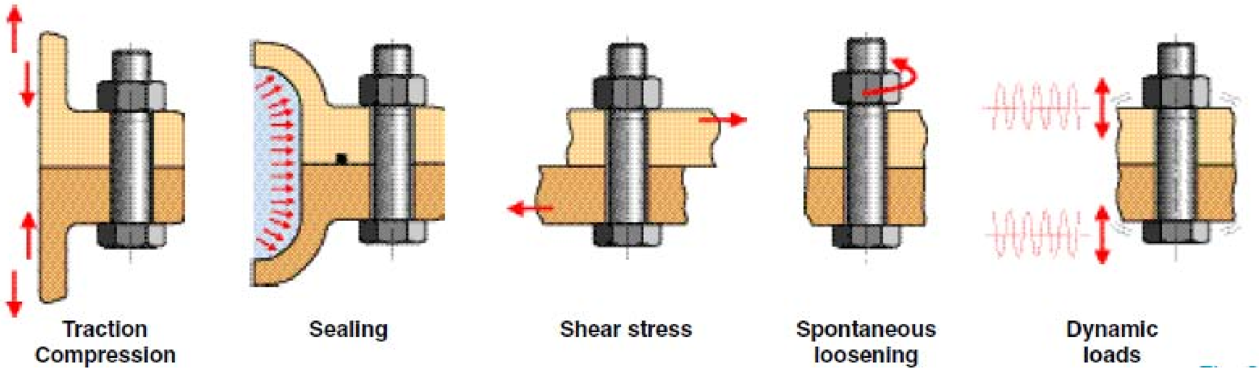
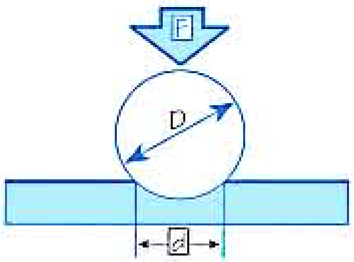


Figure 5:8 Various loads at bolt assemblies

Hardness

The ball testing method is still the principle method for testing the hardness of metals today. The hardness is measured in Brinell hardness (HB) and is calculated by adding a steel ball with one centimetre in diameter that is pressed against the metal to be tested with a force of 30,000 N. The force is then divided by the area of the ball impression. The results provide information on the hardness of the metal.



$$HB = \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})}$$

Figure 5:9 Brinell test

Another way to determine the hardness is to carry out a “Rockwell” test. Here we use a diamond prism at a specific size and do it in the same way with an “impression” in the metal.

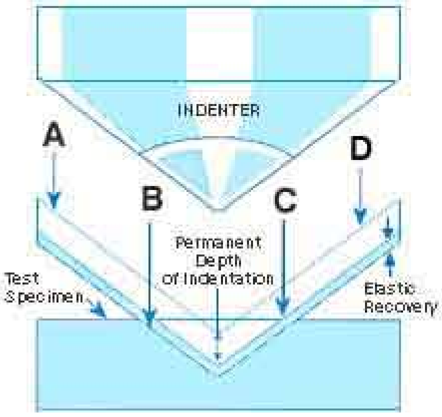


Figure 5:9 Rockwell test

To improve the properties of the metal, for example, to get a hard surface but a soft and tough core, you can harden (surface treatment by heating/cooling) the material. Examples of components of this type are gear wheels and shafts.

Other alloys

The term alloy is the generic name for metallic forgings with a minimum of two components of which at least one is a metal. Many technologically important materials are alloys, such as bronze (copper + tin), brass (copper + zinc).

Production is normally done so that the components are fused together, or also dissolved with the requisite additive metal in a pre-melted main component. Another way is to sinter the powder together.

One condition for forming an alloy is that the components are soluble in each other in a particular temperature range. This is not always the case. Iron and lead are, for example, completely insoluble in each other at all temperatures, if these metals are fused together, the iron immediately beds on top of the lead.

Many metals such as gold and silver are completely soluble in each other in all proportions and also in a solid state. They form what is known as a “solid solution” which has the same composition throughout. A solution of this type is said to be homogeneous.

Other metals (e.g. antimony and lead) are soluble in each other in the melt, but cooling reduces their mutual solubility and the solid alloy is composed of aggregates (crystallites). With at least two phases with different compositions (and antimony and lead crystallites).

By adding a metal with an alloying element we obtain new properties. Hardness or processing and application options usually increase.

For example, soft copper metal was known for centuries before man learned to alloy it with another previously known metal - tin, and thereby produce a harder material, bronze.

Modern metallurgy has produced thousands of alloys that meet almost every demand, everything from metals that fuse just above room temperature (e.g. used for fire protection) to corrosion and heat resistant light metals for satellites. Most of the alloys used today have their own product names.

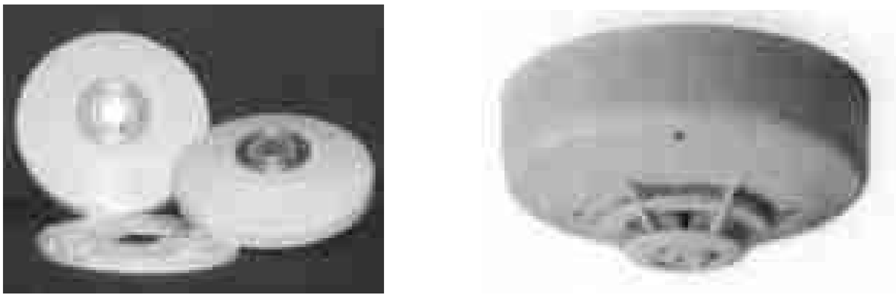


Figure 5:10 Fire detectors

Below is a data sheet of Aluminium Bronze

Standards sheet
SS 5716-15, Aluminium Bronze String-cast
SS 5716-20, Bronze Extruded Aluminium
(Other standards: DIN 1705 CuAl10Ni, BS 1400 AB2, SAE 701 C, JM 7)

Contents (Nom.)

Cu 77-82 %

Al 8.5-11 %

Ni 4-6 %

Fe 2.5-5 %

Max. contaminants:

Mn 1.5 %

Pb 0.05 %

Zn 0.50

Misc. 0.3 %

Mechanical properties	5716-15	5716-20
Yield strength (Rp N/mm^2):	260-325 N/mm^2	300-480 N/mm^2
Breaking point (Rm N/mm^2):	590-645 N/mm^2	630-790 N/mm^2
Elongation in % A^5:	10-18 %	12-25 %
Hardness/Brinell:	140-170 HB	170-220 HB

(All values = Nominal values)

Density ~ 7.6
Mating material: *Min. surface hardness 400 HB Rec. surface finish <1 Ra.*

Miscellaneous
The material is suitable for welding and gluing. Not for soldering.

Examples of applications
Marine equipment and parts, worm wheels, slide rails, non-sparking tools, idler and impellers, bearings subject to heavy shock loads, nut threads, steering parts for hydraulics, valves, valve seats, high pressure fittings, etc.

Nomenclature and standards

As mentioned earlier, the standard steels are grouped on an inventory sheet. There are inventory sheets for:

General structural steel

Pressure vessel steel

Steel for pressure vessel pipes

Steel for gas cylinders

Steel for rivets, screws, bolts and chains

Free-cutting steel

Machine steel

Case hardening and nitriding steel

Quenched and tempered steel

Spring steel

Tool steel

Stainless steel

Steel for cold-rolled strips

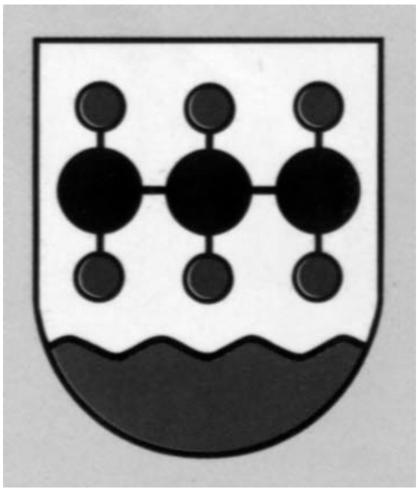


Figure 5:11 Propylene molecule

Non metallic materials

Plastics

Plastic can, without exaggeration, be said to have the best shaping characteristics of all moulding materials because:

- Very complex parts can be manufactured
- Components can be produced wholly in a single step
- Shaping takes place at low temperatures
- Is a good electrical isolator

A plastic consists of a base material (plastic mass), and various additives such as

- Hardener (termo setting plastics)
- Filling agent
- Lubricant
- Dye
- Stabilisator

Plastics have it´s origin in hydro carbon molecules (se figure 5:11). By linking together, for example ethylene molecules, the product will be polyethylene.

There are two main types of plastics

Thermosetting plastics manufacturing process is irreversible (compare the cooking of eggs), and *thermoplastics* manufacturing process is reversible.

The most common manufacturing processes used to produce a finished product of thermoplastics are injection moulding/extrusion, film blowing and casting.

Components out of thermosetting plastic are set up in layers, such as for example wind turbine blades.

Thermoplastics are characterized by the fact that they normally have branched or linear molecular structure that can be shaped by heating, and are often processed into products using high-pressure methods. Thermoplastics represent a very large subgroup within the plastics family. Considerably more products of thermoplastic resins are manufactured today compared to thermosetting plastics.

Thermoplastics

The thermoplastic group is usually divided into the following categories, depending on the substance being impregnated with polymer in order to give the plastic product different properties.

- olefin plastics
- Vinyl plastics
- Styrene plastics
- Acrylic plastics
- Polyacetals
- Polyamide plastics
- Thermoplastic ester resins
- Fluoroethylene plastics
- Cellulose plastics
- Others, including polycarbonate plastic

Each of the categories listed in turn contain a number of plastics. The thermoplastic family includes perhaps 120 to 130 different types.

Thermo setting plastics are around 20.

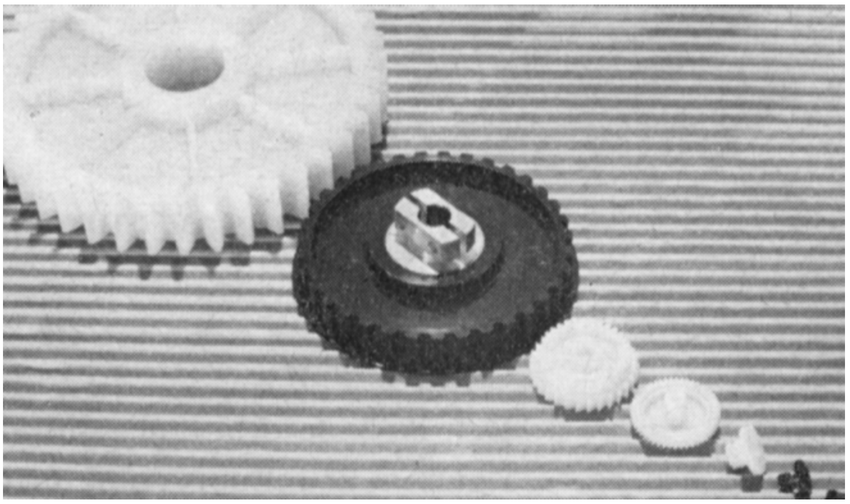


Figure 5:12 Gear wheels of polyamide

Polymers

Olefin plastic is a class of plastic based on a type of hydrocarbon compound, known as olefins. These are characterized for their reactive inclinations.

Ethylenes are a group of plastics that are based on polyethylene, PE. Polyethylene is impact resistant, even in the cold, and it has good electrical properties, negligible water absorption and is resistant to most chemicals and is cheap to manufacture. The disadvantages are that it exhibits limited load resistance, poor heat resistance and limited climatic resistance.

Propylene plastic, PP, is a white milky material. In the form of thin films is transparent. It is stiffer, harder and shows a better resistance than polyethylene. It has good electrical properties and relatively good chemical resistance but is less resistant to impacts than polyethylene. Furthermore, it is brittle at temperatures of about 0 degrees and lower.

PP is used for, among other things, fan propellers, instrument panels, cylinders, pipes, tanks, knobs, electrical insulating components and casings for kitchen appliances and hair dryers.

Copolymers, or inter-polymers are composed of mixtures of polymers, such as polyethylene and polypropylene. It gives a material specific properties, such as impact resistance.

The structure of *high-density (HD) polyethylene* have the side chains shorter, which means that the main chains can be packed closer to each other.

They are used for soft drink cans, sweets containers, bottles for motor oil, petrol cans,

petrol tanks and toys.

The structure of *low-density (LD) polyethylene*, or linear ethylene plastic with low density: In this case, the side chains are short and close together. This means that the material is very tough. It is used for glass cups and toys etc. It is also used as a toughness regulating additive in PE-LD film for carrier bags in particular.

Propylene plastic, PP, is a white, milky material, that in the form of thin films is transparent. It is stiffer, harder and shows a better resistance than polyethylene. It has good electrical properties and relatively good chemical resistance but is less resistant to impacts than polyethylene. Furthermore, it is brittle at temperatures of about 0 and colder.

PP is used for, among other things, fan propellers, instrument panels, cylinders, pipes, tanks, knobs, electrical insulating components and casings for kitchen appliances.

Figure 5:13 Polyethylene components

Vinyl plastic is a generic term for a number of plastics based on a polymer containing certain types of molecular groups, known as vinyl groups. Examples of vinyl resins are vinyl chloride plastic, *PVC,* vinyl acetate plastic, PVAC, and vinylidene chloride plastic PVDC.

Polyvinyl chloride plastic is based on polyvinyl chloride, PVC. Pure PVC usually comes in the form of a white powder. It is possible to produce a range of PVC variants, as the addition of different amounts of plasticisers provides the materials with very different flexibility properties, from soft and flexible materials to hard and rigid ones. Polyvinyl chloride has good electrical properties and excellent chemical resistance.

Using the appropriate stabilisers, PVC can also be given fairly good climate resistance. The material is stiff and brittle at low temperatures. In the event of a fire, chlorine is released, which is a disadvantage from an environmental point of view. This has meant that the material is subject to criticism in the environmental debate. Vinyl chloride plastics is used in such things as pipes, building panels, wall coverings, flooring, cable insulation, cellular plastic components (rigid or soft cellular plastic), and car panels and car upholstery. The material is also used for protective coatings on steel plate and aluminium.

Vinyl acetate plastic is a tasteless, odourless, solid material. It has good adhesion to other materials and is therefore used in adhesives and as binders in paints.

Figure 5:14 Machine parts in different polymers

Vinylidene chloride plastic has very good resistance to acids, alkalis and some solvents. The material has a structure that provides excellent gas tightness. It is therefore used mainly in laminate for vacuum packaging or packaging that must be sealed from oxygen and other gases. Examples are inert gas filled multivac packaging for food that must not be subject to attack from atmospheric oxygen.

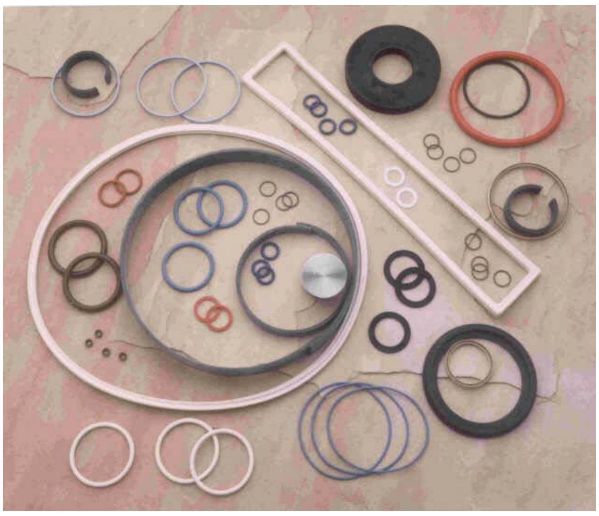


Figure 5:15 Seals and O-rings in various polymer materials

Styrene plastics is a generic term for a group of plastics that are made out of polystyrene material, PS. They form a group with a very extensive property register. Pure polystyrene is a crystal-clear, hard and rigid material with good electrical properties and low water absorption. The material is brittle, however, and micro cracks can easily form. It has poor resistance to oil, solvents and dish-washing liquid and it cannot withstand UV radiation.

Polystyrene is used primarily for packaging, disposable items, and cellular plastics, known as expanded polystyrene, EPS. There are some common types of polystyrene, namely, impact resistant polystyrene, SB, styrene-based plastics/ SAN and styrene-based plastics /ABS. Impact resistant polystyrene PS is a variant that is made resistant to impacts by undergoing co-polymerisation with butadiene, and has the designation SB. The actual material is opaque but it can be stained in many colours. It is used for, among other things, casings for TV and radio receivers, loudspeaker boxes, car interiors and containers for alkaline batteries.

Styrene-based plastics/SAN consist of impact resistant polystyrene, modified with acrylonitrile. The material is hard and rigid and has better chemical resistance than polystyrene. It is transparent and can be stained in most colours. The plastic is used for household items, refrigerator parts, toothbrush holders, cups, trays and containers for cosmetics.

Styrene-based plastics/ABS is a PS variant, that consists of SAN which is modified with butadiene. The material exhibits a good combination of mechanical and chemical properties at a relatively low price. The material itself is white but can be stained in many different colours. ABS is used for, among other things, casings for telephone equipment, vacuum cleaners, kitchen appliances and office machines. ABS is the most commonly used plastic for plastic articles to be metallised. The butadiene is often replaced with acrylic residues. You then get a PS variant, called ASA.

Common abbreviations in plastics are shown below. These abbreviations are often used insted of the chemical name.

- ABS plastic
- Copolymer
- Polyethylene (PE)
- Expanded polystyrene (EPS)
- High-density polyethylene (PE-HD)
- Linear low-density polyethylene(LLDPE)
- Low density polyethylene (LLDPE)
- Olefin plastics
- Polyethylene (PE)
- Polystyrene (PS)

- Polytetrafluoroethylene (PTFE)
- Polyvinyl chloride (PVC)
- Polypropylene (PP)
- Styrene-based plastic/ABS
- Styrene-based plastic/SAN
- Polystyrene (PS)
- Vinyl acetate plastic (PVAC)
- Vinylidene chloride plastic (PVDC)
- Polyvinyl chloride (PVC)

A lot of products have specific trade name like below

Nitrile ®, Buna-N, Viton ® (Black), Viton ® (Brown), Aflas ®, Silicone, Creavy, Teflon ®, PTFE, Teflon ® encapsulated Viton ®, EPDM ®, Neoprene, Silicone.

Viton, for example, is a fluoroelastomer and is regarded as a synthetic rubber. It has great resistance to oils and chemicals.

Figure 5:16 Membrane in Teflon

Keramics (Porcelain)

Keramic products for industry are shaped by sintering. The source material is a powdery mass, consisting of:

- Clay, Kaolin
- Quartz, Feldspar
- Water and crude olive oil

Keramics is formed by pressing (100-200 bar) in steel tools and then drying and finally firing (in 300 - 1 400°C) in a furnace. The most common ceramic materials are porcelain and steatite. Porcelain has a long life but is brittle. Its electrical insulation ability means it is commonly used as an isolator.

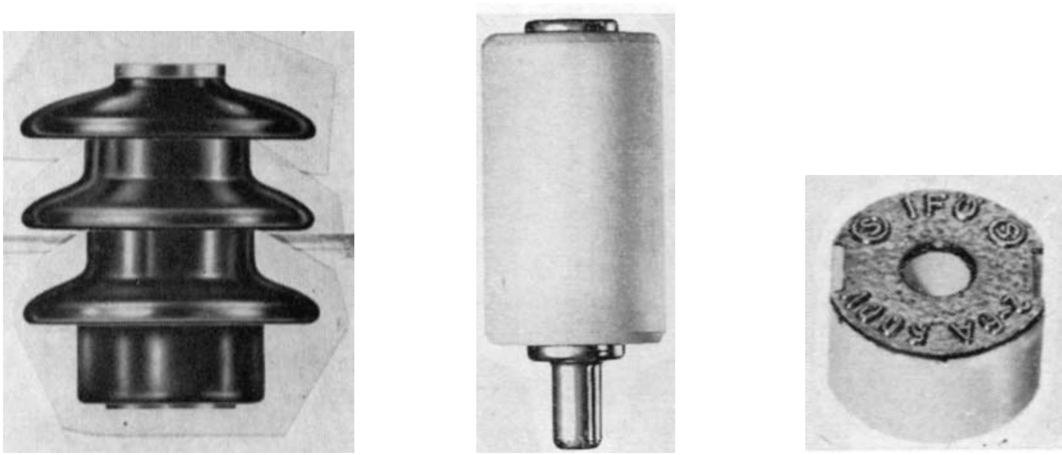


Figure 5:17 Electrical porcelain details

Ceramic Materials

What are ceramics? The very words ceramic and pottery can be related to the Greek word keramos meaning “potter's clay”. The art of firing clay for different kinds of pottery laid the original foundation for today's high-performance technical ceramics.

By definition, all “inorganic non-metallic material that is shaped into products prior to, or in connection with, high-temperature reactions (T>500°C)” is regarded as ceramics. Porcelain, glass, graphite, bricks, etc. can then be defined in this group. However, technical ceramics offer new opportunities as a construction material.

The high-strength variations are often called construction ceramics. Technical ceramics are used where appropriate where there are extreme material impacts such as abrasion, corrosion, high temperatures, high pressure loads, etc. Ceramics special, often unique properties make them suitable as advanced engineering materials. However, material type, design and surface finish should always be carefully chosen.

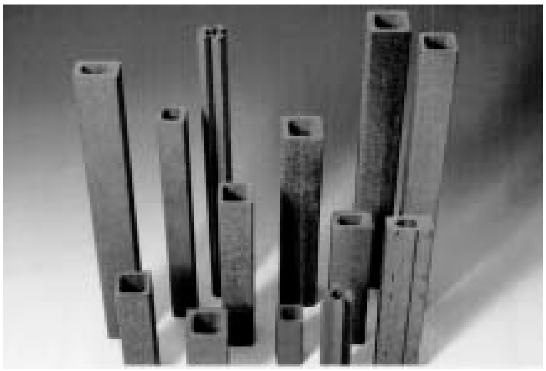


Figure 5:18 Ceramic tubes for high temperature use

Ceramics are often extremely hard, which makes them suitable for applications where wear is great.

The hardness of a normal quality of dense-sintered, pure aluminium oxide, Al_2O_3, is about 81 HRC (at 45 N). When compared to around 60 for tool steel and 85 for hard metal, you start to understand that the wear resistance of even ordinary aluminium oxide is good.

Then there are other ceramics with even higher hardness levels, such as silicon carbide, SiC, which at full density is around 95 HRC.

Ceramics are often made up of strongly bound atoms with relatively little freedom to move in different directions. This means, among other things, that they normally have a very high melting point, in some cases a little above 3,000°C. A normal construction ceramic, dense/sintered 99.6 % Al_2O_3, can be used under load at up to about 1,600°C. Since most high-performance ceramics are oxides or form a protective oxide film, they can also be used in normal air without requiring special protective gas.

Because of the low breaking strain, ceramics are often susceptible to thermal shocks, especially during temperature reduction. When the component is cooled, the surface cools faster than the substrate, thereby exposing the surface to high tensile stresses.

Ceramics are usually good thermal insulators. A major reason for this is that they can be manufactured, except with regard to composition, with a controlled and high porosity. The good insulation ability usually depends on the specific thermal conductivity of the ceramics being low. This applies to many ceramics, however, far from all of them. Some conduct heat as well as metals.

The group of technical ceramics is large, and is expanding continuously. The conventional base materials are becoming more sophisticated and subgroups are emerging. New alloy systems are also being developed, as well as new reinforcement and hardening techniques that produce ceramics that are able to show their worth as construction material. As a general introduction to the most common and basic materials, the following can be included:

Aluminium oxide, Al_2O_3

The most common technical ceramic is aluminium oxide, Al2O3, in varying degrees of purity and density. That this is normal is mainly due to the fact that it can be obtained at a comparatively low price, especially in simple shapes without machining after sintering.

The purest grades are selected for temperatures up to about 1,900°C and for the most corrosive environments.

Silicon Nitride, Si_3N_4

Silicon nitride-based ceramics are a relatively new class of materials suitable for construction purposes. These are a successful combination of several good qualities that allow them to be used in demanding applications.

INDUSTRIAL CERAMICS	Plough shares	LABORATORY MATERIAL
Blast nozzles	Pump shafts, cylinders	Cement
Firing pipes	Cutting edges	Crucibles
Cylinder linings	Spray nozzles	Casting compounds
Pull nozzles	Welding nozzles	Insulation material
Extrusion nozzles	Thread guides	Ceramic adhesive
Filters	Turbine rotors	Woven ceramic fabrics
Flame arresters	Seals	Pipes
Combustion layers	Vacuum components	Spheres
Mould cores	Valve balls	
Skim gates	Valve seats	ELECTRONIC CERAMICS
Slide rings	Heat exchangers	Electronic valve components
Catalytic converter carriers		Enclosures
Surgical instruments	ELECTRICAL CERAMICS	Laser components
Bearings	Lighting ceramics	Microwave components
Grinding balls	Isolators	Piezo-electric ceramics
Metallised ceramics	Winding spools, cores	Substrates
Armour ceramics	Superconductors	

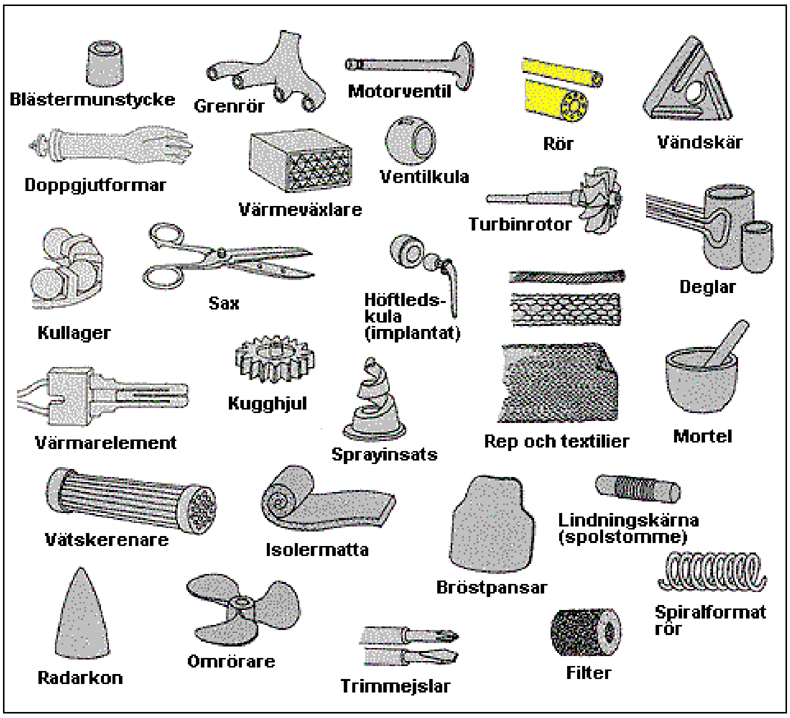


Figure 5:19 Selection of ceramic machine parts

Rubber products

Rubber materials with special properties for different industrial applications have

High wear resistance
Chemical resistant
Ozone resistance
Wear resistant and oil resistant
Easily worked

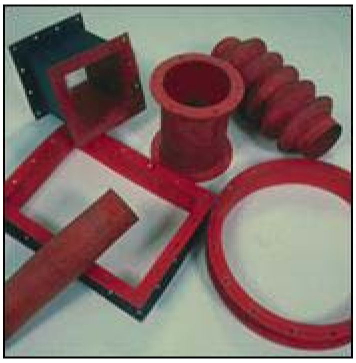


Figure 5:20 Cellular rubber in neoprene with closed cells.

Figure 5:21 Sponge rubber

Natural rubber (Latex) is extracted from the sap of the rubber tree Hevea Brasiliensis, which grows in the Brazilian rainforest. The Indians knew of the properties of natural rubber as early as the 11th century, but it was only in the 15th century that rubber was introduced to Europe. The rubber industry is a major component of today's modern industry. Here are the most common types: NR, natural rubber is still used and is very elastic and durable. Good resistance to oil, solvents and heat.

SBR, Styrene-butadiene rubber used in tires, among other things. SBR is similar to natural rubber but is more durable and ages slower.

Figur 5:22 Shaft seals in SBR

EPDM, ethylene-propylene rubber shares most of the good qualities of natural rubber and SBR rubber, but ages slower and has better ozone resistance.

CR, Chloroprene rubber Neoprene similar to EPDM, but has better resistance to oil and other chemicals.

FPM, Fluorine rubber has very good resistance to oils, chemicals, ageing and ozone. Can also heat up to 300°C.

Q, Silicone rubber, can handle large fluctuations in temperature and has very good electrical insulation properties.

PUR, Polyurethane rubber, is extremely durable and is used for solid rubber wheels for trucks etc.

EPP cellular plastic. This can be used for structural components, packaging or insulation. Withstands severe mechanical stress and is insensitive to temperatures between -40 to +130°C. EPP cellular plastic is also resistant to most chemicals, solvents and lubricants, and is cost effective.

Depending on the activity, there is the need to organise maintenance in the manner that is most optimal and that provides the greatest benefits (efficiency). A number of different philosophies and/or working methods have evolved over the years. Many of the approaches are based on working more effectively on maintenance issues and maintenance activities, but also for the sake of learning “to walk before running”. There is always a way to work as “best practice” undependent of business.

This chapter presents a comprehensive overview of some of these philosophies and working methods.

TPM (Total Production Management)

The purpose of TPM is to provide uninterrupted operation. All the staff will be involved in the operational reliability process. Automation and job rotation within industry has led to operating staff losing ownership with the machines. The consequence of this is that many incipient failures are not detected in time and that the problem is not permanently fixed. “Some other can fix it, I don´t have time”

The original meaning of TPM was Total Productive Maintenance but was extended to include the whole production and maintenance process (Total Productive Management).

The foundation is operator maintenance, where the production staff are trained in and take responsibility for specific maintenance tasks such as technical cleaning, inspection, and lubrication. Operator maintenance is a very effective way of improving equipment performance and thereby operational reliability.

The method has been shown to have significant advantages with regard to:
• Avoiding failures
• Streamlining the process
• Increasing equipment availability
• Improving overall productivity
• Enhancing the working environment
• Enriching the work content
• Encouraging proposal activity
• Improving profitability

Today we talk about Total Productive Manufacturing, which includes the working methods 5S, Improvement groups and Changeover time reduction. An overall concept to improve productivity.

Figure 6:1 Tracking losses

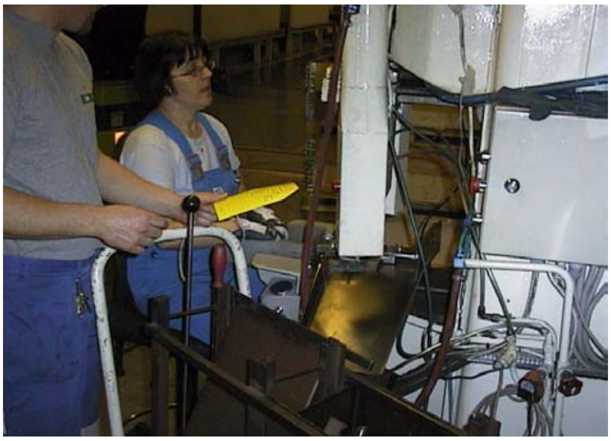


Figure 6:2 Improvement group in action

5S Good order

There are seven steps to implement 5S in the production area, workshop or office

5S is a method to achieve the systematic good order at work. 5S can be implemented in all workplaces and offices.

1. Select a department to start with. The implementation of 5S requires resources, so you should start work in an area where the repayment period is short. Aim to create a good example for other departments/areas.

2. Perform training in 5S. Training should include all staff who need to be in the part of the plant concerned. In a production plant, all the involved operators, maintenance staff, managers and technicians should be included.

The five steps

1. Inventory (Seiri) - Use Seiri as an activity in which all types of waste are identified. The staff who work at the workplace are divided into cross-functional teams that mutually announces measures using red notices in the plant. Anything that complicates cleaning or creates a dirty environment should be addressed. The same applies to all types of known failures and inconvenient work operations that take time from other more beneficial tasks. All unnecessary objects are removed. Have the objective whereby all the red notices should be corrected within 30 days.

2. Place (Seiton) - All tools and aids are located in the right place. Everything to be used is marked up. Floor markings are made visible. In practice, you can either integrate Seiton measures as part of an action plan from Seiri, or perform a separate Seiton activity for the cross/functional teams.

3. Initial cleaning (Seiso) - In this activity, the plant is cleaned thoroughly. There are two objectives with initial cleaning. One is that you mutually agree on the level of cleanliness that you consider is appropriate. The second objective is to document what is required to achieve the new level, which provides input for the new procedures. The initial cleaning is also carried out in teams. After cleaning, let the teams estimate how often this cleaning should be performed in the future and how time consuming it would be if it was undertaken on a regular basis. Finish by taking a photo of the new standard level.

4. Routines (Seiketsu) - This is the most critical phase of 5S. When you come to the routine phase, you will have the benefit of the documentation made during the initial cleaning. If it was documented correctly, you already know which cleaning tasks are required and you have an estimate of how time consuming they are. The new routines will be embraced by the staff as they have been proposed by the same staff during the initial cleaning phase. All that remains to do is to decide on the system you want when scheduling the proposed activities, starting work and then following up in order to develop the routines.

5. Discipline (Shitsuke) - closing the loop. The objective is to get 5S to be a part of the day to day work where it can be developed. Remember that even the most accepted practices are likely to fail unless the managers indicate that they are important. An effective tool is to create a diploma system and monitor the progress of the different departments in 5S on boards. Then perform regular audits at various levels with management involved.

Figure 6:3 Before

Figure 6:4 After

Figure 6:5 Is this a good way to take care of your lubricants?

LCC Life Cycle Cost

As competition stiffens, it becomes increasingly important to plan and calculate profitability before committing to major investments. An LCC costing is then a good tool for reporting the costs incurred in the purchase and operation of plants. The iceberg below symbolises the hidden costs that maybe not everyone is aware of. The purpose of an LCC costing is to estimate and optimise the total cost of an investment over its full life. The term LCC comes from the U.S. armed forces, which in the 1950s wanted better financial controls on investments as a step in their improvement efforts.

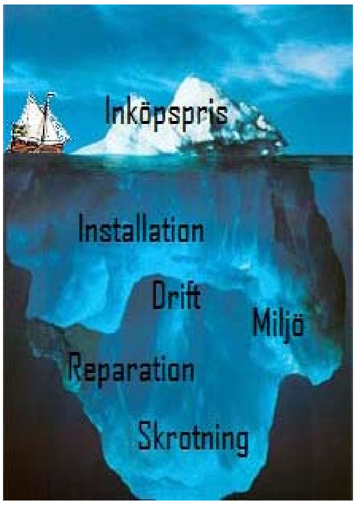


Figure 6:6 Purchasing costs visible. What are the invisible costs?

Figure 6:7 High speed train an example of the results of an LCC analysis

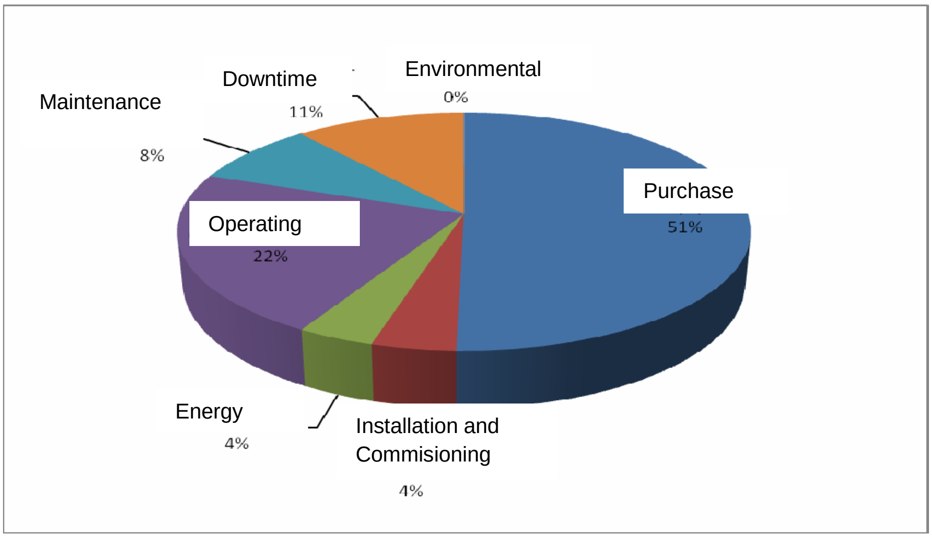


Figure 6:8 Cost allocations in an LCC analysis

Application of LCC

There is as yet no standard LCC in the same way as there is with LCA (Life Cycle Analysis). However, there is a general form to LCC, but it may differ depending on the industry you work in.

It is easiest to make an LCC calculation of the plant that are in constant operation, such as time and load of a pump or fan drive.

In the most common forms the following steps are used:

- Purchase cost
- Installation cost
- Energy cost
- Operating cost
- Maintenance cost
- Downtime cost
- Environmental cost
- Scrapping cost

The LCC costing is a good approach when comparing different investment proposals/tenders against each other

The LCC costing must be defined over a certain period, and is usually linked to the machine's economic life, i.e. the time until the machine is paid off. Consideration to the cost of scrapping also needs to be included. Note that the machine does not need to be worn out at the end of its economic life. You can then decide to continue to have the machine in production for a further period if it would be financially viable.

The difficult factor for a plant that has not been in constant operation is to estimate the likely uptime. If this is not correct, it may have an erroneous affect on the total cost, as there will not be any accurate figures for energy consumption or operating, etc. Another application is that you can use an LCC costing for the design department, for example, to justify the higher prices of components to the purchasing department.

RCM - Reliability Centred Maintenance

RCM is an engineering methodology that can be used to introduce new maintenance techniques, and to review and improve existing maintenance activities. Establish new maintenance tasks to determine the need for maintenance measures for new equipment and to quality assure that a high level of operational reliability can be obtained.

RCM has proven to generate greater reliability and ambient protection, improved performance (output, product quality and customer service), greater cost efficiency for maintenance work and longer life for equipment. The results of an RCM analysis provide a comprehensive yet detailed database about the plant. Staff motivation is improved.

RCM originated in the 60's when Boeing launched its new 747 series. The plane was larger and more complex than before and the need for reliability was great. With the techniques of the time, it was not economically feasible to start the new series and a group was therefore appointed to develop a new approach, and they came up with RCM. The technique has since evolved over the years and the person who has contributed most is an Englishman named John Moubray. In 1991 he developed RCM2 which is the most common version of RCM today.

RCM consists off seven questions that should be answered in the right way. Below is the meaning of the questions and in figures 6:9 to 6:11 are templates used. Figures 6:12 to 6:14 shows an example.

RCM's seven basic steps

1. Functions, primary and secondary. Primary explains why the system exists, secondary addresses other demands on the system, such as environmental requirements, safety requirements, control equipment etc.

2. Determine the function failures, two types: total loss of function and partial loss.

3. Development of failure modes.

4. The effects of the failure describe what happens when the failure occurs. Unlike consequences which evaluate how serious the failure is. The effects of the failure describe how the failure affects reliability, the environment, availability, if it produces secondary damage and what must be done to fix the failure.

5. Evaluate the consequences and develop risk numbers

6. Find the right maintenance activity.

7. What should be done if there is no suitable maintenance activity.

Question 1		Question 2	Question 3		Question 4
FUNCTION	FUNCTION TYPE	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE CAUSE	FAILURE EFFECT

Figure 6:9

Question 5										
COMPONENT	DETECTION	REPAIR TASKS	REPAIR TIME	SPARE PARTS STOCK / NON STOCK	LEADTIME	BACK UP	LEADTIME BACK UP	DOWN TIME	COSTS	PROBABILITY

Figure 6:10

VALUATION & RISK Matrix						RANKING	DECISION CHART									Question 6		Question 7	WHO
S	E	D	B	A	C	RISK LEVEL	1	2	3	4	5	6	7	8	9	PROPOSED TASK	INITIAL INTERVAL	REDESIGN	CAN BE DONE BY

Figure 6:11

Example of RCM analysis

Question 1	Question 2	Question 3		Question 4
FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE CAUSE	FAILURE EFFECT
A1.5.1.1 To receive Methanol from (B4 and B5) ship at 1150 mt/hr	A1.5.1.1.1 Can't receive MeOH at all	Ball valve HV3306 closed	Lack of awareness on human	Cant receive at all
			Lack of knowledge on human	Cant receive at all
			Valve spindle jammed	Cant receive at all
			Valve jammed closed	Cant receive at all

Figure 6:12

Question 5							
REPAIR TIME	SPARE PARTS STOCK / NON STOCK	LEADTIME	BACK UP	LEADTIME BACK UP	DOWN TIME	COSTS	PROBABILITY
1h	NA				1h	5000	7 yrs
1h	NA				1h	5000	7 yrs
5d	Spindle / NS - RM20,000 (mat) + RM10,000 (work)	16 wks			17wks	30 000	7 yrs
5d	Valve / NS - RM70,000 (mat) + RM20,000 (work)	24 wks			25 wks	90 000	7 yrs

Figure 6:13

VALUATION & RISK Matrix						RANKING	DECISION CHART									Question 6		Question 7	WHO
S	E	D	B	A	C	RISK LEVEL	1	2	3	4	5	6	7	8	9	PROPOSED TASK	INITIAL INTERVAL	REDESIGN	CAN BE DONE BY
A2	A0	A2	NA	B3	A2	3	Y	Y								Regular inspection and awareness training	Monthly & Yearly		Ops
A2	A0	A2	NA	B3	A2	3	Y	Y								Regular inspection and awareness training	Monthly & Yearly		Ops
A2	A0	A2	NA	A2	C4	4	Y	Y								Spare must be avialable in the store. Make use of common spare			EMP

Figure 6:14

Blank

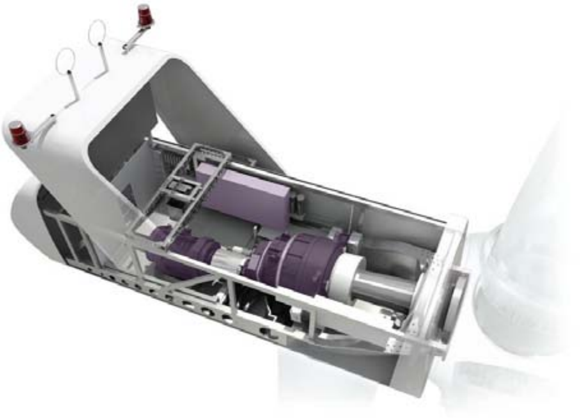
Why do we lubricate?

The main reason why we lubricate is that we want to cut down on **wear** and reduce **friction**. The intended effect is achieved by introducing a thin film of oil from a lubricant between the surfaces, whereby the higher dry metal friction is replaced by the lower fluid friction.

The lubricant has the following main tasks:

- Separate the contact surfaces
- Reduce friction and remove heat
- Prevent welding between the surfaces
- Seal against contaminants from the outside (dust, water, etc.)
- Prevent corrosion

Good lubrication and good cleanliness would enable us to achieve an almost unlimited lifetime for many of our machines.



In the case of wind turbines it has been proved that lubricant plays an extremely important role in the system's technical components if we want fault-free operation and high availability. A wind turbine operates for many hours and several of the machine's component parts are subject to extreme loads.

Wind turbines are therefore an area of particular interest to many oil companies and lubricant experts. Several oil companies have built their own wind farms to carry out tests with their own products.

This chapter initially addresses some general knowledge that you should possess in the field of tribology and lubrication for understanding the lubricating principles of various machine parts.

At the end of the chapter, there are some lubricant applications that are used in wind turbines.

Two fundamental lubrication concepts - Viscosity and NLGI grades

The field of Tribology contains many descriptions, names, concepts and technical terms. To describe them in a brief context for the reader to understand the reasoning is difficult.

Beginning by describing just two basic concepts that will help you better understand the following pages in the for tribology and lubrication.

Viscosity

Viscosity is a measure of oil's internal friction. The higher the viscosity the higher the internal friction and the thicker the oil. Viscosity is temperature dependent and it changes significantly depending on the ambient temperature. The lower the temperature, the higher the viscosity. When choosing an oil for a particular application the viscosity is critical. Essentially, oil is measured using the hourglass principle.

Figure 7:1 Hourglass principle

The standard temperature where oil is measured today is 40ºC, expressed in number of seconds. (mm^2/s). Viscosity is measured today in industry using a standardised measuring system called the ISO VG 3448 system. (ISO VG = International, Standard Organisation Viscosity Grade) The viscosity grade that you see on the drums is the viscosity expressed in number of seconds it took for the oil to pass through a glass tube called a capillary viscometer. See figure below.

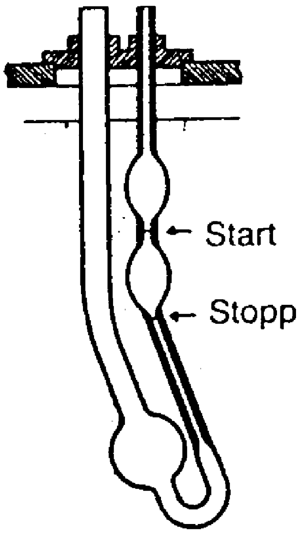


Figure 7:2 Measuring ISO VG

An international committee has agreed to use the following viscosity index for industry: ISO VG 2, 3, 5, 7, 10, 15, 22, 32, 46, 68, 100, 150, 220, 320, 460, 680, 1000, 1500.

In figure 7:3 isthe most commonly used ISO VG grades (the top row) in comparison with SAE grades appearing on transmission oils (middle) and motor oils. (bottom).

You can convert vertically from the top down. ISO VG 220 thereby corresponds to SAE 90 series in the transmission series or SAE 50 in the motor oil series. Note that these SAE grades are known as single grade oils. These do not show how oil behaves at different temperatures. The newer multi-grade numbers with two digits (e.g. 10w/40) demonstrates the oil's range at different temperature conditions.

How it is affected by the cold and heat respectively. The greater the spread between the two numbers, the less the oil changes at changed temperatures. Multigrade oils are not included in this booklet.

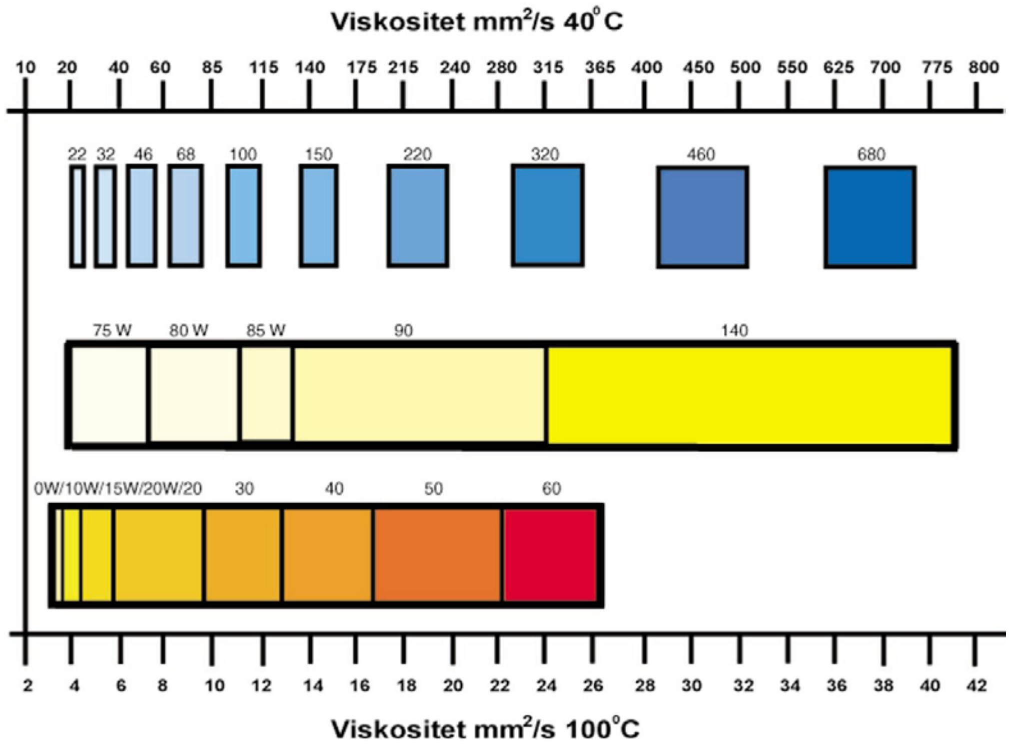


Figure 7:3 Viscosity

NLGI grade - grease consistency
Grease is a complex product made up of about 90 % oil, 8-9 % thickener and 1-2 % additive. The NLGI grade describes the thickness of the finished product.

The consistency of lubricating grease is measured by a metal cone sinking into the grease for 5 seconds.

You read the depth of penetration in tenths of a millimetre. You then use a standard chart that shows the NLGI grade for the tested product. The scale ranges from 000 to 6. The higher the number, the stiffer the grease. As standard, the grease is processed before the test in a “grease worker” 60 strokes.

Note that the grease thickness has nothing to do with the speed the grease should be used at. The speed range the grease is suitable for is mainly determined by the base oil viscosity of the grease. The base oil represents as much as 85-95 % of the grease, the remainder is the thickener.

It is therefore the thickener that determines the NLGI grade issue. A lot of thickener in the base oil gives a high NLGI grade.

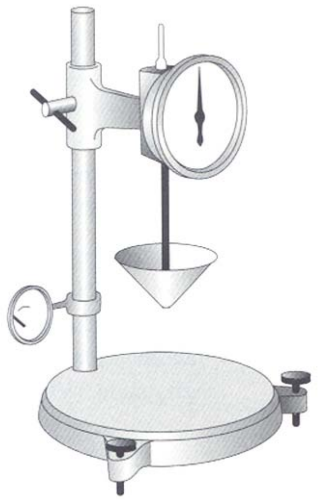


Figure 7:4 Measuring NLGI

Description	**NLGI grade**	Penetration
LIQUID	**000**	445-475
SEMI-LIQUID	**00**	400-430
VISCOUS	**0**	355-385
SEMI-SOLID	**1**	310-340
SOLID	**2**	265-295
EXTRA SOLID	**3**	220-250
VERY SOLID	**4**	175-205
SEMI-HARD	**5**	130-160
BLOCK GREASE	**6**	85-115

Why do we need different NLGI grades?

The main reason for the production of grease in various thicknesses/NLGI grades is that grease is applied in different ways to the machines out in the workplace.

Sometimes the grease is pushed into a nipple directly, and sometimes you use a central lubrication system with long lubrication pipes. When grease is fed into the long lubrication pipe you usually have a softer grease in order for the grease to access the lubrication point more easily. Low temperatures are another problem area for grease. Both the base oil viscosity and NLGI grade play a major role in how much grease “brakes” at low temperatures.

- Central lubrication systems NLGI grades 0, 00, 000
- Grease filled gears NLGI grade 00.
- Nipple lubrication NLGI grades 1, 2
- Open gear wheel NLGI grades 2, 3
- Vibrating enclosures NLGI grade three due to the fact that the grease softens from strong vibrations

Tribology and lubrication pyramid

The word **tribology** is derived from the Greek word “tribos” which means the science *of the mechanisms of friction, lubrication, and wear.* Today's machines have entirely different lubrication requirements than those of yesterday.

The lubrication pyramid summarises, in a simple and useful way, the most important factors you need to know to understand the key elements of the world of tribology. The lubrication pyramid consists of:

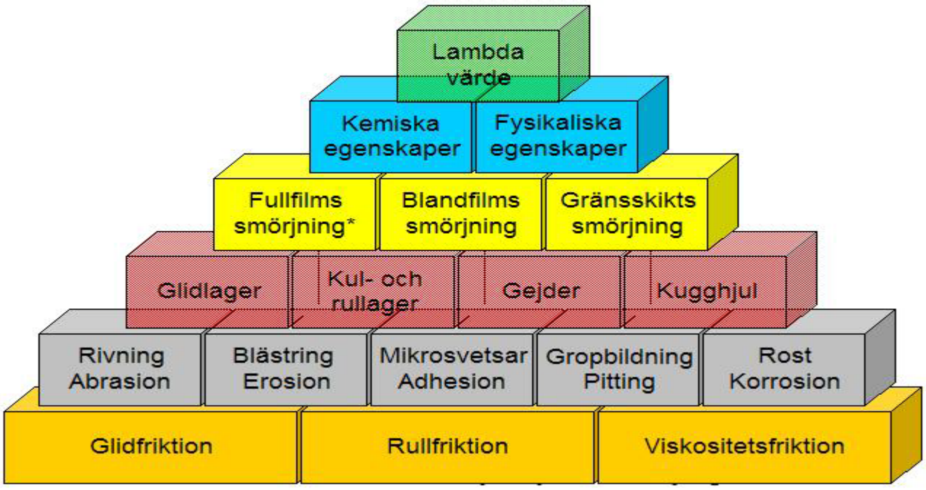


Figure 7:5 Lubrication pyramid Richard Wolffelt

- 1 lubrication certificate (λ – value)
- 2 properties (Chemical and physical)
- 3 lubricating condition (
- 4 machine parts (Slide bearings, Ball/roller bearings, Guideways, Gears)
- 5 wear types (Fretting, Blasting, Micro-welding, Cavitation, Corrosion)
- 3 friction types (Sliding, Rolling, Viscosity)

Three types of friction

We start from the bottom and describe the three basic friction conditions.
Friction is a loss of energy. It is estimated that over 30 % of the energy generated is consumed by friction, i.e. release of heat. Friction is one of the most important phenomena in nature. It can be both detrimental and beneficial. For example, you would not be able to walk unless the friction between the sole of your shoe and the ground prevented the shoe from slipping. A car would not be able to brake unless there was friction. Friction generates heat and can therefore result in high operating temperatures and high energy loss. All friction is proportional to the load. The scope of the friction coefficient varies depending on the material and surface roughness of the contact surfaces. There are three types of friction:

Sliding friction
The friction that opposes the motion of two solid surfaces sliding past each other. The starting friction, from sliding friction, is greater than the kinetic friction. Sliding friction occurs for example on slip joints.

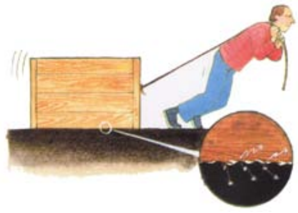


Figure 7:6 Sliding

Rolling friction
Occurs when a wheel or a ball rolls against a surface. The friction that occurs in a roller bearing is rolling friction. However, this is very small in these types of bearings, and therefore need not be reduced to the same extent as for sliding friction. But if we are to be totally correct, we have both rolling and sliding friction in ball bearings as the ball swivels in the bearing.

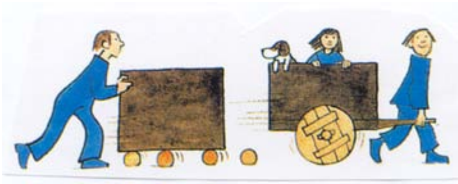
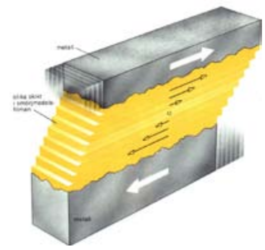


Figure 7:7 Rolling

This particularly occurs in the unloaded zone of the bearing.

Viscosity friction
Viscosity friction is the third type of friction. This can be likened to fluid/oil on lamella that slide against each other. The higher the viscosity the oil has, the higher the viscosity friction and heat generation. A thick oil brakes more than a thin oil etc. Pulling a rowing boat in thick oil feels significantly heavier than in light oil. Choosing the right oil viscosity is important. Choosing the viscosity with precision saves energy. (2-5 %)



Source image: SKF

Figure 7:8 Viscosity

Five types of wear

Essentially five different types of wear occur in a lubricating context and these are: fretting, blasting, micro-welding, cavitation and corrosion.

Fretting/abrasion/wear/grinding This is about the classic phenomenon of running-in problems. The surfaces of mechanical components have been milled, turned and ground at the machine manufacturer. Once you get your machine running these small burrs are rubbed off and a variety of particles move around in the oil. This type of wear will appear initially as indentations in the bearing race or the sliding surface. This is because the hard particles have worked their way in between the sliding surfaces, thereby causing indentations in micro-format. These abrasive particles contribute in turn to wear and a vicious cycle has begun. The solution to this problem is to try to remove the particles with an early oil change.

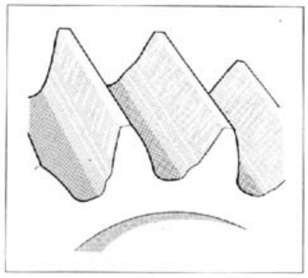


Figure 7:9 Fretting

Studies by SKF's Bo Jacobsson have shown that the 70/30 rule applies. This means that 70 % of the running-in process is complete after just 30 minutes. An early oil change therefore applies to new machines!

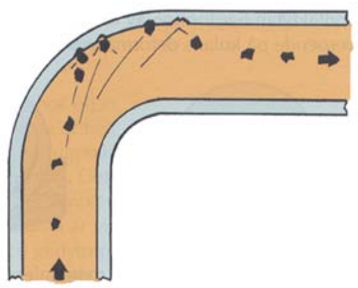


Figure 7:10 Blasting

Figure: Idhammar AB

Blasting/erosion is a problem often encountered in hydraulic systems. Steel is about 10 times heavier than oil and therefore this phenomenon occurs where hydraulic oil speeds are too high.
The particles present in the oil cannot keep up with the changes in direction in pipe bends and valves, but continue straight ahead bombarding the bend in the pipe. This bombardment eventually leads to the erosion of the material whereupon the wall becomes thinner and thinner. Blasting is another word for this phenomenon. The solution is to remove the particles through effective purification/filtration and/or ensuring that the oil speed is greatly reduced in the system via, for example, thicker pipes.

Micro-welds/adhesion/welding/smearing is a wear phenomenon that results from a high load and/or lack of lubricating film. Sometimes this is also caused by a speed that is too low. For this type of wear to occur, the sliding surfaces must have metal contact. When you look at the profile surfaces with sufficient magnification, you can see that the profile is uneven, with peaks and valleys like an alpine landscape.

The purpose of the oil film is to try to separate the metal surfaces, but sometimes this is impossible and the result is that two peaks collide.

The collision bends one or both peaks very abruptly and the resulting deformation generates heat. The heat is so concentrated and intense that in some cases this welds the two metal surfaces together only to be torn apart again moments afterwards. (micro-welding)

This type of wear is also known as smearing as the point of wear sometimes resembles a smeared surface. The solution to the phenomenon of adhesion/welding is to use EP additive in the lubricant. EP means extreme pressure. As a rule, chemical EP additives are used in oils and grease. Sulphur, phosphorus and chlorine are the most commonly used EP additives. In the past, lead was also used. There are also solid EP additives such as graphite, molybdenum disulphide and Teflon particles that are used in the oil or grease. The most common application is that these are used in grease at low speeds.

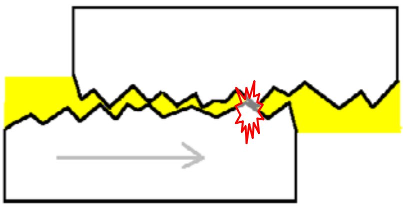


Figure 7:11 Micro welding

Chemical EP additive creates an oxide on the metals when impacting. At significantly raised contact temperatures (200-700 C) the EP additive is activated, and an oxide is formed on both surfaces from sulphur and phosphorus compounds. These surfaces will then not be able to weld together at the next impact. EP additives are currently used in many products such as gear oils, greases, hydraulic fluids and engine oils.

Cavitation/pitting/fatigue is probably the most common type of damage in the industry. In slide bearings the load is distributed over a large area and surface pressure is comparatively low. Fatigue damage occurs in machine parts where high surface pressure prevails. Examples of these machine parts include roller bearings and gear drives. If you look at the load zone of a ball bearing, it is a very small area that transfers the load between the ball and the rings. The phenomenon is similar to a car tire being pressed to the ground. Fatigue is also known as scaling, cavitation or pitting.

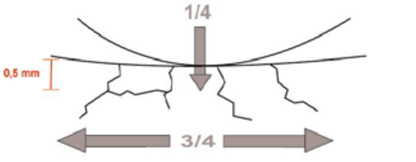


Figure 7:12 Cavitation

Rust, corrosion is a familiar problem that costs Swedish industry billions each year, and lubrication applications are no exception. Two types of damage can be attributed to water.

1
Water causes a hardening of steel and is called hydrogen embrittlement. The outer layer peels off when the ball or roller rolls in the bearing race and the gap increases gradually in the bearing. SKF's tests have shown that very small amounts of water, e.g. 0.01 %, will shorten the life of a roller bearing by 50 %.

2
Water that has penetrated into the oil or grease will also attack the iron surfaces, where the water along with the atmospheric oxygen reacts with the iron molecules to form iron oxide, which is more commonly known as rust.

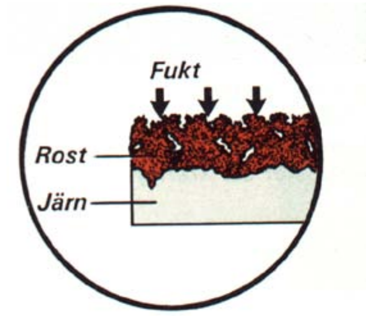
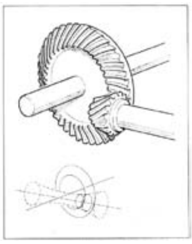


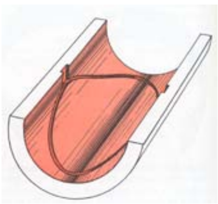
Figure 7:13 Corrosion

Four machine parts

- Gear wheels
- Slide bearings
- Ball and roller bearings
- Slip joints/guideways

It is important to understand the differences between the four machine parts and how they work. All have their pros and cons.


Gear wheels


Slide bearings


Ball and roller bearings

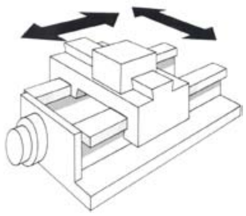

Slip joints/guideways

Figure 7:14 Machine components

Speed, temperature and diameter provide the most important input data that we use in the selection of lubricants for different machine parts. We can then add some more input data for some of the machine parts in order to determine the correct lubricant to use.

Gears, guideways, slide bearings, ball and roller bearings should all be handled separately in the lubricant instructions, both in terms of lubricant selection and frequency. In some cases, the same product is probably used for several machine parts. But if you are trying to cut down too much on the range as a way of combining an oil or grease for many lubrication points, it is generally the case that some machine part will suffer. There is no universal oil for all machine parts. Dimensioning with the correct oil and grease is essential for the overall life of a machine.

Compare the major load-bearing surface of a slide bearing with the small point contacts you have in a ball bearing.
Compare also the speed you have in a ball bearing in an electric motor (usually 1500 rpm) with the speed of a joint in a mechanical digger.

These are a few examples of completely different applications that require completely different types of lubricants to achieve the optimum life span in each application. Carelessness in this dimensioning will prove costly fairly quickly, resulting in the need for overhauls after a relatively short operating time.

Many people often blame this situation on the machine being poorly designed and therefore inadequate for the task. Very often, it is the faulty dimensioning of the lubricant that is the cause.

Dimensioning correctly with the correct viscosity is as important as choosing the right thickness of the component material
in a machine design. You could say that the lubricant is the fifth machine part. There are softwares commercially available that is specifically designed for the easy selection of the right viscosity for the application in question.

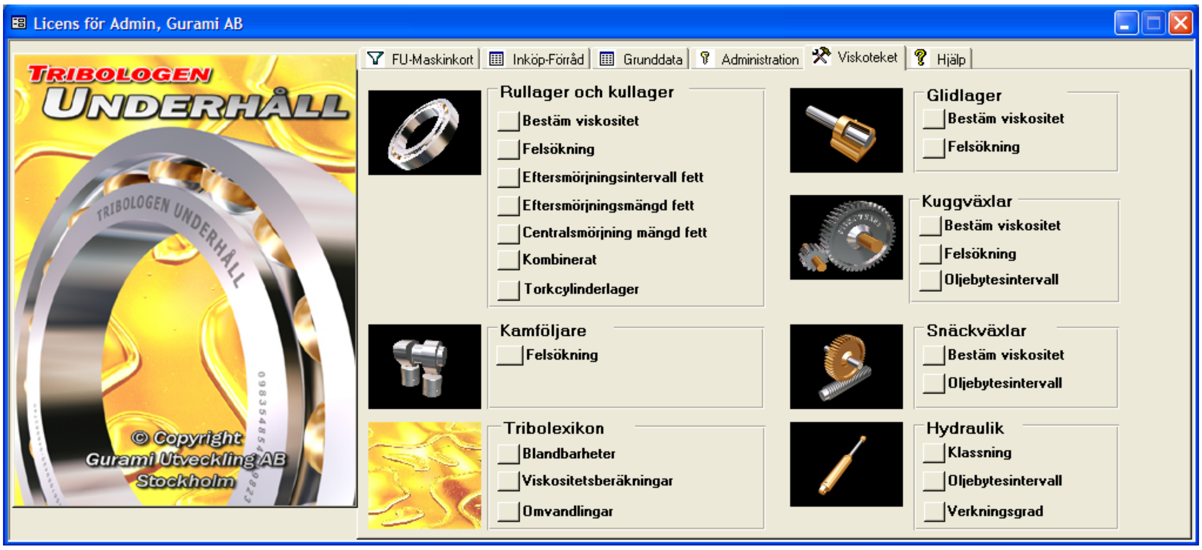


Figure 7:15 Software to determine lubrication

The reason that softwares has been developed is that normal mathematical skills are not enough if you want to ensure the correct lubricant is used on a machine.

This process is troublesome if you do not have very good mathematical aptitude. This is why, many major industries and oil companies today use this type of software to quickly ascertain the correct viscosity, the right interval and the correct amount.
In the maintenance workshops, it is much appreciated that it takes just a few minutes to identify the correct oil.

Often old recommendations are applied
All too frequently "old lubricant recommendations" from machine manufacturers are applied, even though both running times and speeds have changed significantly since the machine was installed 15-20 years ago. The working environment can also be quite different from what the manufacturer of the equipment expected when making its basic recommendation.
Because of this the incorrect base oil viscosity in greases and incorrect amounts are applied at many lubrication points, and elsewhere the intervals are perhaps too long or too short.

Gear drives
Below is a list of input data that you need when selecting the right oil for a gear drive.

You always make the analysis on one gear pair at a time. You then consider the results and make a choice that is often a bit of a compromise between the speeds in gears.

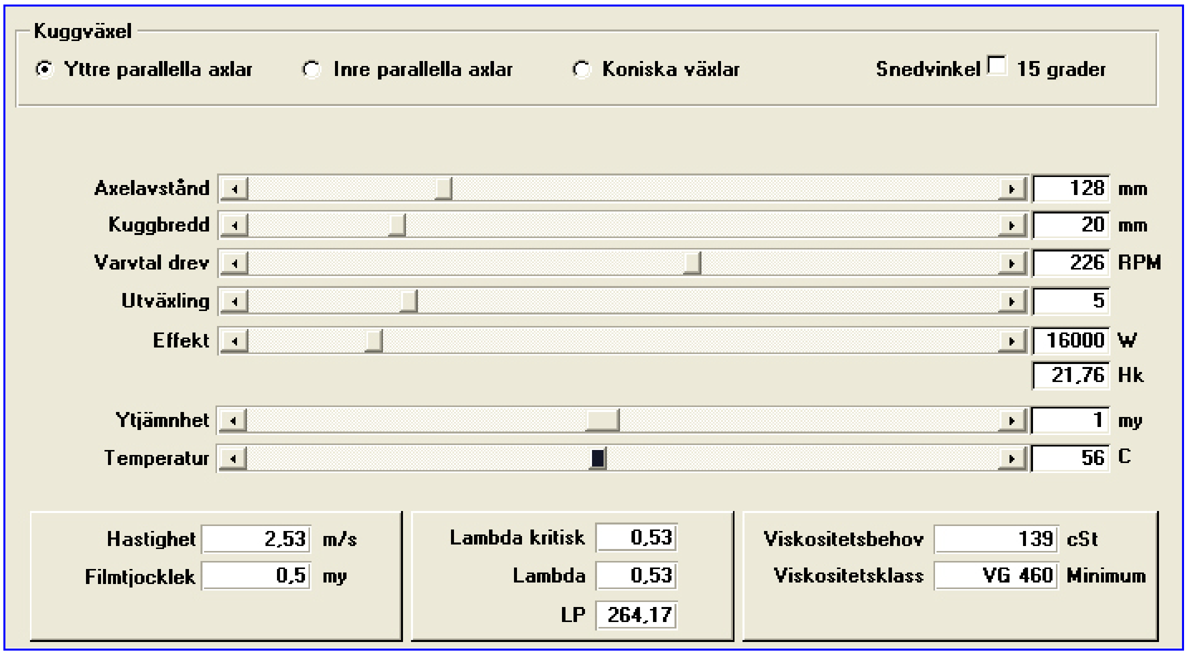


Figure 7:16 Gear drives

Slide bearings
Below is a list of input data that you need when selecting the right oil for a slide bearings. In the case of slide bearings it should be made clear that the play/gap is one of the most important variables. The width and length ratio of the bearing also affects the choice of oil significantly. The semi-manual method is used which is explained in the back pages of this course booklet.

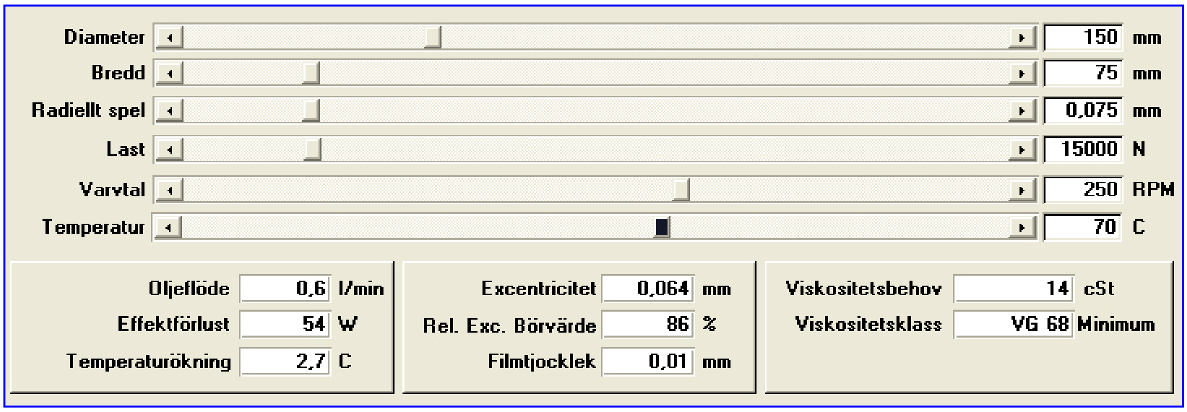


Figure 7:17 Slide bearing

Ball and roller bearings

The key input data required for a ball and roller bearing is shown below. Speed and temperature have the greatest impact. The diameter also affects the viscosity, but not as much as speed and temperature.

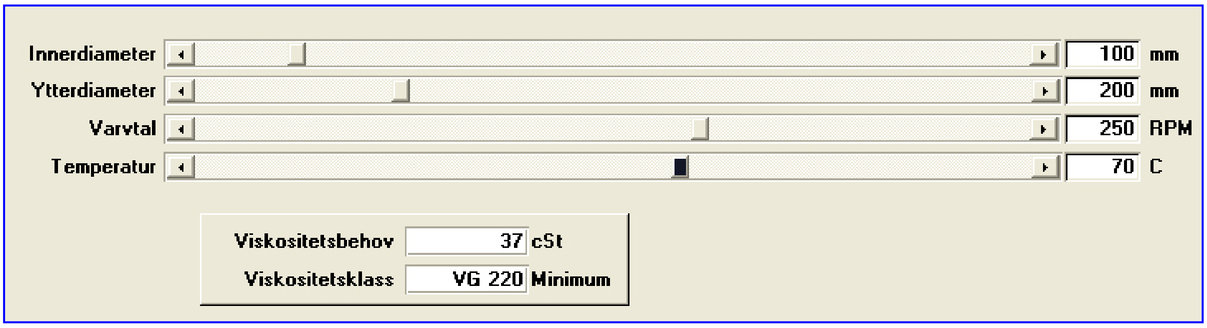


Figure 7:17 Ball and roller bearings

Worm gears/slip joints

Worm gears are classified the same as slip joints/guideways as the surfaces between the screw and gear wheel (crown wheel) are perfectly parallel. This in particular characterises the slip joints - that the surfaces are parallel.

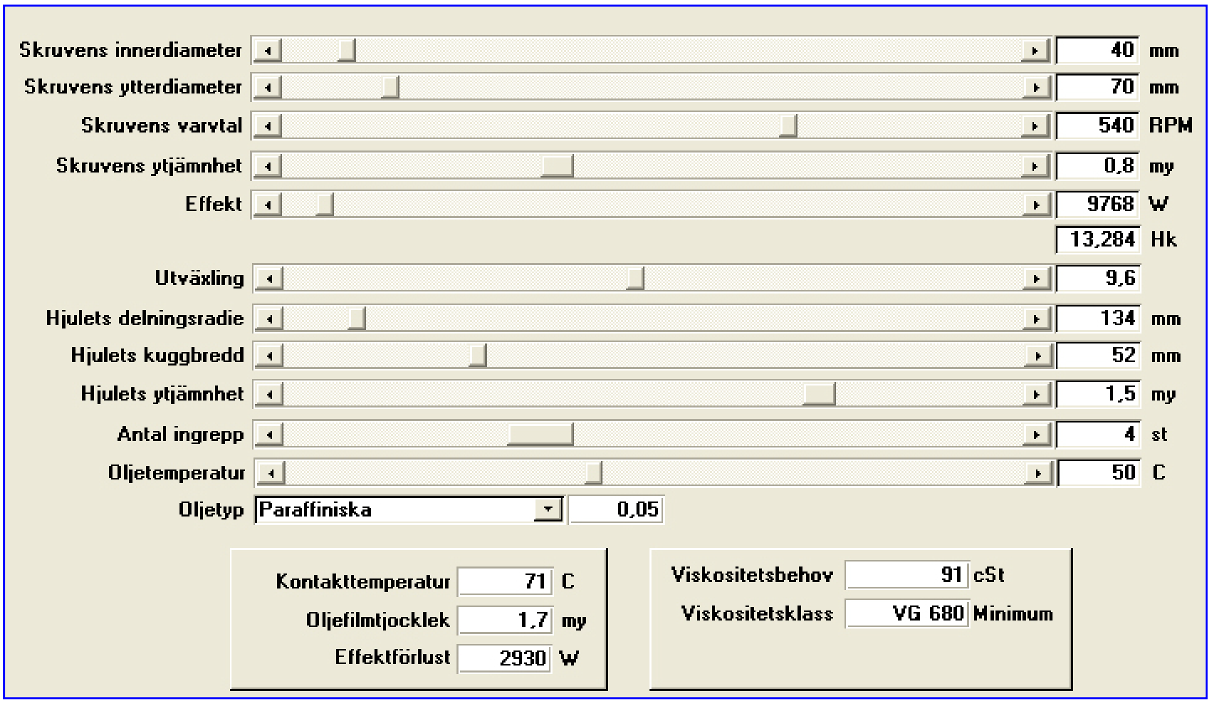


Figure 7:18 Worm gears/slip joints

Three lubricating conditions

In order to achieve minimal **friction** and **wear** between two surfaces, the aim is to keep these apart as far as possible. It is the task of the lubricant to ensure this. How well this succeeds depends primarily on two factors:

- the viscosity of the lubricant
- the relative speed between the surfaces.

This means that if the surfaces move relatively slowly in relation to each other, a high-viscosity oil is needed to keep the surfaces apart. As speed increases, the resistance of the oil increases as well and you can then select a lower viscosity. If you use an oil that is too thick at a high speed, this will result in viscosity friction in the oil and this will generate significant heat in the oil. It normally takes only a few minutes before an abnormal temperature is reached.

Full film lubrication
When the sliding surfaces are completely separated from each other, you can say that hydrodynamic lubrication or full-film lubrication has been achieved. This is the optimum lubrication condition with no or very little wear. The only time wear can occur is on start-up or during the stopping phase when the speed is low and the surfaces scrape against each other and metal contact can occur. Full film lubrication can be compared to when a boat starts to plane on water when increasing its speed. The higher the speed, the better the planing.

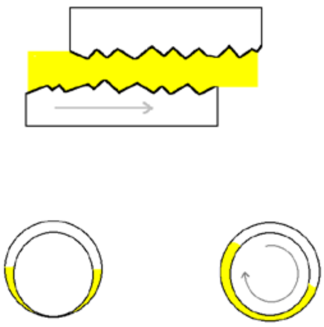


Figure 7:19 Full film lubrication

Mixed film lubrication is a lubricating condition that is in a mixed state where the surfaces still plane on the oil film, but where some of the load is carried by the metal surfaces. Especially in the event of instantaneous load increases, the surfaces come together and some of the load is carried by the metal.

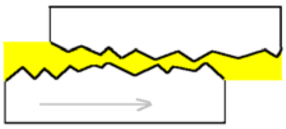


Figure 7:20 Mixed film lubrication

Boundary lubrication is a lubricating condition where there is full-metal contact at all times. This is because the relative speed is so low that a supporting film cannot be achieved even if you increase the lubricant's viscosity, or the load is so high that the oil is unable to create a plane.

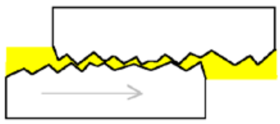


Figure 7:21 Bondary lubrication

In this case, it is about trying to limit the wear damage and save what can be saved. This is done by adding special additives to the lubricant. These additives are called **EP additives** where EP is an abbreviation for Extreme Pressure. EP additives create oxide on metal surfaces, which makes the surfaces very difficult to weld together. See previous text on the wear types micro-welding/adhesion

Two properties

- Chemical properties
- Physical properties

In the analysis of a lubrication problem, tribologists usually divide up the problem area into the lubricant's *physical* and *chemical* functions. This division is helpful in focussing the problem analysis in the right areas.

Does the problem/breakdown concern additives in the oil or the oil's physical properties that are being attacked or changed?
In everyday language we usually call the chemicals in the oil additives. These can age over time and are thereby consumed resulting in negative consequences. Examples of this may be EP additive, defoamer or viscosity index enhancer that over the years can be used up.

Or maybe the problem is about the purely physical properties of the oil. (E.g. viscosity or density) Viscosity that is too low can cause serious wear damage if the right viscosity is not maintained.

An example of this is cavitation.

A lubrication certificate

To describe the lubricant film thickness and current lubrication condition we usually use the Greek letter λ (Lambda). The lambda value refers to the relationship between the oil film thickness and the surface roughness of the contact surfaces.

The lambda value highlights, in a useful and simple way, what we in a lubrication context want to ascertain which is the oil film thickness compared to heights of the metal peaks. (Ra-value)

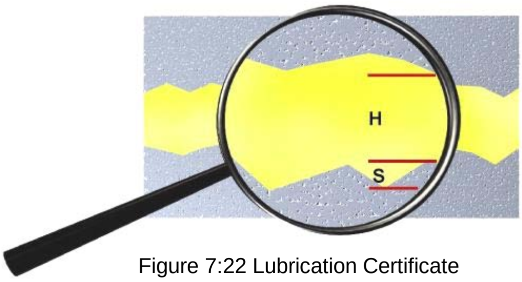


Figure 7:22 Lubrication Certificate

If the oil film is three times higher than the height of metal peaks, the lambda value is 3. This falls under concept of full film lubrication and it tells us that the lubricating film is approved.

$$\frac{\text{OLJEFILM}}{\text{PROFILDJUP}} = \frac{H}{S} = \frac{3}{1} = 3$$

Lambda	Område	Risk
>3	Fullfilm	Låg
1-3	Blandfilm	Mellan
<1	Gränsskikt	Hög

SKF uses the letter "Kappa" to describe the lubrication certificate. This is calculated in a similar manner and the values follow each other.

Lambda 3 is equivalent to Kappa 3.66, for example.

How is oil made?

Base oil

The crude oil that is extracted is transported to a refinery where it is distilled in a distillation column. Distillation works whereby the crude oil is heated with the light fractions (gas, diesel and kerosene) evaporating first and rising to the top of the column where they condense and are drained.

The structure of the oil has been changed in the synthetic oils or greases by chemical means to ensure better properties.
Synthetic lubricants are much more expensive and are used in special circumstances such as at high or low temperatures.

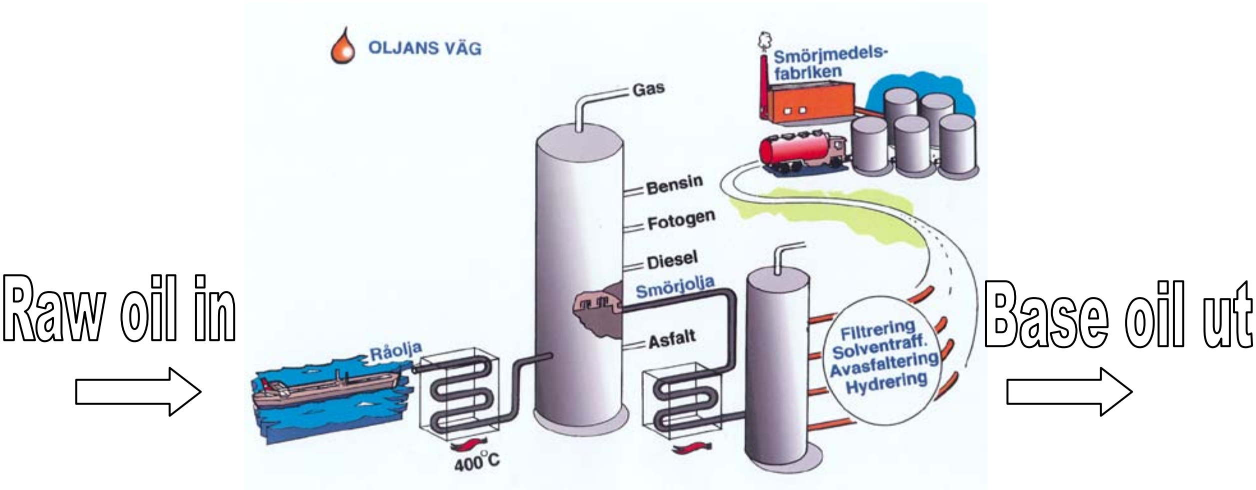


Figure 7:23 Reffinery principle

Additives

In order to ensure other quality properties that are not obtained by the base oil alone, but that are required in modern oils, a range of chemicals are used called additives. The additives that are included in each oil depends on the demands placed on the product.

There are negative aspects to using too much additive, for example, from a caburisation and oxidation perspective. Some products have large amounts of additives added, such as motor oil, while other products such as compressor oils and turbine oils have a minimum amount of additives.

The primary purpose of the additives is to help compensate for some of the deficiencies in the base oil's original appearance. You use the additives to obtain these enhanced properties. Using additives, a large number of speciality oils are derived, each suitable for its own particular purpose. By combining the right additives you can also increase the applications of the oils many times over.

The oil mill, as a rule, mixes the thinnest oil in an oil series in a tank. The thickest oil from the same series is stored in another tank. All intermediate viscosities are mixed directly down in the barrel from these two. Before the oil is poured into the barrel it is thoroughly filtered.

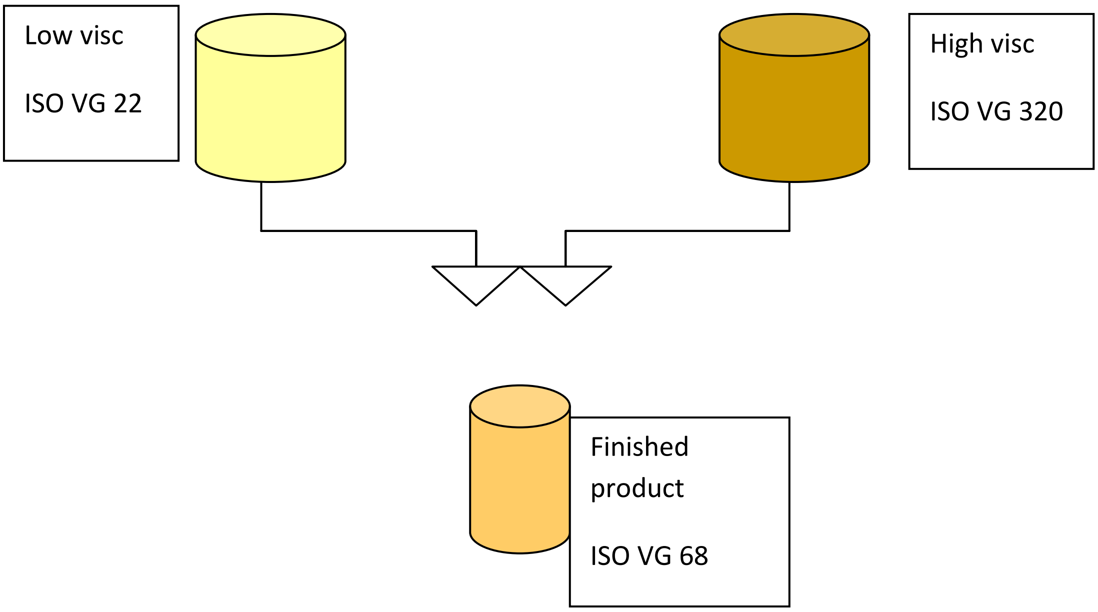


Figure 7:24 Mixing oils

Examples of additives

There are many different additives used in oil and some of the more common additives are described below in brief.

OXIDATION INHIBITOR
To prevent the oil changing character when oxygen is present.

ANTI-CORROSION AGENT
Prevents corrosive attacks to metal surfaces.

DETERGENTS
Prevents deposits and has a cleaning effect on existing deposits.
Motor oil is a product that always contains detergents.

ANTI-WEAR ADDITIVE
To reduce friction and wear.

EP ADDITIVE
Additives that increase the ability of a lubrication oil to bear extreme loads and prevent welding between the surfaces. In rear axles on cars, an EP additive is a must.

FOAMING INHIBITOR
Makes it easier for the air that is mixed with oil to move up to the surface and thereby prevent foaming.

VI-IMPROVER
Reduces the viscosity change with the temperature.

MELTING POINT REDUCER
Drops the lowest melting temperature/point of solidification.

EMULSIFIERS
Added to oil to make it miscible with water. For example, in mist lubrication oil and cutting fluids.

DEMULSIFIERS
Makes the oil in the water emulsion separate easier/faster from the water.

ADHESION ADDITIVES
Increases adhesion of the lubricant on metal.

Figure 7:25 Additives

How is grease made?

Grease is a variation of lubricating oil where a thickener is added to get the oil to convert to a more solid form. You can compare this with the addition of potato flour to thicken a mixture into cream after heating. Grease usually consists of about 90 % oil and 8-9% thickener and a few percent additive.

75-95 %	Base oil (mineral or synthetic)
5-10 %	Thickener
1-5 %	Additive

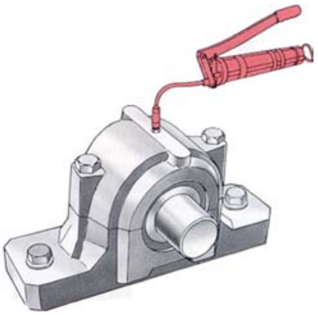


Figure 7:26 Manual grease point

1 Base oil

The base oil is the component that essentially gives the grease its lubricating properties. The viscosity of the base oil, in the grease, is selected according to the temperature and speed range the grease is to be used in. Grease for high speeds has thin base oil. Grease for low speeds has thick base oil.

As regards the type of base oil, the same range is available to choose from as for lubricating oil manufacturing.

- Mineral oils
- Synthetic PAO/polyalphaolefins
- Synthetic PAG /polyalkylene glycols
- Silicone oils

2 Thickeners

Thickener is like a sponge with many holes, which binds the base oil. This is known colloquially as soap. The most commonly used thickeners today are lithium and lithium-complex. These thickeners dominate the market because they are universal and affordable. Other types of thickeners on the market include aluminium, aluminium complex, bentonite, polurea and calcium, calcium sulfonate complex etc. The difference between the different thickeners is primarily the pour point and water resistance. Unfortunately there are no thickeners that are ideal for all areas. If you have high temperatures you should of course choose a thickener with a high
pour point. If you have an extremely wet environment, you should select a thickener that is water-resistant.
Each grease-producer's speciality is soap production which is one of the secrets of a good grease.

How is soap made?

Fatty acid + metal hydroxide + base oil = soap and water

In the manufacture of soaps, you can use a wide range of metal hydroxides and/or metal oxides. By combining these you can produce many different properties.

Metals used to manufacture soap:

- Lithium
- Calcium
- Aluminium
- Barium
- Magnesium
- Titan
- Sodium
- Zinc
- Lead
- Tin
- Bismuth
- Strontium

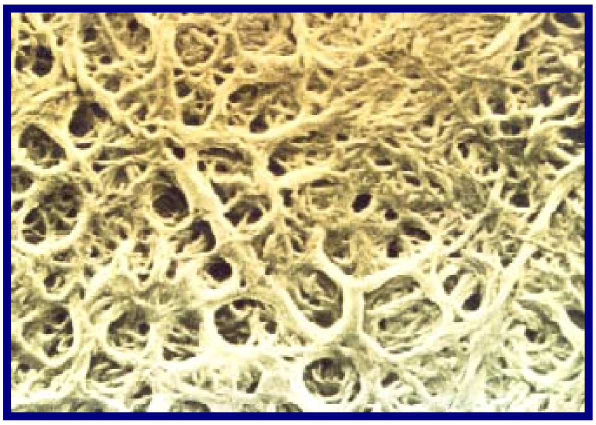


Figure 7:27 Thickeners in 10,000 times enlargement

Fatty acids

These materials are derived almost exclusively from the plant and/or animal kingdom. They are always refined in some way e.g. chemically and/or by separation and purification.

- 12-Hydroxy-stearic acid
- Stearic acid
- Azelaic acid
- Lanolin acid (Wool fat)
- Fatty acids from oily fish

3 Additives

Additives are used to steer the grease properties in the desired direction. Again, you can draw parallels with the technology used for the production of lubricating oils. In a similar way, additives are added to the grease to enhance the lubricating effect with, for example, Anti-wear and EP additives etc.

The most common chemical EP additives are sulphur, phosphorus and chlorine.

Solid lubricants are also frequently used to improve the performance of grease. Examples of solid EP additives include molybdenum disulphide, graphite and Teflon. These represent a group of solid lubricants with the ability to mechanically separate the friction surfaces. These are mainly used at low speeds and high loads.

- Graphite
- Molybdenum disulphide
- Teflon

Dyes are also present in greases. These help the user distinguish between the different greases so that mistakes do not occur. By way of example, using a low speed grease on a high speed application can cause viscosity friction in the oil/grease and create temperatures that are too high resulting in a breakdown.

Figure 7:28 Different types of grease, *SKF*

The amount of grease in bearings and re-lubrication intervals

You can fill a slow speed bearing with more grease. You fill high speed bearings with less grease otherwise you risk overheating the bearing.
However, most greases on the market today are designed to fill the spaces fully which means, in principle, you should be able to fill the free space in the bearing to 80-90 % without any imminent danger of overheating in most cases. In general, you could say the higher the speed the more important the care you need to take with the amount of grease.

Packing a new bearing

Too much grease in a bearing could result in temperature rises and cause negative impacts on both the grease fat and steel in the bearings. At low speeds (> 100 rpm), it is rarely a problem to fill the bearings full with grease, but the higher the speed the more sensitive this issue becomes. The basic recommendation for the new bearing therefore is:
Fill the clear space in the bearing to 30-50%.

Packing of a bearing housing with two bearings, and a clear space between the bearings. As a general rule, the bearing must be completely filled but the clear space in the housing, usually between the bearings, is only partially filled (30-50 %). This universal recommendation tends to be a good solution.

Re-lubrication of bearings

When you lubricate a bearing using a grease gun, the grease content can be adapted to suit the size of the bearing. Sometimes this is stated on the machine or in the lubrication instructions. If this is not the case, this can be calculated very easily using the following formula. The machine should run when you lubricate the bearings if this is possible from a practical and safety aspect. The following standard recommendation applies for a clean environment. If the environment is dirty or damp the lubrication amount must be increased substantially. This is also the case if the temperature is above 70°C. If the temperature is above 100°C, lubrication must be increased dramatically due to the thermal decomposition of grease.
Normally, a grease gun provides about 1-2 grams of grease per pump stroke.

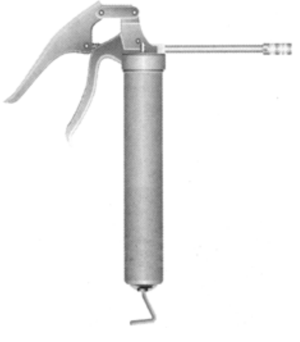


Figure 7:29 Grease gun

D x W x 0.005 = G (number of grams of grease)

D = Bearing outer diameter in mm.

B = Outer ring width in mm.

G = Grease quantity in grams.

Re-lubrication interval

The re-lubrication intervals are very different for different types of bearings. The basic rule is that roller bearings require much more frequent lubrication compared to ball bearings. Roller bearings often have intervals of around 1-6 months. Ball bearings often have intervals of around 1-2 years.

The time interval for correct re-lubrication of the various types of bearings are detailed in SKF or FAG's main catalogue. As a rough rule of thumb, the interval recommendation can be said to be as follows for the different bearing types:

BEARING TYPE	INTERVAL
• Radial ball bearings	6-24 months
• Cylindrical roller bearings and needle-roller bearings	3-12 months
• Tapered roller bearings, spherical roller bearings, cylindrical full roller bearings	1-6 months
• Axial roller bearings, cylindrical axial roller bearings, axial needle-roller bearings	1-6 months
• Spherical axial roller bearings	1-6 months

The environmental conditions at the lubricating point in question obviously affects the intervals.

The above recommendations are based on the environment being good/clean.

Dirty, hot or wet environments require much more frequent lubrication intervals.

The reduction factor for severe environments is usually in the interval above x 0.9 - 0.05

Figure 7:30 Grease nipples

Computer aids for the management of lubrication maintenance

Administration of lubrication maintenance

The “Lubricant” often accounts for a major proportion of the number of PM-points in a normal company.

Usually up to 60-70 % of the number of points are lubrication points such as nipples, gears, chains, clutches, electric motors, hydraulic systems, ball and roller bearings, etc.

Many companies often have upwards of 5,000-20,000 lubrication points to manage annually. Managing these annually is a very complex task that requires specially designed software to ensure this management is good and rational, without too much administrative time at the computer.

In many major maintenance programs such as SAP, Movex, Maximo, IFS and others, a lot of effort has been put into financial controls and reporting time. This type of information is hardly of interest to the oiler. He needs to know the details of all machine parts instead, and how these should be lubricated. Some of these detail areas can be:

- Where are the points?
- Who is responsible for the point in question? (Operator or workshop)
- What volume is required? (grease and oil)
- Which method should be used? (Grease gun, can, centr. lubrcn. , brush, lubricator)
- What tools are needed?
- Which lubricant should be used? (which product is suitable for speed and temp.)
- How often should the point be lubricated? (interval taking into account the environment)
- What leakage volumes have been filled over the years? (at a detail level)

And you should be able to select all the above points from your computer.

Producing a weekly list for a department and reporting this at a detail level should not take up many minutes of your day as you will not be able to keep up with the most important task of lubricating the machinery.

For this reason, special software programs are on the market that satisfy this particular need with more technical data and fewer time and financial reports.

The foundation of these systems is usually a machine card containing fields for the particular lubricating needs. This has been supplemented by an inspection round system that can handle inspection routes and a simple check mark function at a detail level.

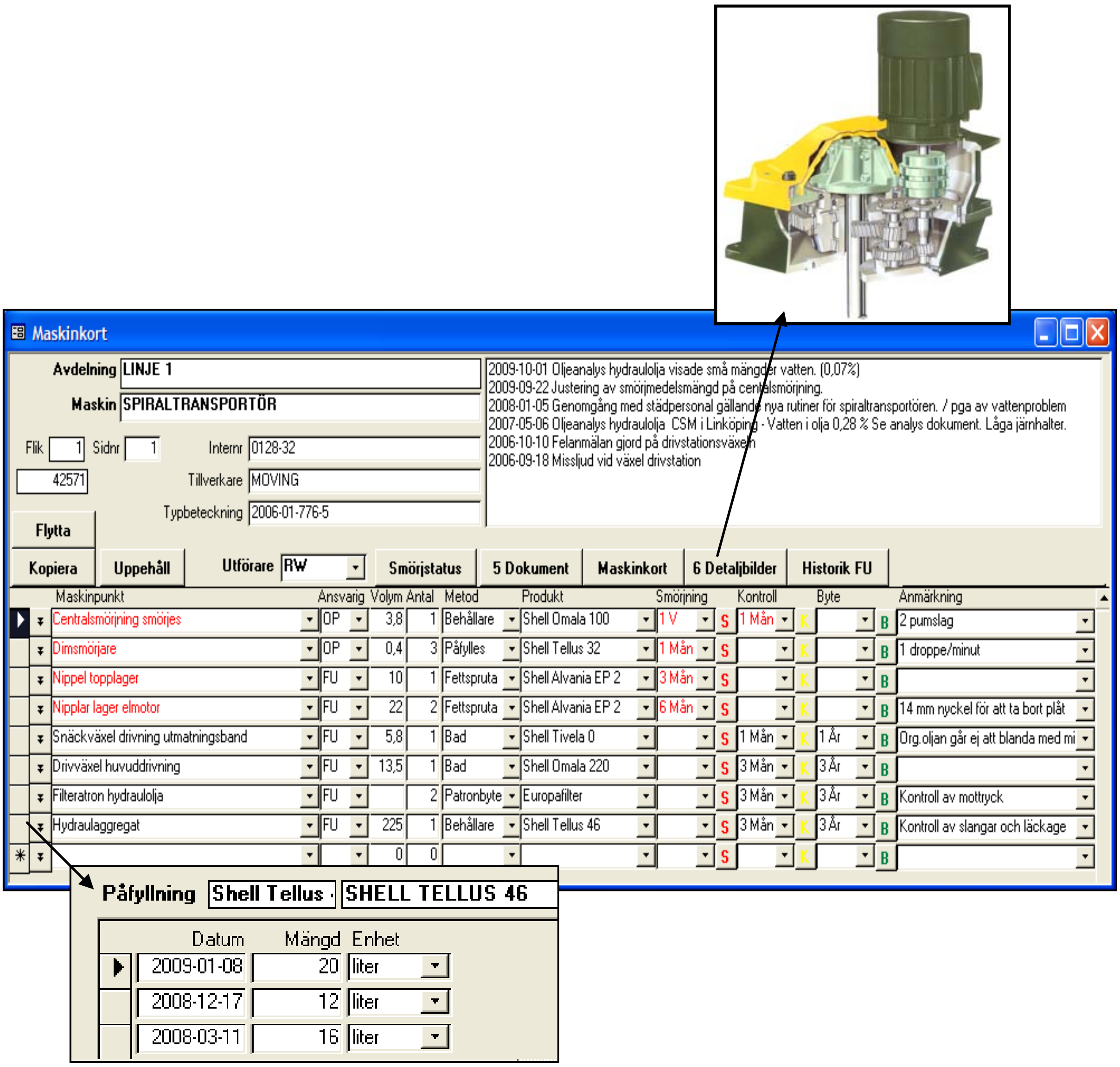


Figure 7:31 Lubrication software

Quality assurance of lubrication maintenance using RFID

Using an administrative expert system you ensure good quality lubrication maintenance.

For “Tribology Lubrication” the Assalub system has “Lube-Right” built in for use by those looking for a guarantee that the relevant lubrication points have actually been lubricated de facto.

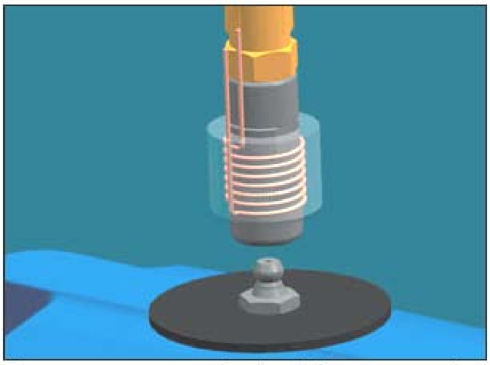


Figure 1. Grease Nipple with Transponder and Hydraulic Coupling with Antenna

This entire method is based on RFID discs mounted under the nipples.
The lubrication for the round is loaded in the grease gun in the morning. You then execute the lubrication round according to the daily or weekly list.
In the afternoon you check off the lubricating points with a cord directly from the grease gun to your computer - All done!

The Lube-Right system checks that all the lubrication points have been lubricated and with the correct amount. No nipples are missed and checking off is made even easier.

In addition, you have the advantage that you cannot manipulate by “unchecking” at your computer.
The only way to check off the point is to lubricate the machine at the place where the disk is located, as it is then a check mark is input into the lubricating system.

Figure 7:32 Lubrication control

Contaminants in oil

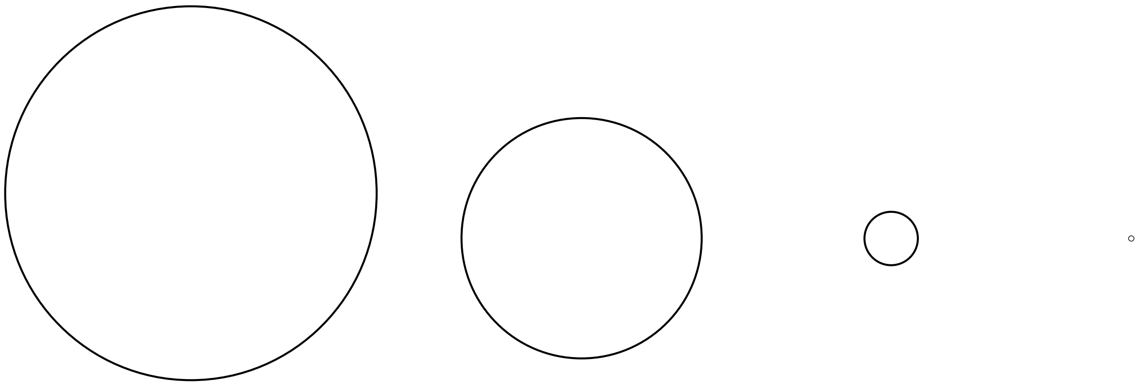
Contaminants in oil are always a bad thing. Contaminants in oils are often the same as the wear of machine parts, (usually iron) but you must remember that it is just as much about the wear of the oil.

By keeping the oil free of contamination, you extend the life of the oil and the machine.

In practice this means that with good filtration you can also extend replacement intervals. A lubricant or hydraulic fluid that has worked for some years often contains a large amount of particles that has a negative impact on the oxidation speed in the oil.

Scope of contamination:

A micron is a unit of linear length. It is the same as one millionth of a metre or one thousandth of a millimetre. One my also stands for the same dimension as one micron.



Hair	*Eye visibility limit*	*Wear particle*	*Lubricating film in bearing*
70 microns	*35 microns*	*10 microns*	*1 micron*

Figure 7:33 Contamination

The eye visibility limit is 35-40 microns, and most of the particles in the used oil are often around 3-10 microns in size. The degree of filtration for normal hydraulic systems is usually around 8-15 microns. When we know that the play in valves and pumps in hydraulic systems is often around 0.5 to 5 microns, we understand the importance of keeping the oil as clean as possible. The lubricating film in a roller bearing is around 1 micron in size. Particles that are larger than this will produce indentations in the bearing race. Having a good and effective filtration system is very important for ensuring a long machine life.

Many lubrication systems unfortunately have no filter at all which is why oil changes are the only remaining option to remove the particles. One such example is gear drives. Magnetic plugs can be a great lifesaver in the gear drives which are unfortunately becoming increasingly rare.

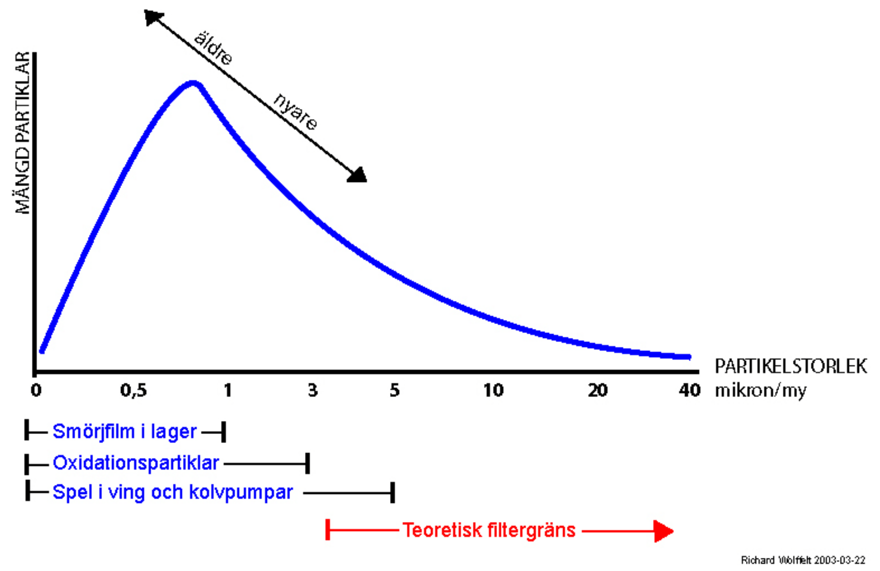


Figure 7:34 Amount of particles vs size

Contaminants
Contaminants are usually divided into three main groups:

Contaminants:

- Particles
- Water
- Air

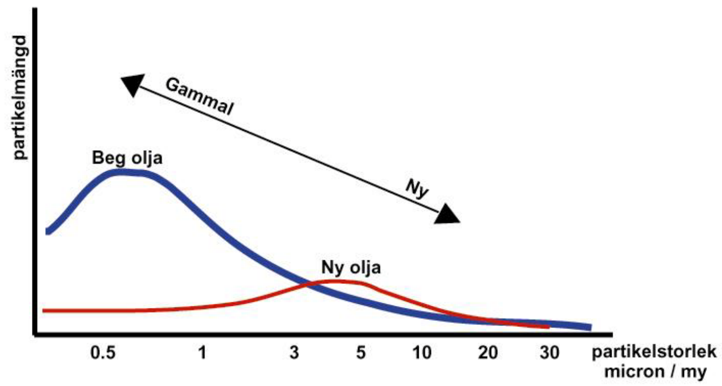


Figure 7:35 Amount of particles vs size old oil (blue) new oil (red)

This is how particle distribution appears in new and used oil

Particles/External contamination
Dirt, water and particles will often enter into the machine's vital parts. The machines often work in a dirty environment where products such as flour, rock dust, water, blood, paper dust, etc. are present in the bearings and gears.
Other examples include venting holes in hydraulic systems that often lack filters. When the hydraulic pump starts, the oil level in the tank drops and air from the room is drawn into the tank. This happens in every work operation/start-up and the particle content increases gradually in the oil.

Particles/Internal contamination
Particles generated by the machine through internal wear are called internal contaminants. Wear particles erode new particles which produce indentations in the baring races and in the cogs, etc. This gradually increases the amount of particles, and the particles themselves therefore create a vicious circle where the particle content is ever increasing.

Water
Water is also a contaminant and has a very negative impact on bearings and cogs and shortens the life expectancy of the machine parts substantially. (See chapter on Tribology/wear types/corrosion) Water can be removed from the oil using special water filters.

Oils must not contain more than 0.02 % water. Water is formed in system tanks where the water in the air condenses and precipitates in the form of water droplets. This is especially common in outdoor systems or when you store oil outdoors. It is easy for a small amount of water to get into the oil in an unopened barrel by storing it incorrectly. SKF's research shows that as little as 0.01 % water will shorten the life of a bearing by 50 %.

Air
Is also a contaminant that accelerates the oxidation (ageing) process in oil. Air also has the negative effect as the oil film becomes thinner. (carrying capacity decreases)
A good air separator in hydraulic and circulation systems is crucial.

Cleaning methods

The most common way to remove contaminants is through filtration. These are often found online in the system flow, but also sometimes offline and circulate in a separate oil circuit. There are other cleaning methods such as sedimentation basins, magnetic plugs, separators and electrostatic oil cleaners etc. However, filters remain the dominant cleaning mechanism in both the manufacturing and automotive industries.

Cleaning methods:

- Filters (online and offline)
- Separators
- Electrostatic oil cleaner
- Magnets/Magnetic filters
- Sedimentation

Figure 7:36 Offline cleaning system with pump and two filters

Filters and Beta value
Verifying the differential pressure across the filter is important. This increases the dirtier the filter gets, and if not replaced in time, it could start to leak past the seals around the filter or, at worst, the filter could collapse completely and non-filtered oil will then pass through the filter.
The same thing happens when the relief valve that is attached to the filter opens. Too many times, a breakdown occurs due to inadequate filter maintenance. There is a filter holder that has a mechanical indicator for the differential pressure in the form of a pin or a manometer; these must not be overlooked.
Many filters have none of these control functions and you then only have to decide to change the filter at a predetermined interval.

Filtering performance is expressed as a beta value, for example, $\beta_8 = 75$.
This shows the particle size that the filter cleans 75 times. I.e. that the particles are reduced 75 times. In the example above, the filter therefore cleans 75 times for 8 micron particles. 75 times is the reduction that has become standard in the filter industry today. This is sometimes called the reduction factor.

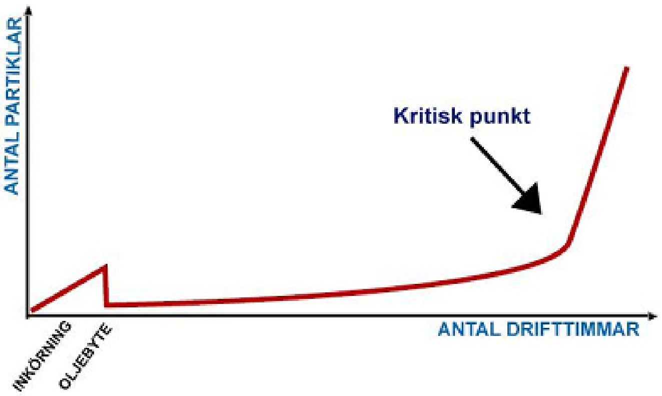
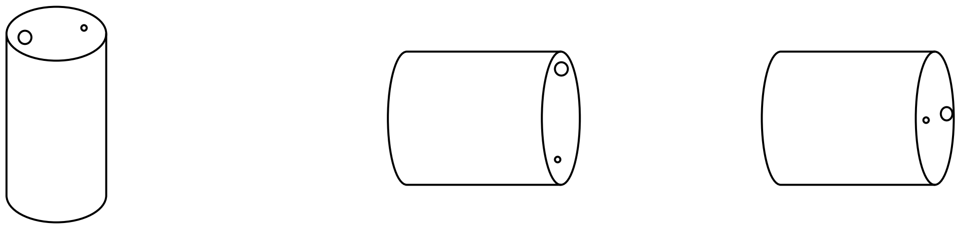


Figure 7:37 Change oil after run in

Storage of oil and grease

Indoors:
Most systems must sometimes be topped up with oil, which means retrieving the oil from storage tanks or barrels. It is assumed that the new oil is in top condition even though it may be a few years old. Oil is not a perishable commodity like food and as long as the oil is stored properly, it has a shelf life of about five years. (Indoor storage) The risks for oil with more than five years in storage is that the additives in the oil sink to the bottom. Oil should be stored indoors at an even temperature. Grease normally has a shelf life of 3-5 years. If the grease is kept where it is too hot (such as in boiler rooms) the oil will bleed easily from the grease and the quality deteriorates.

Outdoors:
A barrel of oil in an unopened tight state is sealed for oil but not for air or water. An upright drum that is located outdoors absorbs moisture laden air, which can then condense inside the barrel. What happens is that the oil reduces in volume at night when the oil turns cold and negative pressure occurs inside the barrel. The cold air is drawn into the barrel through the threads. On days when the sun shines, the oil in the barrel expands after which the air is driven out. But the water that dripped down into the oil remains in the oil.
If the barrel is laid down, the air will not enter the barrel. Therefore, oil drums stored outdoors must be horizontal with the seals at a quarter to three.



Right *Right* *Wrong*

Figure 7:38 Storage of barrels

Location efficient storage

Oil and grease often end up in an area far removed from production due to lack of space. This produces a threshold effect every time the oil and grease must be retrieved.
The following cabinets are examples of space-efficient storage for oils if you use smaller amounts or if you want a store close to production so that the distance does not become a barrier when it is time to apply grease. The cabinet holds 8x25 litres or 5x10 + 4x25 litres.

Figure 7:39 Storage Cabinets

Oil Analyses

Why do we test oil?
That an oil fulfils its designated task is of paramount importance, as the slightest problem with lubrication can have disastrous consequences. One problem that many face is determining when the oil is spent and must be replaced.

Normally, the oil supplier gives recommendations on oil change intervals based on the prevailing operating conditions. That the oil is spent at this particular time is not definite.
A comparison in this context is that it you do not replace ball bearings after SKF's nominal lifespan, but conditioning monitoring of the bearings is used to give an indication when replacement should occur. For this reason, conditioning monitoring of the oil is carried out.

- What condition is the oil in?
- Do we need to change the oil?
- What condition is my machine in?
- What wear particles do we find in the analysis?

Figure 7:40 Oil analysis

Condition monitoring of oil

Most companies with major oil systems (> 600 litres/systems, for example) do not change the oil according to intervals, but send oil samples to an independent laboratory for analysis. This analysis is a good gauge as to the condition of the oil and also the machine. An alternative method is to use portable analysis cases on site enabling you to get an immediate indication of what should be done. The advantage with this do-it-yourself approach is that the analyses can be done as frequently as necessary, and you can begin condition monitoring for the smaller systems as well.

In addition to the oil's condition, you use the oil to check the condition of the machine. By examining the oil under a microscope, you can identify metal particles that have come from the machine. Shiny, yellow-red particles, for example, indicate brass or bronze has eroded from the machine and the beginnings of damage can be detected early on. The objective of the analyses therefore is to detect failures in the machine and/or oil.
Depending on the metals you find, you can get a reference point to the location in the machine where the wear is occurring.

Oil analysis cases like the ones below can be bought on the market. The microscope will normally have a measuring scale in the eyepiece, and you can see how big the particles are in the used oil. The microscope should have 100 times magnification.

Figure 7:41 Test equipment

Sampling
Whether the oil must be analysed on site or sent for laboratory analysis, a sample must be taken. This sampling must be done correctly to avoid any wrong decisions. The following points are important when sampling:

1.
Never take the oil from an idle system, ensure that it is and has been in circulation for several hours

2.
Always use a totally clean and new sample container

3.
Take the oil sample from a point that is representative of the whole system

4.
Follow the same procedure every time

Figure 7:42 Taking samples

It is therefore pointless to siphon off oil from a drain plug as the task of a tray is to gather dirt that settles on the bottom. Use a suction gun designed for the purpose where possible and draw from the middle of the oil bath. There are a number of good oil sampling syringes for purchase.
To ensure a successful outcome, sampling needs to be done properly and in particular in a **clean** way.

What do you test?
These four tests are usually included in a standard analysis.

- **Viscosity**
- **Water content**
- **Particle content**
- **TAN/acid value**

Viscosity
Viscosity is a measure of oil's internal friction. The viscosity to be used is predetermined - our job is to ensure that the viscosity is maintained. A drop in viscosity means that the lubricating oil film is thinned out and the risk of contact with metal increases. The opposite produces a good lubricating film, but also an increased viscosity friction in the oil resulting in raised temperatures. Oil viscosity does not usually change very much under normal operating conditions. Changed viscosity is usually due to oil oxidation, or that the wrong oil has been used.

Water content
Water is a contaminant in many lubrication points. Water in oil must be avoided at all costs. Water originates from condensation in the tanks, leaky coolers, washing etc. A water content above 0.02 % (200ppm) should not be permitted under any circumstances. Water causes a host of problems on the metal surfaces it comes into contact with, in addition to the adverse oxidation effect on the oil that arises together with iron particles and water.
A quick way to check if there is a high water content is as follows:

Pour some used oil on a spoon. Heat under the spoon with a lighter. If you hear a sound/crackles from the oil , there is water in the oil. This method indicates a water content above 500 ppm (0.05 %). A simple and useful “hands-on method”.
If you want a more exact answer, you will need a laboratory analysis. Most oil laboratories can analyse water contents down to 0.01 %.

Particle content
Particles occur as hard and soft. The hard particles cause wear on metal surfaces that contribute to particle formation while they grind each other into micro-particles. The particles that do the most damage are those that are equal to or slightly larger than the current play. At the same it must be said that, as a rule, the full range of particles present in the oil originating from the machine's component parts work a little like a rock crusher.

A simple but very rough check of the particle content is to compare the oil sample with a new oil in two test tubes. However, this method has its limitations because the eye cannot see particles smaller than 35 microns. Checking the quantity of iron particles with a magnet can be done quickly and easily. Stir with a magnet in the used oil sample and study the appearance of the magnet.

A more reliable way is to filter a certain amount of oil through a specially designed filter paper (round) and compare it with previous samples to assess the degree of contamination. If you want to take a closer look at the sample, place the filter paper under a microscope and identify the number of metal particles you find per unit area. The size can also be assessed because the inside of the microscope has a measurement scale to compare against. You can make more accurate particle counts in the laboratory and the oil will then have a class according to the ISO standard with a two-digit or three-digit number that describes the oil's degree of contamination.

TAN/acid value
Oxidation is the same as “ageing” of the oil or grease. The oil will, over time and when exposed to heat, air, dirt, particles or water become increasingly acidic. This acidification/acid value in oil-language is called TAN (Total Acid Number). You will almost certainly encounter this TAN value when studying an oil analysis. Neutral in these contexts is a TAN value = 0. When the product then ages, the Tan value rises by one or more units (e.g. TAN 3-4) and it is then necessary to change the oil before the acid value rises too high. If the acid value is too high, this could affect the packing and it may even cause corrosion and fretting inside the machine's parts.

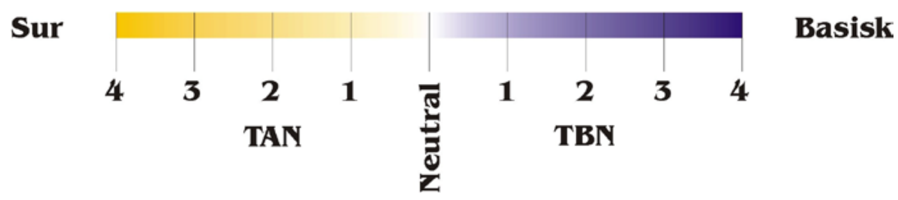
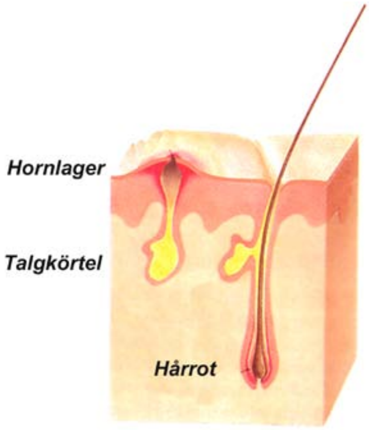


Figure 7:43 pH number

Health risks

New lubricant oil must be regarded as relatively harmless if it is not marked with a skull or other warning sign. Always read the product information sheet when purchasing a new type of oil so that you know exactly what you are using. It is not forbidden to sell dangerous products, you simply need to explain how dangerous they are in the goods information and on the packaging.



Used oil however, must be treated as if it were toxic. This is because you never know what a used oil contains. During the oil's use, a variety of dangerous compounds and heavy metals are formed in the oil. In addition, chemicals can come from external sources. (such as vacuum pumps). When you wash your hands you should use lukewarm or cold water to ensure that the pores of the skin do not open up and allow oil and dirt to enter the sebaceous glands. Dirt and oil together can start a bacterial growth in the sebaceous glands and the end result can be oil acne.

Figure 7:44 bacterial growth in the sebaceous glands

Personal hygiene is very important, and you should avoid letting your skin come into direct contact with oil. The skin (the body's largest organ) is perforated with holes where the oil has almost direct contact with blood, especially through wounds.

Poor hygiene, washing between shifts or oily overalls increase the risk of skin problems in the long run. There is then a high risk of mineral oil substances washing away the natural skin fat and, in the long run, this may cause the skin to dry out following prolonged contact with oils or greases.

This "dry" condition can develop later into an **eczema-like** condition with subsequent skin cracking and bleeding. Always be careful therefore to wear protective gloves when working with oil and/or wash thoroughly between shifts.

Warning List

It is not easy to try to classify oils for their toxicity as different people may be sensitive to different things. In addition, it is also about how much you are exposed to the substance. But it is clear that used motor oil is one of the more hazardous products we can come into contact with. This is how you rate the degree of hazard for different lubricating oils (most hazardous at the top):

1-Used motor oil	Because the combustion residue ends up in the oil
2-Used hydraulic oil	Because of the diesel effect and nitrogen oxides (Nox) formed in the oil
3-Oil mist	Because the oil mist will settle in the lungs/alveoli
4-Used oils	Because hazardous substances can form in oil during operation

Swallowed oil
If you accidentally swallow oil, you should not try to induce vomiting, but instead dilute the swallowed oil with milk or cream, and contact your doctor, of course.
If you vomit, some of the oil could get into your lungs causing chemical pneumonitis as a result.

Oil in eyes
If you splash oil on your skin or in your eyes, clean with soap and cold water. Rinse with plenty of cold or lukewarm water.

Get medical attention if discomfort occurs.

What is REACH?
REACH is European chemicals legislation that came into force on June 1, 2007 in all EU member states. It replaces the Swedish legislation in major areas of the chemical field.

REACH stands for *Registration, Evaluation, Authorisation and Restriction of Chemicals*.

All companies that sell products (lubricants and chemicals) in Europe must register the products they produce and possibly import with REACH.
From a Swedish perspective REACH is an important and necessary development of the EU regulatory framework in the field of chemicals. The ordinance is very comprehensive (1,300 pages) and replaces 40 different EC regulations in the chemical field. It includes fundamental changes to the system for regulating chemicals. The various parts of REACH will take effect gradually.

REACH means that all new substances and those already on the market must be registered, risk assessed and approved. The legislation includes both the substitution and the precautionary principle.

According to the principle of substitution, hazardous substances must be replaced by those that are less hazardous if the alternatives exist.
The precautionary principle is about the operator of a business having to take the precautions necessary whenever there is reason to believe that the business activity may cause harm or undue inconvenience to human health or damage to the environment. These measures are also central to the Swedish Chemicals Policy.

The responsibility for generating knowledge about the chemical properties of substances is put firmly on industry. This information is then registered in a single European registry administered by the European Chemicals Agency ECHA.

A new element is that consumers must receive information upon request on the content of specific hazardous substances in products, such as substances that can cause cancer.
REACH includes fundamental changes to the system for regulating chemicals. Some examples include:
A clear responsibility is put on industry when it comes to generating data on chemical substances, making risk assessments and proposing measures to manage the risks. The responsibility is primarily on manufacturers and importers.

Industry must register approximately 30,000 substances by 2016 and assess the risks for about a third of these. This will improve the knowledge of chemicals already on the market.
Chemicals with particular hazardous properties must not be used without special permission.
The legislation demands that safer alternatives must be considered when testing hazardous chemicals. If the alternatives are economically and technically feasible, the hazardous substances must be substituted.
A new independent European authority (based in Helsinki) is to administer the chemical system.

ADVICE FOR THOSE WHO COME INTO CONTACT WITH OIL:
-You must always wash your hands between shifts along with any body parts that come into contact with oil. Apply a skin care product to your skin after washing to help the skin re-establish its normal moisture and grease balance.
- Never wear oil-soaked clothes
- Wear protective gloves as much as possible
- Replace hazardous oils with less hazardous ones
- Avoid contact with used oils. Used oil is more hazardous than new oil. Oil composition changes over time. The most hazardous are motor oils (benzene, lead, etc.) used hydraulic oils (nitrous oxide) and used cutting fluids.

- Arrange for “safety data sheets” for the various products to be readily available
If you know that a product is hazardous, you can take the right precautions.

Wind farm design

Wind power is an increasingly attractive energy source as it is recognised as providing an environmentally friendly source of electricity. Wind power is the world's fastest growing energy source with an annual growth rate approaching 32 %. And growth is expected to continue growing at double-digit pace over the next decade.

The process for the wind turbine is fairly simple. The wind is used to generate mechanical energy or electricity. A wide range of wind speeds that pass across the blades are converted into mechanical energy. The wind turns the blades and the power from the rotation of the wind turbine rotor is transferred to the generator via the gondola which houses the gearbox, low and high-speed shafts, generator, controller and brake.

In order to produce energy as reliably as possible, the machine must be kept in good condition.

Med bra skick menas ett bra förebyggande underhåll med lämpliga smörjmedel som byts med rätt intervaller. Ofta är det en blandning av tillståndsbaserat underhåll (via mätningar) och tidsintervallbaserat fu. Lubrication is a very important part in contributing to the turbine's hopefully long life.

There are a number of different solutions for a wind turbine design, but the most common principle today is shown below.

In the figure below you can see the majority of the mechanical components of a wind turbine.

The bulk of all the various machine parts must be lubricated with either oil or grease.

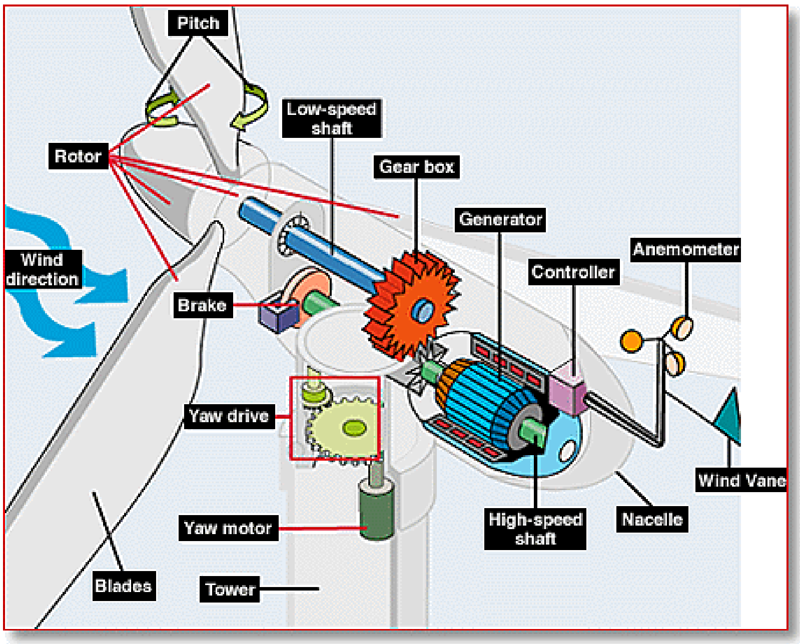


Figure 7:45 Lubrication in a nacelle

Problem areas

The following figure shows a bearing taken from a gearbox of a wind turbine. There is widespread cavitation due the speed being too low relative to the selected oil viscosity in the gearbox.

We should point out however that the oil in a gearbox is much of a compromise. The gearbox is a series of gear wheels and bearings operating at very different speeds.

A wind turbine gearbox runs in principle in reverse. Within the manufacturing industry you would normally have a lower speed out of the gearbox to the machine drive. The electric motor speed is often 1,400 rpm, for example, in the gearbox and maybe 280 rpm on the output shaft from the gear. (Ratio 5:1)

A wind turbine works precisely in reverse. On the input shaft (windward side) the speed is extremely low, and out to the gearbox the shaft to the generator runs at a much higher speed.

Most manufacturers of gearboxes for the wind power industry have experienced similar problems. The problem concerns the gearbox which usually starts in one of the bearings on the low-speed side. (windward side).

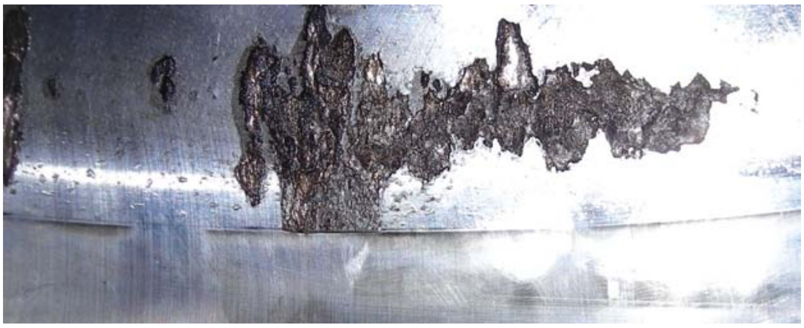


Figure 7:46 Bearing seized, *SPM Strängnäs*

The problem is that some bearings in the gearbox have extremely low speeds, while others have high speeds. All the bearings must work with the viscosity of the oil.

Service costs are extremely high for maintaining and repairing equipment that is very inaccessible, and this is a problem for the economy and the ultimate profitability of wind turbines. The entire mechanism sits high in the air on a column, sometimes up to 200-250 metres high, plus they are often located in inaccessible areas in deserts or offshore.

An experienced wind turbine maintenance engineer told me that the gearbox on some wind turbines needs replacing about 3 times over a 20-year period.

This means that profitability will be jeopardised in some cases and even more so if the turbine placed out at sea, as replacement costs then become very high. The following articles give an insight into how lubricant manufacturers, maintenance engineers and machine builders look at the issue of lubrication maintenance of wind turbines.

Hydraulics

Hydraulics are not to be regarded as a machine part as a hydraulic system is a complex system composed of several different mechanical elements. The hydraulic system often has roller bearings, slide bearings, guideways and gear wheels.

Hydraulics enjoyed a major breakthrough in the early 1960s when fully mechanised, cable-guided excavators were replaced by hydraulic excavators.

Hydraulics had an immediate impact in several areas. Hydraulics has meant a revolution to manufacturers of mobile mechanical devices through the ability to seamlessly transfer large outputs at high efficiency from a central power source to distributed users combined with the ability to continuously adjust the hydrostatic power and torque ratio in the energy transfers.

The oil in a hydraulic system is not only used to transfer energy but is also responsible for the lubrication of the components in the system where the lubricating properties under different conditions are of major importance for the life of the components.

By working at high pressure (200-300 bar), low flow rates (maximum 4-5 m / s), small plays in pumps, motors and valves, an optimum viscosity (15-30 cSt) and a hydraulic oil with low air content, an efficiency of 80-90 % can be obtained for a single circuit hydraulic pump-hydraulic motor or hydraulic pump-hydraulic cylinder.

The distance between the power source and user of 20-40 metres is no problem if the pipes and hoses are of the right capacity.

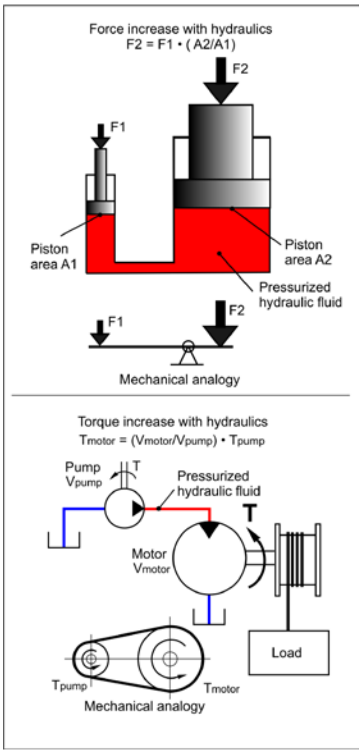


Figure 7:47 Hydraulic principle

With a hydraulic line with an inner diameter of 25 mm, an output power of 83 kW (111 hp) is transferred at a flow of 200 l/min (equivalent to a flow rate of 7 m/s) and pressure of 250 bars.

What is the correct oil?

Oil based on mineral oil is normally used with various additives to reduce the viscosity's dependence on temperature. These additives provide hydraulic oils with a high viscosity index (VI). Viscosity-enhancing polymers are mainly used in hydraulic oils for outdoor use. The viscosity index is a value that describes how the viscosity of the oil changes at different temperatures. The viscosity index is a very important variable in outdoor hydraulics, as the viscosity should not vary too much in order to ensure correct operation at different temperatures. Other properties that are important for a hydraulic oil are air separation capacity, and that oil does not age at higher temperatures. (Oxidised)

Ageing
The temperature determines mostly how long the oil can be used before a change must be made. The degree of filtration is often around 8 microns in hydraulic systems. Hydraulic oils can usually be used for between 1-10 years in most cases if there is a good filtering system in place.

Efficiency and viscosity
Generally speaking, the right operational viscosity for hydraulic oil should be between 15-30 cst.

Lower operational viscosity results in leaks, a poor lubrication film and a deterioration of the volumetric efficiency. Higher operational viscosities (e.g. 50-200 cst) produce a low efficiency, cavitation, and a more sluggish response in the system. The absolute maximum recommended starting viscosity is 1,000 cst.

Synthetic or mineral oil
Mineral oils are used today in 99 % of hydraulic systems as the volumes are usually relatively large and the price is a key factor.

From a purely technical aspect, it makes sense to use synthetic oils as they have a higher natural viscosity index. The composition of synthetic oils (e.g. PAO Poly alpha olefins) usually provides a higher efficiency and longer interval between replacements. The problem has been that it is often difficult to recoup the higher purchase price for larger systems. With rising energy prices, the picture has changed for the better for synthetic oil. Efficiency improvements between 3-5 % are not impossible to achieve using a synthetic oil. What this yields financially obviously depends on how many cycles the machine runs a year. The more cycles, the more potential there is to save money.

A normal-sized excavator could save 3,000 litres of diesel per year, for example, resulting in a reduction of eight tonnes less carbon dioxide.

Environmentally friendly oil
For mobile and stationary machines located outdoors, a requirement for many applications, is that biodegradable oils are used where there is a risk of major leaks where mineral oil can contaminate land and groundwater. This could, for example, apply to wind turbines, bridges, sluices etc. Both vegetable and mineral oil based oils are currently on the market that meet the requirements set for biodegradable oils.

Purity
Hydraulics worst enemies are particles, water and air.

The major hydraulics manufacturers claim that between 70 and 90 % of all hydraulic problems are due to poor oil condition. (= Too many particles/too much dirt)

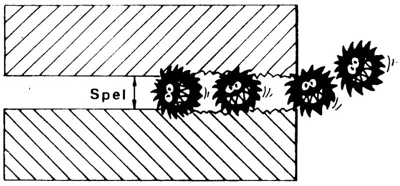


Figure 7:48 Particles in hydraulic system

The particles can be generated internally or come from the outside such as sand, production dust and more. A hydraulic system design is based on very fine tolerances and small play to ensure good performance and efficiency. Slide valves may, for example, have a play of 5 microns. Particles that are equal in size to the play in question or slightly bigger are obviously dangerous and will cause wear. Efficient filters are therefore essential.

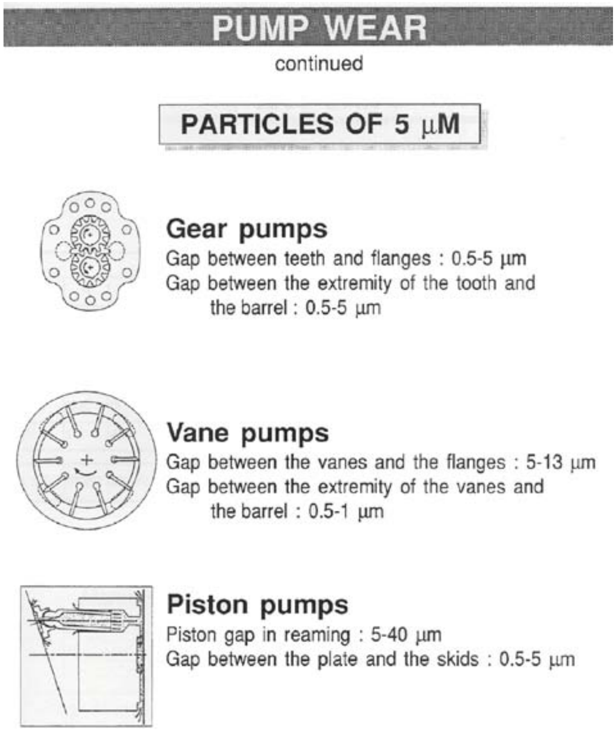


Figure 7:49 Clearances in hydraulic components

Filters

The small plays in the figure above illustrate how important it is to have efficient filtration of the hydraulic oil to ensure that expensive components in the system do not wear out prematurely. The components that are most sensitive are valves and pumps as the plays are very small in both of these components. The most common type of pump on the market today is a gear wheel pump because of its rugged and simple design.

Filters can be installed online (in the system flow) or as offline filters. (has a separate pump that slowly pumps oil through the filter)

Online filters can be divided into suction or pressure filters, depending on which side of the pump they sit.

The offline filter is more efficient and takes less particles compared to online filters.

Online filters filter particles down to 5-8 microns. Offline filters filter particles all the way down to 0.1 microns. A combination of the two types of filters in larger systems is usually the optimum configuration.

These two types of filters usually have a breathing filter to ensure that the particles in the ambient air are not sucked into the oil tank and then adhere to the oil.

Purity classification of oil

Most hydraulics manufacturers today set demands on the purity of hydraulic oil being maintained for the warranty to be valid. To ensure disturbance-free operation after this warranty period, oil should of course maintain this purity level.

The purity classification is ISO 4406 and consists of a three-digit purity code. The codes for the number of particles are read in a table designed for this purpose which provides a code for a certain number of particles.

The three-digit ISO code therefore describes the number of particles there are in the used oil that is greater than 2, 5 and 15 microns. The lower the ISO code, the purer the oil. Example ISO code: 16/14/12.

See table on next page

ISO 4406

Maximum number of particles per 100 ml.	CODE
1,000,000,000	30
500,000,000	29
250,000,000	28
130,000,000	27
64,000,000	26
32,000,000	25
16,000,000	24
8,000,000	23
4,000,000	22
2,000,000	21
1,000,000	20
500,000	19
250,000	18
130,000	17
64,000	16
32,000	15
16,000	14
8,000	13
4,000	12
2,000	11
1,000	10
500	9
250	8
130	7
64	6
32	5
16	4
8	3
4	2
2	1

1	**0.9**
0.05	**0.8**
0.25	**0.7**

Example:

> 2 my	**64.000**	**16**
> 5 my	**16000**	**14**
> 15 my	**4.000**	**12**

= ISO CODE 16/14/12

In Chapter 1 there was a parameter affecting the operational reliability called maintenance supportability. Maintenance supportability means that maintenance must ensure that the logistics concerned with maintenance activities and their execution are carried out correctly from both a quality and quality aspect, and at the right time. What underlying areas does the impact of maintenance supportability have?

Example 1: Corrective maintenance unscheduled (“emergency work”)

One Saturday morning a hydraulic pump breaks down at a plant, which is why the turbine is subject to emergency shut down. A steady wind is blowing, so the owner would like to restart as soon as possible and contacts the maintenance provider.

A technician who is on-call at weekends is contacted. He/She, in turn, calls around to see if someone wants to do “a bit of overtime” as there has to be two technicians. They travel out on Saturday afternoon. Once they are there they can clearly state the pump has tripped (electrically). Fault tracing reveals the cause of the stoppage: A seized bearing on the drive motors DE (Driving End). The electric motor (10 kW), or bearing must be replaced.

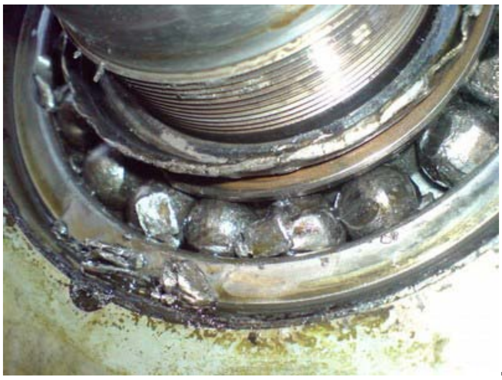


Figure 8:1 Seized bearing

The owner takes the decision to change the bearing on site as it is faster (Saturday night is approaching), and it is confirmed that there is a spare in the service van. The motor is removed and “dismantled”, and one of the technicians go to get the spare bearing.

Back down at the van, she find the right type of bearing but it turns out that the new bearing has rust damage. It is evident the box has been previously opened and the oily protective paper removed, and the bearing has been put back without the protective paper.

Full speed ahead to the workshop to look for a spare motor. It then turns out that the spare motor is for foot mounting and a flange motor is needed. The flange motor had been used on another turbine last Thursday, and the replaced motor was sent for rewinding (motor burned)

With a heavy sigh, they have to call and notify the owner that the turbine will not be up running before Monday afternoon at the earliest when they have got hold of a new bearing/motor.

Do you invoice the customer for the work? Will the customer pay? What went wrong?

What have we learnt from the example above? How could downtime be reduced within the term (parameter) maintenance supportability?

Maintenance organisation

If maintenance work is to be performed outside regular working hours, the number of staff should reflect the actual needs for a rapid deployment of this type. It should not be the duty of a technician to call around to see if anyone can “help out”.

Routines

It must be clear from the beginning how to act when faced with a specific situation (breakdown/disturbance). Improvisations for solving a problem usually result in longer downtime/repair time, or that only a temporary repair is made that somehow becomes “permanent”.

Tools and aids

It must be clear as to the type of work, even urgent, that is to be performed at the turbine (routines). This is to ensure that the correct tools and aids are stored in the service van.

Spares management

A review of replacement needs (the number of different parts) and levels of spares (number of same part) must have been made. The spare parts store must reflect the number of turbines and the estimated needs. Furthermore, the parts held in storage (including the service van) must avoid “value maintenance”.

Quality

Replacing the bearing on site should be avoided if it can be done under more controlled conditions in the workshop with the correct tools. This has a direct effect on the life of the bearing.

Planning and preparation

Once the cause is established, there must be a plan. The estimation of time and need for resources, aids and supplies for executing the work.

Follow-up

What amount should be invoiced? What work has been performed (invoice text), and the spare parts and supplies used (specified on the invoice)

As we see from the examples above, we need an internal structure for maintenance ensuring the right action is taken at the right time, regardless of whether the operation is of a corrective or preventive nature. The following addresses some of the areas that provide this structure.

Administration using maintenance systems

Stock keeping of spare parts and supplies

Planning and preparation of maintenance operations

Routines and documentation

Planning and preparation

Planning and preparation is one of the key tasks that maintenance has to improve maintenance reliability. Properly functioning planning and preparation not only provides better maintenance reliability but also better discipline and improves staff motivation. It also raises the quality of work performed, which paves the way for fewer “implemented failures”.

Planning means to establish a series of events that take place over a specified time period. This period may extend over different time horizons, depending on what is scheduled.

If we look at how a working day is utilised, it may look as follows (not unusual).

- Hours worked – performed 45 %
- Transport - to/from work site 8 %
- Discussions with supervisors etc. 2 %
- Retrieve materials, transport before shipment 15 %
- Locate the documentation, reading drawings etc. 10 %
- Breaks, personal needs. 12 %
- ………………. 8 %

We see that time is consumed for the various activities both within and outside the task you are set to perform. By *preparing* the work, these hours can be reduced.

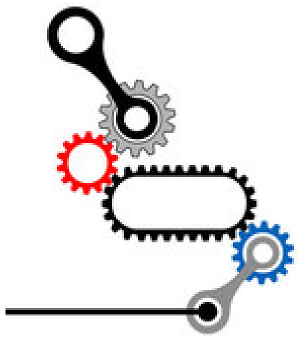


Figure 8:2 Do you have the right spares

Planning and preparing maintenance tasks can be both complex and labour intensive, but the result of thorough planning and preparation work yields results.

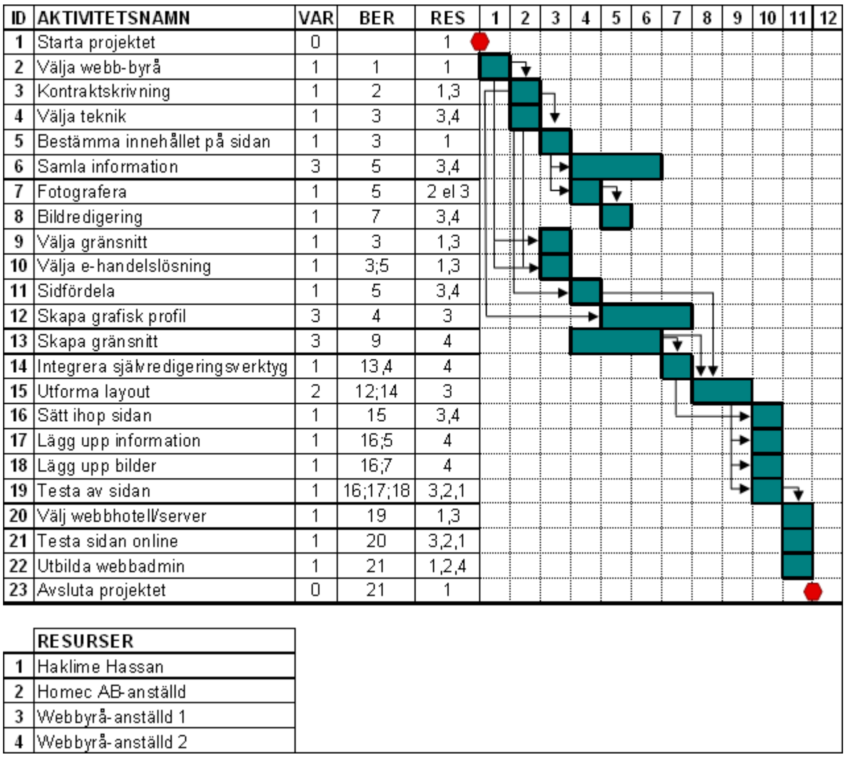
The planning horizons can be

- Day - allocation of daily resources
- Week - allocate resources over the week, ordering of cranes and other equipment
- Month - purchasing, ordering of spare parts, service staff
- Year - Budget, resource needs
- Specific efforts - major stoppages, audit inspections

For the planning work, some type of aid must be used to structure the time of the tasks to be performed.

Figure 8:3 Tools for daily and weekly preparation

For simple and short-term planning (day) it is enough with pen and paper to keep support notes. However, for a longer planning horizon (week, month and year), and several related activities it would be unmanageable. There are therefore a number of simple and more qualified planning tools currently available. Most are based on some form of Gantt chart.



ID	AKTIVITETSNAMN	VAR	BER	RES
1	Starta projektet	0		1
2	Välja webb-byrå	1	1	1
3	Kontraktskrivning	1	2	1,3
4	Välja teknik	1	3	3,4
5	Bestämma innehållet på sidan	1	3	1
6	Samla information	3	5	3,4
7	Fotografera	1	5	2 el 3
8	Bildredigering	1	7	3,4
9	Välja gränsnitt	1	3	1,3
10	Välja e-handelslösning	1	3;5	1,3
11	Sidfördela	1	5	3,4
12	Skapa grafisk profil	3	4	3
13	Skapa gränsnitt	3	9	4
14	Integrera självredigeringsverktyg	1	13,4	4
15	Utforma layout	2	12;14	3
16	Sätt ihop sidan	1	15	3,4
17	Lägg upp information	1	16;5	4
18	Lägg upp bilder	1	16;7	4
19	Testa av sidan	1	16;17;18	3,2,1
20	Välj webbhotell/server	1	19	1,3
21	Testa sidan online	1	20	3,2,1
22	Utbilda webbadmin	1	21	1,2,4
23	Avsluta projektet	0	21	1

	RESURSER
1	Haklime Hassan
2	Homec AB-anställd
3	Webbyrå-anställd 1
4	Webbyrå-anställd 2

Figure 8:4 Gantt Chart

The Gantt chart can be created easily using MS - Excel, or the MS - Project and Primavera software. This chart shows how the different activities are dependent or independent of each other.

The planning work gives you a time, resource and material needs for a task. The preparation can be complicated and requires a lot of experience in order to get it right. Preparation includes answering the following questions:

- What is the job?
- On what equipment will work be performed?
- Who is responsible for the work?
- In what priority will work be performed?
- When (in time) will the work be performed?
- What resources are required in terms of numbers and skills?
- External inspection of the results?

- Spare parts & materials?
- Aids such as cranes, scaffolding, special tools?
- Instructions?
- Documentation?
- Risk analysis?
- Function check-out?
- Review with person responsible and performer?

To ensure accurate preparations, it is necessary to look back in time (past measures) to see where the problem areas were, and how long it took to correct them.

One area where P & P can be used to great effect is in preventive maintenance. Here you can “once and for all” document preparations which can then be part of the documentation that accompanies a work order (AO - see Maintenance system below).

Figure 8:5 A planner in action, what about 5S?

Maintenance system CMMS

Maintenance systems are not only used to manage maintenance activities such as planning and preparation as above, but they are also a tool to maintain control over the purchase of spare parts for stocking.

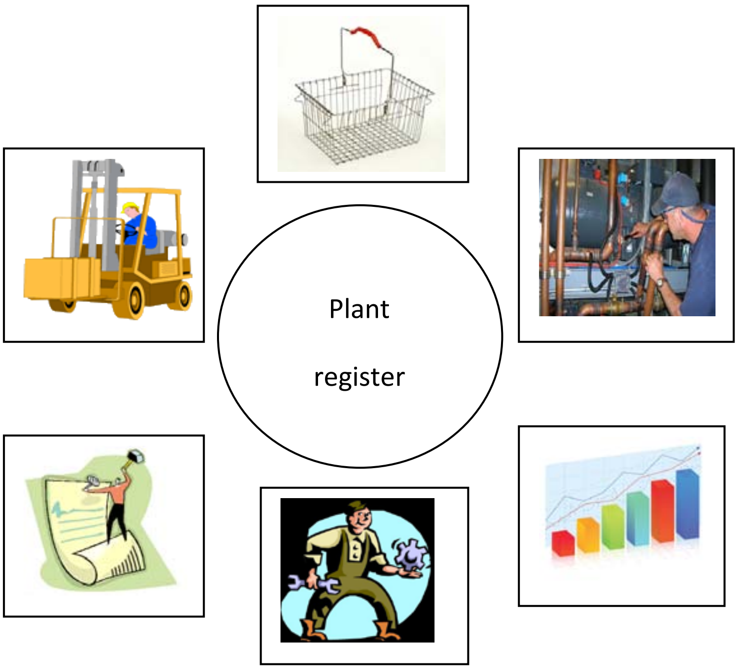


Figure 8:6 CMMS - system

The maintenance system can be seen as a wheel, where the hub of the wheel is the *plant or equipment register*, around which support functions (modules) are connected for stock keeping, work order management, preventive maintenance, purchasing, scheduling, equipment history, and financial monitoring/statistics.

The *work order module* deals with the work to be performed. The order is sent electronically to the performer. The order can have supporting documentation in the form of work permits, hot work permits, instructions and lists of requisite materials.

The purchasing module handles purchase requests and purchase orders.

The *PM - module* manages preventive maintenance. It specifies what, when and how work is carried out. When the time comes for a “PM - job”, a work order is generated.

The statistics module allows you to monitor history, economy, and various types of reports can be generated.

Today there are a number of different suppliers of maintenance systems. Maximo, Rejus and Terema to name a few.

There is also a similar system which also includes a production module. The module is designed to schedule, control and monitor production. These systems are called business systems. Examples of business systems, SAP, IFS and Movex

Store keeping

The store has an important task in maintenance, since in many industries or other businesses it still has a remote location. The concept of maintenance supportability is largely that there is a good supply (logistics) of spare parts and materials.

Figure 8:7 Store keeping

As the antithesis to this, there are always financial demands to hold as little stock as possible. This is due largely to capital being tied up “and put on the shelf”.

Furthermore, calculations have been made on what the cost is on an annual basis based on the value of the stocked parts. In a “badly” managed store room, where control and monitoring of current parts is not made on a regular basis, the annual cost could amount to nearly 40 %. This compares to a “well-managed” store room which is around 15 % - 20 %. It should also be noted that the value of parts for a major company may reach SEK 100 million.

The challenge is to balance the need for the inventory level and what parts should be kept in stock, against the cost. There are a number of financial methods to determine the most economical storage approach. One basis for this is to divide the parts into degrees of importance. Some examples are:

- Insurance spares
- General spares
- Supplies or consumbles

From a maintenance perspective you should therefore develop preventive maintenance, so that you can clearly predict needs (e.g. on an annual basis).

1. What is the definition of maintenance?
2. Explain the development of maintenance work over the last 50 years.
3. Indicate areas of operation where maintenance is well developed and where it has a low priority?
4. What is meant by the term operational reliability?
5. Which parts (parameters) does operational reliability consist of, and what do the parameters refer to?
6. Explain the concepts of MTBF, MTTF, MWT, DT, MTTR. What are their mutual relationships (connections)?
7. For a wind turbine the down time for corrective maintenance was 42 hours over 1 year. During the same time the gearbox was changed with a new design. This resulted in a down time of 90 hours for the gearbox replacement. Routine preventive maintenance was then carried out on a quarterly basis. This took 16 hours each time.

   Calculate the availability of the wind turbine.

   The turbine has a capacity of 1.5 MW. The energy produced during 1 year was 8,530 MWh. How great was the plant performance?
8. Calculate the "technical efficiency".
9. What is meant by the term maintainability? Name three factors that can improve maintainability.
10. What is meant by the term maintenance reliability? Name three factors that can improve maintenance reliability?
11. What is meant by functional reliability? How can this be affected?
12. How can time be reduced for repairs?
13. How can waiting time be affected?
14. Calculate the key performance indicators of two different wind turbines, through contact with your trainee post. Both availability and plant performance if possible.
15. In a drive chain on a wind turbine, we have the following functional reliability.

Blade:	0.999	Brake	0.999
Feathering mechanism	0.958	Yawdrive	0.995
Shaft	0.990		
Gearbox	0.950		
Generator	0.995		

   Calculate the functional reliability

1. Into which three main groups is maintenance divided?
2. Give three examples of unscheduled corrective maintenance
3. Give three examples of scheduled corrective maintenance
4. Give three examples of subjective inspection
5. Give three examples of objective inspection
6. Give three examples of improvement maintenance
7. What are the four maintenance activities? Rank according to “degree of importance”.
8. How is maintenance affected as automation increases?
9. What is meant by function check-out?
10. Which is the most important asset for a maintenance technician, to be “multi skilled” or “highly skilled”?
11. Which professions are involved in maintenance?
12. Give examples of direct maintenance costs.
13. Give examples of indirect maintenance costs.
14. Why should we avoid maintenance activities of an inspection nature in which the object is affected by the inspection?
15. In what phase of life must maintenance be considered?
16. Name five activities that are classed as indirect preventive maintenance
17. Name five activities that are classed as direct preventive maintenance
18. English terms are often used in maintenance. Translate into Swedish, using the list of definitions in the chapter.

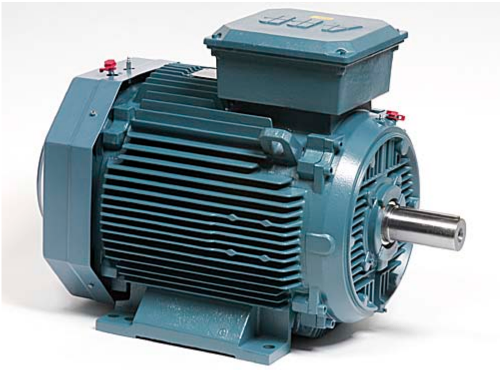
a.	Corrective Maintenance	i.	Monitoring
b.	Availability	j.	Function Check-out
c.	Maintainability	k.	Temporary Repair
d.	Redundancy	l.	Improvement
e.	Failure cause	m.	Up time
f.	Hazardous state	n.	Down time
g.	Scheduled maintenance	o.	Life cycle
h.	Predictive maintenance	p.	Maintenance record

1. What is the purpose of preventive maintenance?
2. Why is it seldom profitable to engage in preventive maintenance to avoid all corrective maintenance?
3. What is meant by improvement maintenance? Give examples.
4. What is meant by the term CBM?
5. What is meant by “red-line machines”?
6. What type of preventive maintenance should aim to minimise impacts on the object/equipment?
7. Why is corrective maintenance difficult to schedule?
8. Give examples of scheduled corrective maintenance?
9. Is it possible to “run to failure”, and if so, what?
10. What “times/activities” will disappear if you substitute corrective maintenance with scheduled preventive maintenance?
11. Preventive maintenance takes on average 4 hours to complete. The time you have available to perform maintenance is 3 hours. How do you manage to cut the time to 3 hours without reducing the amount of maintenance activities?
12. You are carrying out service on a machine. During the service work, you discover that a hydraulic oil pipe has a small leak. You do not have time to fix it during the current stoppage, because you do not have the spare parts. What do you do?
13. Why is it so easy for a temporary repair to become a permanent one. How do you avoid this?
14. What is the most important element of condition monitoring?
15. What are the three parameters (measurands) that are vital to keep track of from an operational aspect?
16. Specify three examples for the above parameters.
17. What types of vibration measurement are there?
18. For a bearing at a given application (location), the failure development time is set as 3 months. How often should you check the functionality of the bearing?
19. Why should you avoid compressed air and high-pressure spray when cleaning?

20. Why is it important to check the clamping of pipes, tubing and electrical cable?

21. In order to carry out the correct indirect preventive maintenance, a maintenance inventory, and a general inventory must be made. You must use the attached forms to provide suggestions for activities for the equipment listed below.

Electric motor



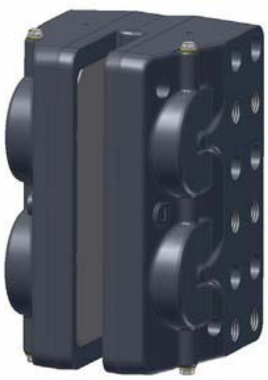
Hydraulic system

Frequency converter

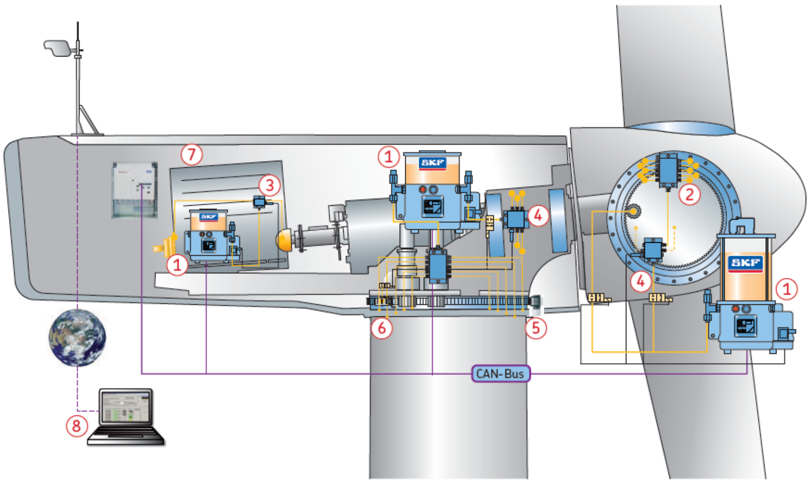
Gearbox

Monitoring system

Brake



Support system



1. How do we use the normal distribution curve in maintenance for determining the lifetime of a component?
2. What is meant by a regular and random failure.
3. There are two types of failure development. What are they?
4. For which failures and failure types can we prevent the occurrence of a failure?
5. Give examples of failures, failure types and the FD method.
6. What does it mean to implement a failure?
7. What type of failure implementation is most common? Why?
8. What is TBR and what is it used for?
9. Specify any method that can be used for fault tracing
10. What does FMEA mean?

1. Which grounds for classification are there for materials?
2. What is the difference between a casting and steel?
3. What contaminants are found in iron ore?
4. What is meant by a “black” metallic material?
5. Name two parameters used to characterise a metallic material's properties.
6. What is Hooke's law, and what does it mean?
7. What does it mean when a material floats?
8. What should you consider when tensioning a bolted joint?
9. What affects the mechanical tension in a pre-stressed joint?
10. An academic question: Does a standard machine screw have a right or left hand thread?
11. What does it mean if a machine screw has class 8.8?
12. What is an alloy, and why have different alloys been developed?
13. What is meant by a polymer and elastomer?
14. Give the trade names of some common plastic products
15. What should you consider when stocking plastic and rubber products?
16. What do the terms ESD and EMC mean?

1. What is meant by maintenance philosophy?
2. Why has TPM made such a good impact?
3. What tasks should the operating staff carry out, in your opinion?
4. What is meant by the term 5S?
5. What are the benefits of implementing 5S?
6. Why is it important to have written routines/instructions?
7. What is a TPM board?
8. Explain the concept of LCC?
9. A seller had a filter that was “optimised” for your fan system. It was enough to replace it once a month, and it only took 5 min. According to the supplier, the filter could be used on all 70 wind turbines, and it only cost SEK 50. The total annual cost would be SEK 49,000, if the cost per man hour was SEK 100. Is this correct?
10. A company had 15 cooling water pumps running around the clock all year round. These were currently fitted with a standard braided stuffing box. The uptime before changing the braid was estimated at 9,000 hours. Replacing the braid takes 3 hours for one man. The cost of the braid is SEK 200. Furthermore, you have to check the stuffing box seals every 2,000 hours. This takes 1 hour and includes the tensioning of the stuffing box where necessary. In order to reduce maintenance costs, replacing the braid with a mechanical seal was being considered. This costs SEK 3,000 to purchase. Installation takes 5 hours, but in return the estimated life is 15,000 hours and the inspection interval is estimated at 5,000 hours. Is it worthwhile switching to a mechanical seal. The cooling water pumps are located in a wind turbine with 2 MW of power, and the reimbursement for 1 kWh is SEK 0.4. Assume that the plant gives 50 % energy contribution on an annual basis.
11. What is meant by Reliability Centred Maintenance?
12. Can you describe the process of an RCM analysis.
13. What is meant by a risk?
14. In what areas does RCM provide improvements in addition to operational reliability?

1. What is an NLGI grade?
2. Name at least five different types of wear
3. What should the maximum permissible amount of water be in oil?
4. Name three lubricating conditions
5. What does a lambda value denote?
6. What viscosity do you select at low speeds?
7. How small are the particles in microns (my) the eye can see?
8. How thick in microns (my) is the lubricating film in a bearing?
9. At what standard temperature is oil measured?
10. What is the viscosity system called?
11. What three pieces of input data do you need to find out what the base oil viscosity of a ball bearing should be?
12. Give examples of three thickeners used in the manufacture of grease.
13. Name three chemical EP additives used in oil and grease.
14. What is meant by a “Beta value”?
15. What is a TAN value?
16. Name three solid EP additives used in grease.
17. When are these EP additives to be used?
18. Which two pieces of input data have the most influence on the selection of oil for ball bearings?

19. What input data is needed when selecting the oil for slide bearings?

20. What countermeasures do you use for the type of wear called corrosion?

21. What countermeasures do you use for the type of wear called abrasion?

22. What is the name of the viscosity measurement system used for motor oils?

23. What is the name of the quality classification system used for motor oils?

24. What is REACH?

1. Name at least five areas of maintenance that we can influence to improve maintenance reliability
2. What is the difference between preparation and planning.
3. What is meant by a Gantt chart?
4. What time horizons can we use to plan?
5. Make a check-list to use in the preparation of work on a wind turbine.
6. What is the difference between a production system and a maintenance system?
7. What modules are included in an industrial maintenance system?
8. What is the cost on an annual basis of the value of parts in a poorly managed and a well managed store room?
9. Name three classes that you usually divide stocked parts into.
10. Preparation of a task “Changing the gearbox”

    A 1 MW gearbox needs replacing. It weighs 2 tonnes and is located in a Nacel at a height of 45 m. The reason for replacing the box is that the pinion on the input shaft is heavily worn after being in operation for 10,000 hours.

    Information:

- A spare box must be ordered from the supplier.
- The price of a new gearbox is SEK 750 thousand with a deadline of 8 weeks
- A company undertakes to carry out metal coating and grinding, and replace the bearings for SEK 175 thousand. The time at the workshop is calculated at three weeks. Continuous operation for at least 20,000 hours is guaranteed.
- To dismantle and remove the gearbox takes 14 hours
- The crane costs SEK 7,000/hour, the cost of transporting it to the site is SEK 15,000
- Resource needs for 3 months. Cost SEK 450/hour

Which of the above options would you choose? Justify. As a precaution, prepare both jobs and schedule them in a Gantt chart.