University of Stavanger

# Faculty of Science and Technology

# MASTER'S THESIS

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| Study program/ Specialization:<br><br>Offshore Technology – Industrial Asset Management | Spring semester, 2012<br><br>Open |
| Writer:<br>Erik Sellevold Bleika | ………………………………………….<br>(Writer's signature) |
| Faculty supervisor:<br>Professor Tore Markeset, University of Stavanger<br><br>External supervisor(s):<br>Åse K. Bjørnestad, Bergen Group Rosenberg | |
| Titel of thesis:<br><br>Risk based maintenance of the three portal cranes at Bergen Group Rosenberg Yard | |
| Credits (ECTS):<br>30 | |
| Key words:<br><br>Maintenance<br>Condition monitoring<br>Risk based maintenance<br>Spare parts inventory | Pages: …………………<br><br>+ enclosure: …………<br><br>Stavanger, ………………..<br>Date/year |

# Abstract

The portal cranes at Bergen Group Rosenberg as been a major part of the success that the yard has achieved since the first two were built in 1960. The third one came 15 years later with a slight different structure and with a larger capacity. As these cranes grow older more thorough maintenance are needed, and for them to still have success they need to move away from corrective maintenance and towards new technology and condition monitoring.

This thesis will focus on condition monitoring and to come with suggestions on improvements to the existing maintenance program with regards to risk based maintenance.

This thesis concludes with that vibration monitoring and NDT should be implemented to the maintenance program. Keeping the fresh incident from last year in mind, where a nut of 3,1 kg loosened and fell down from the tension rod and hit the ground underneath the crane (45 meters drop). With vibration monitoring already in place this might have been prevented from happening.

Even though it is expensive to implement these techniques this is something that Bergen Group Rosenberg will profit by over time, and will help keeping the good reputation that the company and the Yard has had for decades.

# Acknowledgements

This thesis concludes my Master of Science degree in Offshore technology at the University of Stavanger.

First of all, I would like to thank Professor Tore Markeset for good guidance and comments during the work with this thesis.

I would like to thank Åse Kristin Bjørnestad for helping me find this good and relevant problem that were interesting both for me and Bergen Group Rosenberg and for the guidance throughout the process.

I would also like to thank Kjell Thorbjørnsen and Steinar Winum at BGR for good guidance regarding the build up and help finding relevant information for this thesis.

Finally a special thank to my parents for being very supporting during the work with this thesis.

Erik Sellevold Bleika

July 2012

# Contents

# 1 Introduction

## *1.1 Background*

The cranes located at Rosenberg yard are used daily and have a very important role here. As the cranes are old, maintenance is even more important to make sure that the risk of a failure is kept at a minimum. With the accident last year fresh in mind, there might be wise to check the maintenance plan for the cranes.

## *1.2 Study Objective*

An old crane that doesn't go through solid maintenance could be a hazard for both equipment and personnel and may as well not be cost efficient. Therefore, there is a need to check the current condition and health of the cranes and to review the existing maintenance program.

The main objective is to recommend improvements to maintenance program, regards to inspection, condition monitoring and maintenance programs. Sub-objectives include:

- Establish the current condition of the cranes (what is the current availability of the cranes, What is the downtime, Is there increasing downtime, Are the cranes functioning as they should, is the downtime effective, how much of the downtime is planned (preventive maintenance) as compared to unplanned (corrective maintenance)
- Establish the current condition of the maintenance program (Regulatory requirements, maintenance activities, condition monitoring, inspections, etc.; what is required by law, what is actually done, are the resources spent towards the real needs, etc.)
- Establish the current condition of the spare part inventory (are there too many/few spare parts, are the "right" spare parts in the inventory, what are the delivery time of new spare parts needed in the periodic maintenance program, are the spare parts still manufactured or available in the marked, are the spare parts in usable conditions, how long has the spare parts been in the storage, are they maintained, etc.)

- Establish the gap between the existing maintenance program and the real needs of the cranes (Is the resources spent on maintaining the cranes spent well, is enough maintenance performed, should there be done more inspections or condition monitoring, etc.)
- Optimize the maintenance program for the cranes.

## 1.3 Limitations

- The thesis will only cover the three Portal cranes at Rosenberg
- The thesis will suggest improvement based on the analysis of the data and information collected. Any actual updating of the maintenance program will be outside the scope of the thesis

## 1.4 Methodology

- Literature study
- Interview key personnel
- Gathering of information from IFS (CMMS Maintenance records at Rosenberg)
- Gather data about current spare parts inventory
- Inspection of cranes and spare part inventory

## 1.5 Structure of the thesis

This master thesis is divided into 6 chapters. Chapter 1 is the introduction of this thesis which covers the background, the study objective, limitations, methodology and the structure of the thesis. Chapter 2 gives a brief introduction of Bergen Group Rosenberg and the three portal cranes. Chapter 3 covers the theoretical background for this thesis beginning with relevant abbreviations, definitions and terms relevant with respect to condition monitoring and risk based maintenance. Then follow the results which also include the consequence classification.

After that the results are discussed with the final conclusion where the suggested improvements are presented.

# 2 Bergen Group Rosenberg

The yard at Buøy was established in 1915:

- a large assembly hall completed in 1918
- construction of a dry dock for ships up to 12 000 tons. The dry dock was completed in 1920.  A larger dry dock with capacity for ships up to 65 000 tonnes was completed in 1959.

From June 1920 the main activity was located at Buøy which was the most modern and advanced shipyard in Norway. From 1945 to 1970, Rosenberg was owned by Sigval Bergesen and established a solid reputation as a major builder of large tank ships. Kværner bought the ship yard in 1970. Kværner's patent for tankers for freight of liquid gas was the basis for the building of a series of large LNG tankers. In 2007 Rosenberg was included in the Bergen Group ASA and the company name was changed to Bergen Group Rosenberg AS.

**Figure 1 – Overview of Rosenberg Yard at Hundvåg, Stavanger. Here are also the three Portal Cranes shown. (BGR, 2012)**

Bergen Group Rosenberg operates within a wide spectre of project and the orders vary from small and simple to large and complex. We perform projects of all types from fabrication Contracts to complete EPCIC (Engineering, Procurement, Construction, Installation and Comissioning) projects within many market areas.

Our target market areas are:

- delivery of design and study contracts,
- modules,
- complete deck structures,
- offshore maintenance and modifications,
- subsea installations
- fabrication of structural steel and piping including surface protection.

The value chain includes concept development, design, fabrication, assembly, installation, testing and completion/handover.

## *2.1 The portal cranes at Rosenberg*

The three portal cranes located at the Rosenberg Yard has been a major part of the yards success. Two of the cranes are of the same type, produce by Stork Hensen in 1960, and has a maximum lifting capacity of 100 tons. The third portal crane was delivered by Wisbeck Refsum in 1975 and has a maximum lifting capacity of 130 tons. They are standing on rails and Figure 2 gives an overview of the yard and where the cranes can operate. The crane Hensen 519 is located on the north side by dock I, which is rented by GMC. GMC are also frequently renting the crane service from Hensen 519.

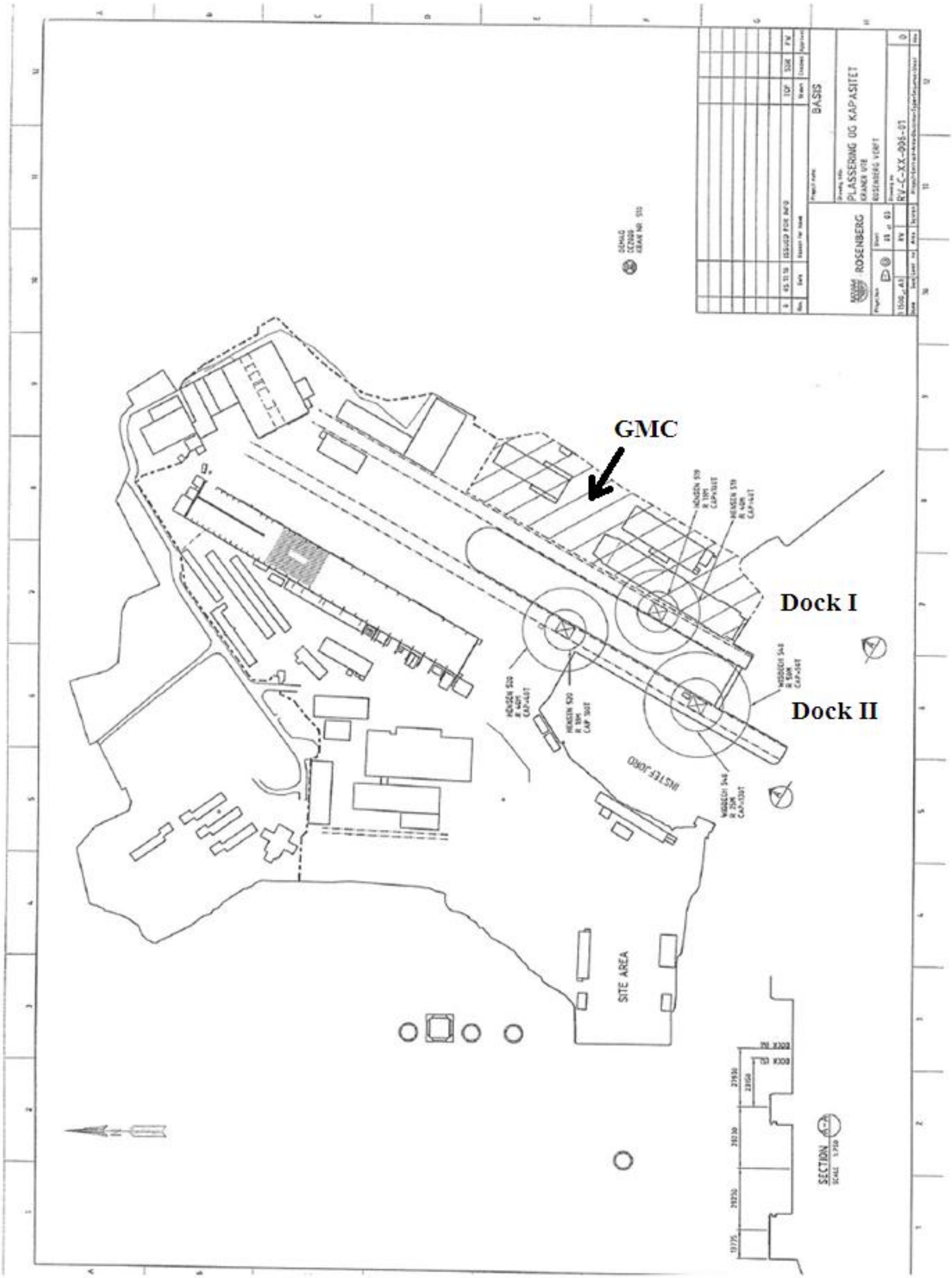



**Figure 2 – Map of the Rosenberg Yard (BGR, 2012)**

# 3 Theory

## *3.1 Abbreviations*

| | |
|---|---|
| API | American Petroleum Institute |
| BGR | Bergen Group Rosenberg |
| CBM | Condition based maintenance |
| CM | Condition monitoring |
| CMMS | Computerized maintenance management system |
| EN | European Standard |
| FMECA | Failure mode, effect and criticality analysis |
| GMC | Generic maintenance concept |
| HSE | Health, safety and environment |
| ISO | International Organization for Standardization |
| KPI | Key performance indicator |
| MF | Main function |
| MTBF | Mean time between failure |
| MTTF | Mean time to failure |
| NDT | Non-destructive testing |
| OLF | Oljeindustriens landsforening |
| P&ID | Process and instrumentation diagram |
| PM | Preventive maintenance |
| PS | Performance standard |
| QRA | Quantitative risk analysis |
| RBI | Risk based inspection |
| RCM | Reliability centred maintenance |

## *3.2 Basic definitions and terms*

**Availability:**

Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided (NORSOK 2011)

**Condition monitoring:**

The continuous or periodic measurement and interpretation of data and information to indicate the condition of an item or a system to determine the need for maintenance (MOM350, 2010).

**Consequence classification**

Quantitative analysis of events and failures and assignment of the consequences of these (NORSOK 2011).

**Corrective maintenance**

Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function (NORSOK 2011).

**Generic maintenance concept**

**GMC**

Set of maintenance actions, strategies and maintenance details, which demonstrates a cost efficient maintenance method for a defined generic group of equipment functioning under similar frame and operating conditions (NORSOK 2011).

**Inspection**

Activity carried out periodically and used to assess the progress of damage in a component (NORSOK 2011).

**Maintenance**

The set of activities required to keep these means of production in the desired operating condition, or to restore them to this condition (Piltelton, et al., 1997).

**Maintenance management**

All activities of the management that determine the maintenance objectives, strategies, and the responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvements of methods in the organisation including economic aspects (NORSOK 2011).

**Performance standard**

**PS**

The performance standard describes the role of the barrier as a risk reducing measure and its relations to other safety systems managing a potential hazard. The performance standard outlines the requirements of the specific system in terms of its functionality (i.e. the essential duties that the system is expected to perform), integrity (i.e. reliability and availability parameters of the particular barrier) and survivability (i.e. the functionality of the barrier under the conditions of a major accident when the system is required to operate) (NORSOK 2011).

**Preventive maintenance**

**PM**

Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the function of an item (NORSOK 2011).

**Redundancy**

Existence of more than one means at a given instant of time for performing a required function in an item (NORSOK 2011).

**Reliability centred maintenance**

**RCM**

Method to identify and select failure management policies to efficiently and effectively achieve the required safety, availability and economy of operation (NORSOK 2011).

**Risk based inspection**

**RBI**

Risk assessment and management process that is focused on loss of containment of pressurized equipment in processing facilities, due to material deterioration (NORSOK 2011).

**Safety function**

Physical measures which reduce the probability of a situation of hazard and accident occurring, or which limit the consequences of an accident (NORSOK 2011).

**Unsafe failure modes**

Failure modes dangerous to personnel but which do not threaten the MF of the equipment (NORSOK 2011).

## *3.3 Maintenance*

During the last decades, there has been a huge change when it comes to the attitudes and strategies applied to maintenance. In the 1940s it was regarded as a necessary evil which was difficult to manage, and today it is seen as an opportunity to reduce the downtime when it is applied the right way. There are several definitions to maintenance, and two of these are:

> "the combination of all technical, administrative and management measures during the life cycle of a unit intended to keep it in, or restore it to, a state in which it can perform its intended functions" (ISO, 2010).

and:

> "the set of activities required to keep the means of production in the desired operating condition, or to restore them to this condition" (Piltelton, et al., 1997).

The view of maintenance has gone through a big change over the last decades as shown in Figure 3.

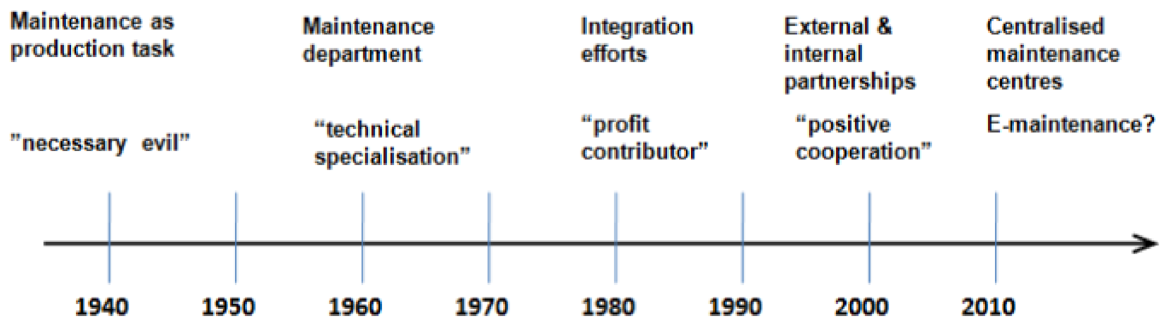



**Figure 3 - Change of the Opinions of Maintenance (Piltelton, et al., 1997) and (Liyanage, 2007).**

Figure 3 is based on Piltelton, et al., (1997) and Liyanage (2007) showing the extended trends. The figure shows that maintenance was not recognized as a potential profit-generating operations function until the 1990s. Maintenance management has changed over the last decades as a result of the industries increased usage of machines, more complex equipment and regulations (Meland, et al., 2009). The development has been driven by the companies that identified the meaning of maintenance in the value creation process.

New maintenance methods have been developed to improve the efficiency and reduce the costs. Today, maintenance systems are tailored to the condition of the equipment in order to adapt the maintenance to the equipment's criticality, use of CM and to remove the source for the different failure modes, not the symptoms (Arbeids- og administrasjonsdepartementet, 2001). It is necessary to invest enough resources to achieve the wanted outcomes. Economy campaigns with reduction in maintenance have been shown to give a negative outcome regarding the profit and Health, Safety and Environment (HSE).

Meland, et al., (2009) defined four generations in the development of maintenance, and Figure 4 shows the different generations over the years. This figure shows that there has been a huge development regarding maintenance and has a coherence with the development of maintenance which was shown in Figure 1.

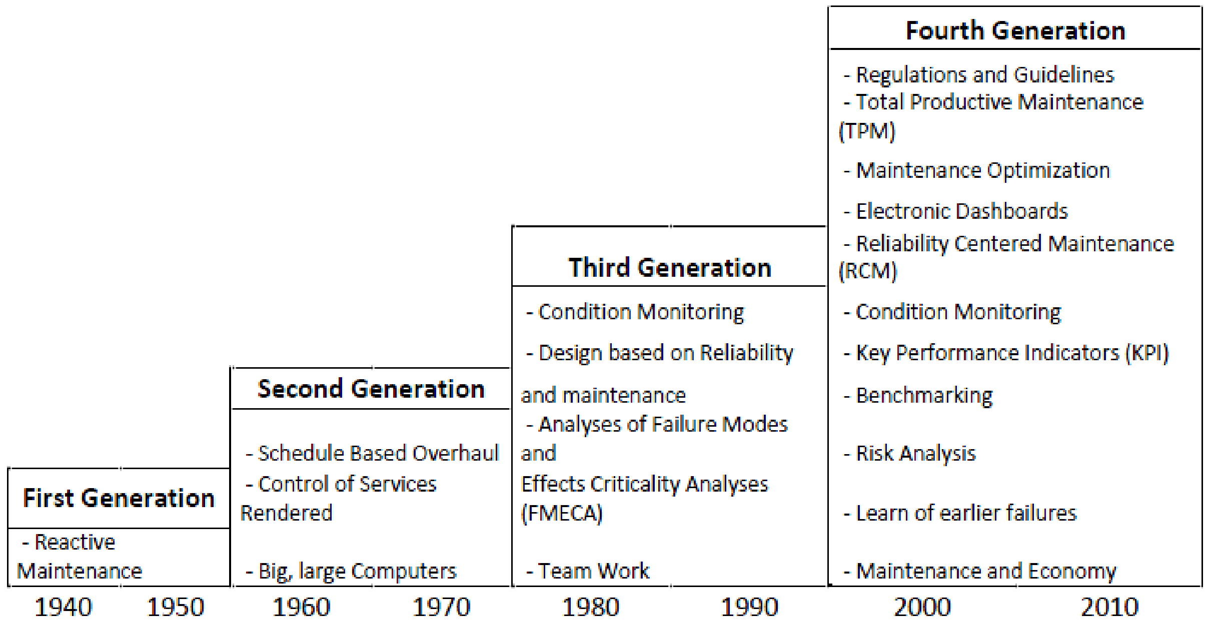



**Figure 4 - The Evolution of Maintenance (Meland, et al., 2009).**

Why, what, when, how, who and where maintenance is needed are all questions that need to be answered to get a worthy maintenance program. Maintenance needs to be viewed as a dynamic process rather than a function. The purpose of maintenance is to reduce the business risk, operation risk, reduce health risk and environmental risk. It can also reduce the downtime which is defined according to (ISO, 2010) as a time interval throughout which an item is in fault or by a possible inability to  a required function during preventive maintenance.

Figure 5 is from ISO (2006) and shows the different processes during downtime. Downtime means loss of production for oil and gas companies. It has been shown that planned maintenance takes less time than reactive maintenance.

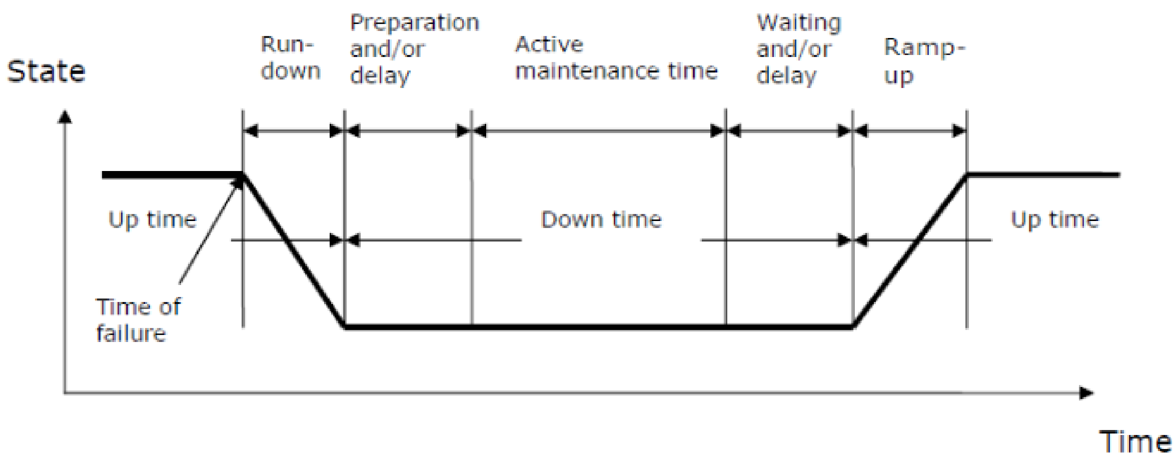



**Figure 5 - Downtime (ISO, 2006)**

Downtime is influenced by the active maintenance time, logistics delay time and administrative delay time. The active delay time is divided into two groups; corrective and preventive maintenance. Corrective maintenance is often connected with unexpected failures, and can be a result of lack of maintenance.

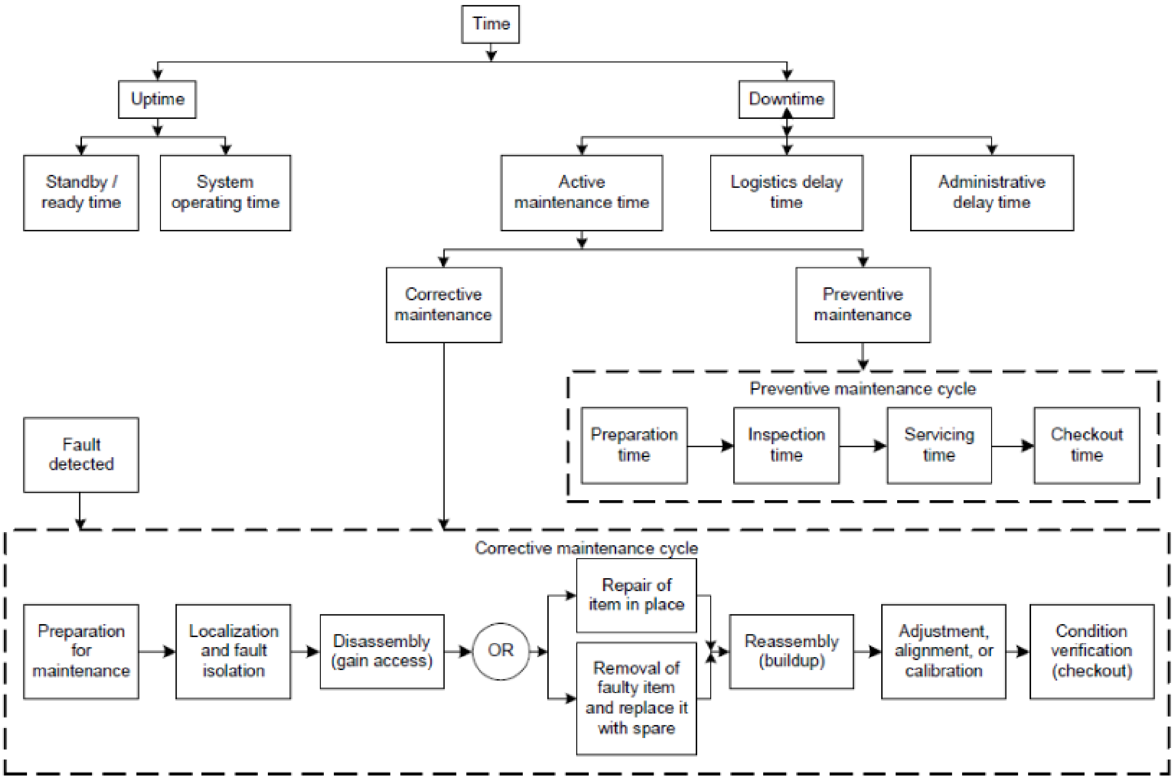



**Figure 6 - System/Equipment Uptime and Downtime (MOM460, 2010)**

Preventive maintenance is done to maintain the operability and availability of the equipment. The different processes of system/equipment uptime and downtime are shown in Figure 6.

The “preparation and/or delay” and “active maintenance time” can be reduced by using Condition Based Maintenance (CBM), and the different maintenance types are shown in Figure 7.

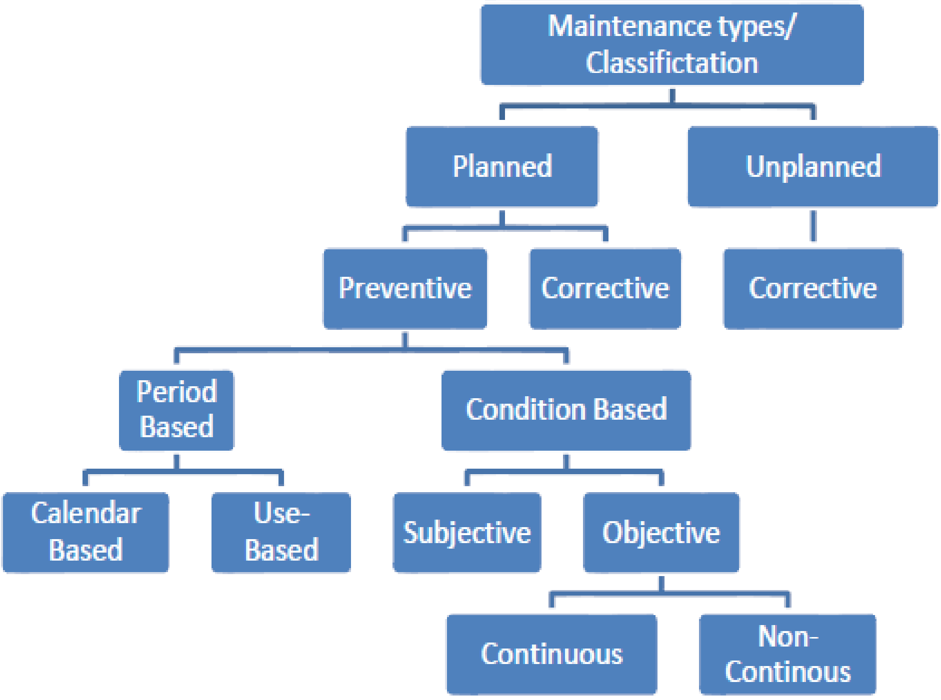



**Figure 7 - Maintenance types (MOM460, 2010)**

Maintenance costs are a major part of the total operating costs of all manufacturing or production plants, and Mobley (2002) states that maintenance costs can represent between 15 and 60 percent of the cost of goods produced, depending on the specific industry. In food industries, the overall maintenance costs can be around 15 percent, whereas it can be up to 60 percent in the heavy industries.

Maintenance is often based on statistical trend data, or the actual failure, and one of the main reasons for ineffective maintenance management is the lack of factual data to quantify the actual need for repair or maintenance of plant machinery, equipment, and systems. The development of microprocessor- or computer-based instrumentation has provided the means to reduce or eliminate unnecessary repairs by applying the needed technology to monitor the critical elements.

### *3.4 Maintenance techniques*

Maintenance is still under development. Meland, et al. (2009) made a synopsis of different techniques where the efficiency is shown with the historic development as shown in Figure 8.

The Repair After Failure is also called Run-to-Failure. This is a reactive method where a system, machine or equipment is not fixed until it breaks down. This is the most expensive and least efficient method due to high spare parts inventory cost, high overtime labour cost, high machine downtime, and low production availability. Reactive repair mode normally gives a three times greater maintenance costs than the same repairs made on a scheduled basis (Mobley, 2002). Few plants use a true Run-to-Failure as they for example lubricate and adjust machines and systems.

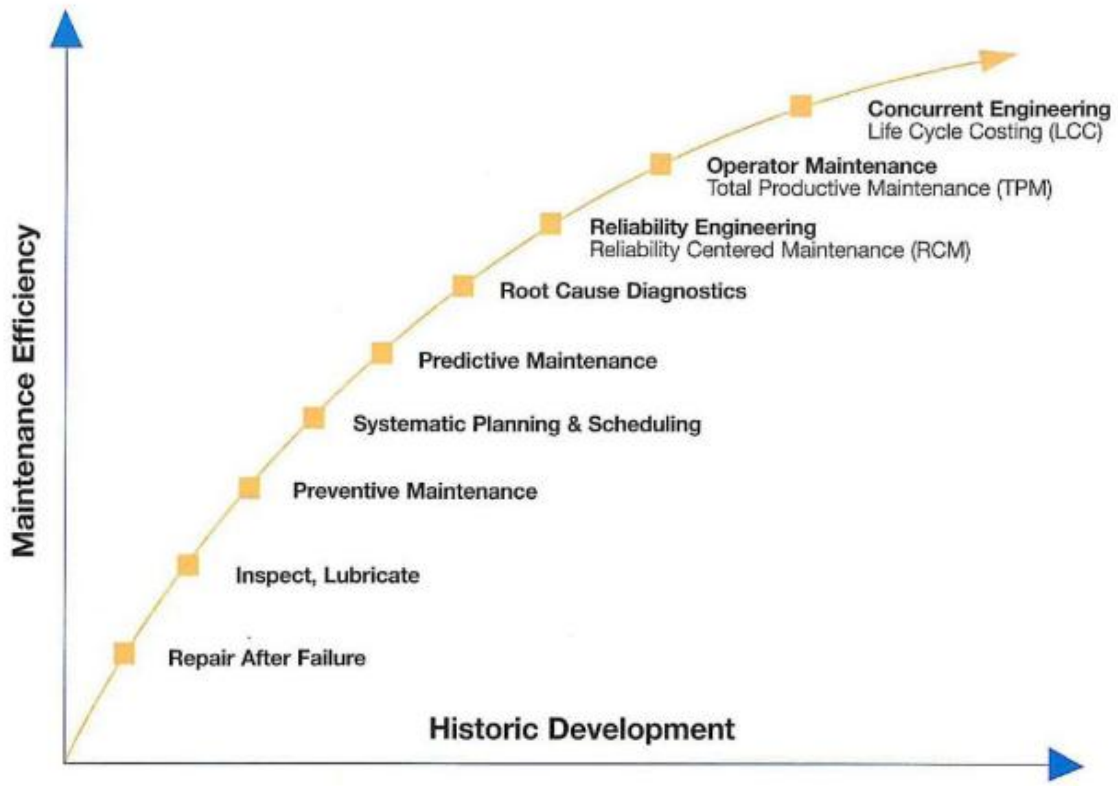



**Figure 8 - Development of maintenance concepts and techniques according to the efficiency (Meland, et al., 2009)**

Preventive maintenance is a time driven maintenance program and is based on Mean-time-to-failure (MTTF) statistics. MTTF and bathtub curves (Figure 9 and 10) are two indicators that show that a new machine has a high probability of failure because of installation problems during the start-up. In the machines normal life, it has a relatively low probability of failure, and when the equipment starts to wear out, the probability raises again. This method assumes that for example all valves off type A will have the same Mean-Time-Between-Failure (MTBF). This will often lead to unnecessary repairs or failure before the repair has been executed.

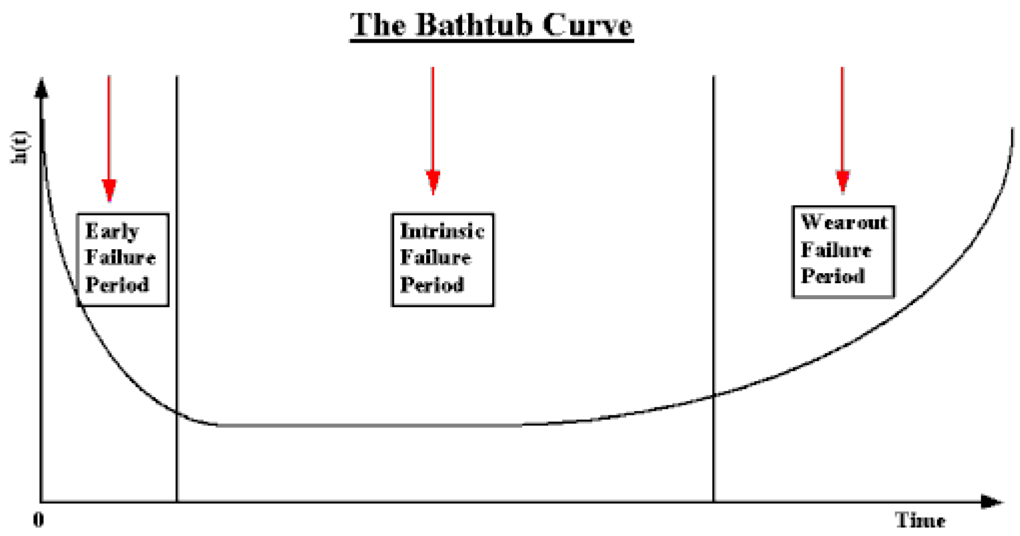



**Figure 9 - The Bathtub curve (NIST 2012)**

As mentioned earlier, maintenance has gone through three generations, and is now in the fourth. The understanding of the correlation between age and failure has gone through a transformation since the 1940s. The understanding of the correlation is shown in Figure 10 (using Norwegian terminology). The horizontal axis shows the time, and the vertical shows the probability for failure.

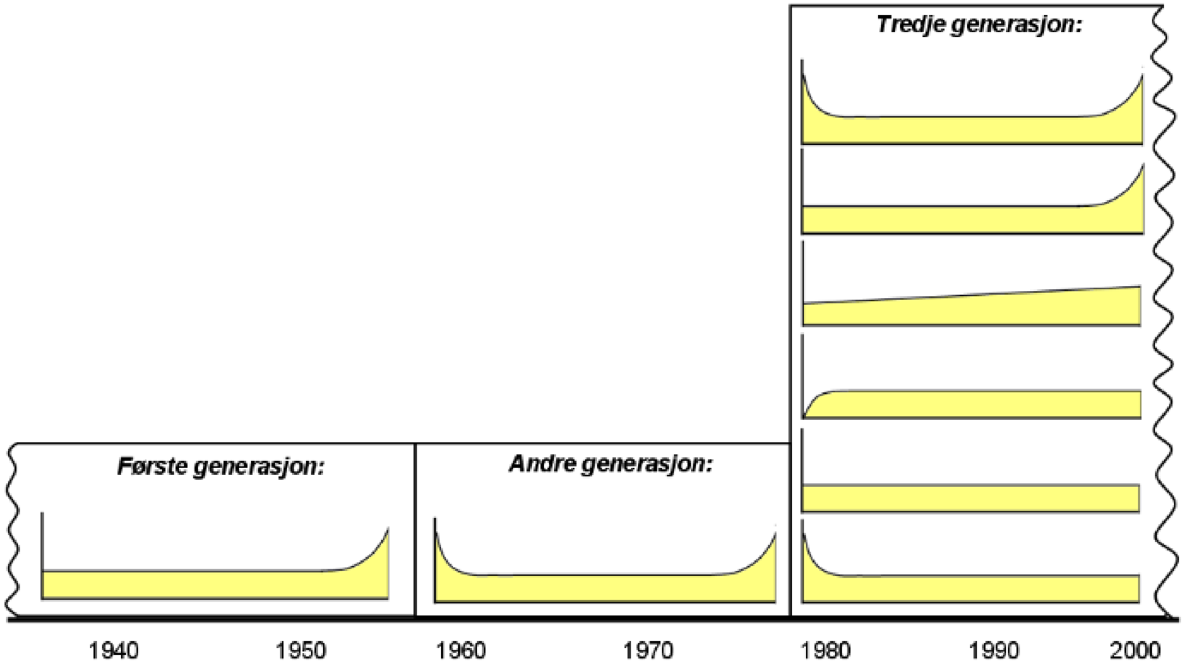



**Figure 10 - Different views of failure development (Meland, et al., 2009)**

When a predictive maintenance method is used, it will regularly monitor the actual mechanical condition and operating efficiency and can improve productivity and product quality. This should optimize the total plan availability and reduce the cost of maintenance. According to (ISO, 2010) predictive maintenance is condition based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item.

This method have indicators which will determine the MTTF or loss of efficiency instead of using statistics, which makes it easier to schedule maintenance at the right time and avoid unscheduled breakdowns by identifying problems before they become serious. If a failure is detected early, major repairs which are expensive can usually be prevented.

Process efficiency, heat loss and other nondestructive techniques like vibration monitoring, process parameter monitoring, thermography, tribology, and visual inspection can be used to monitor machines and systems. Vibration analysis is often the primary tool since most of the normal plant equipment is mechanical (Mobley, 2002), but it does not cover electrical equipment, heat loss, condition of lubricating oil and other parameters that perhaps should be included to get a better system.

### 3.5 Condition based maintenance

(MOM350, 2010) states that condition based maintenance is preventive maintenance initiated as a result of knowledge of the condition of an item from routine or condition monitoring.

Implementation of a predictive maintenance method does often fail to give the desired benefits that are wanted because of the failure to make the necessary changes in the work place. Predictive technologies are strictly a maintenance management or breakdown prevention tool, an optimization tool, and this are the attitude and perception needed at corporate level to pass throughout the plant organization. According to (Mobley, 2002) studies from the 70s till 00s show that maintenance is responsible for about 17 percent of production interruptions and quality problems, and the remaining 83 percent comes from inappropriate operating practices, poor design and non-specification parts. Approximately 40 % of failure modes to systems and equipment can be controlled with use of CBM (Meland, et al., 2009).

There are many different methods used to monitor different machines and systems, and vibration monitoring is the most used technique. But this method alone will in most cases not give enough information to have an effective, efficient and successful predictive maintenance program. Techniques like thermography, tribology, process parameters, visual inspection, ultrasonic, and other non-destructive testing techniques should also be included to give adequate information about the state of the system or machine. The methods chosen are based on the failure causes and the type of machines or systems, and in the following paragraphs will some of the different methods be discussed.

### 3.6 Condition monitoring

(MOM350, 2010) states that condition monitoring is the continuous or periodic measurement and interpretation of data and information to indicate the condition of an item or system to determine the need for maintenance.

CM is used to know the health of a machine or equipment using measured parameters which has a connection with the integrity of the machine. Potential benefits from CM are (MOM350, 2010):

- maintenance cost savings
- reduced repair time and costs
- less downtime
- no miss-use of machines
- reduced personnel
- improved plant design

To establish a CM system, critical systems need to be identified. Techniques and parameters which will monitor these critical systems are selected, and then limits for the alarms need to be set. This process is shown in Figure 11. Measuring, diagnosing and informing are the main parts of CM.

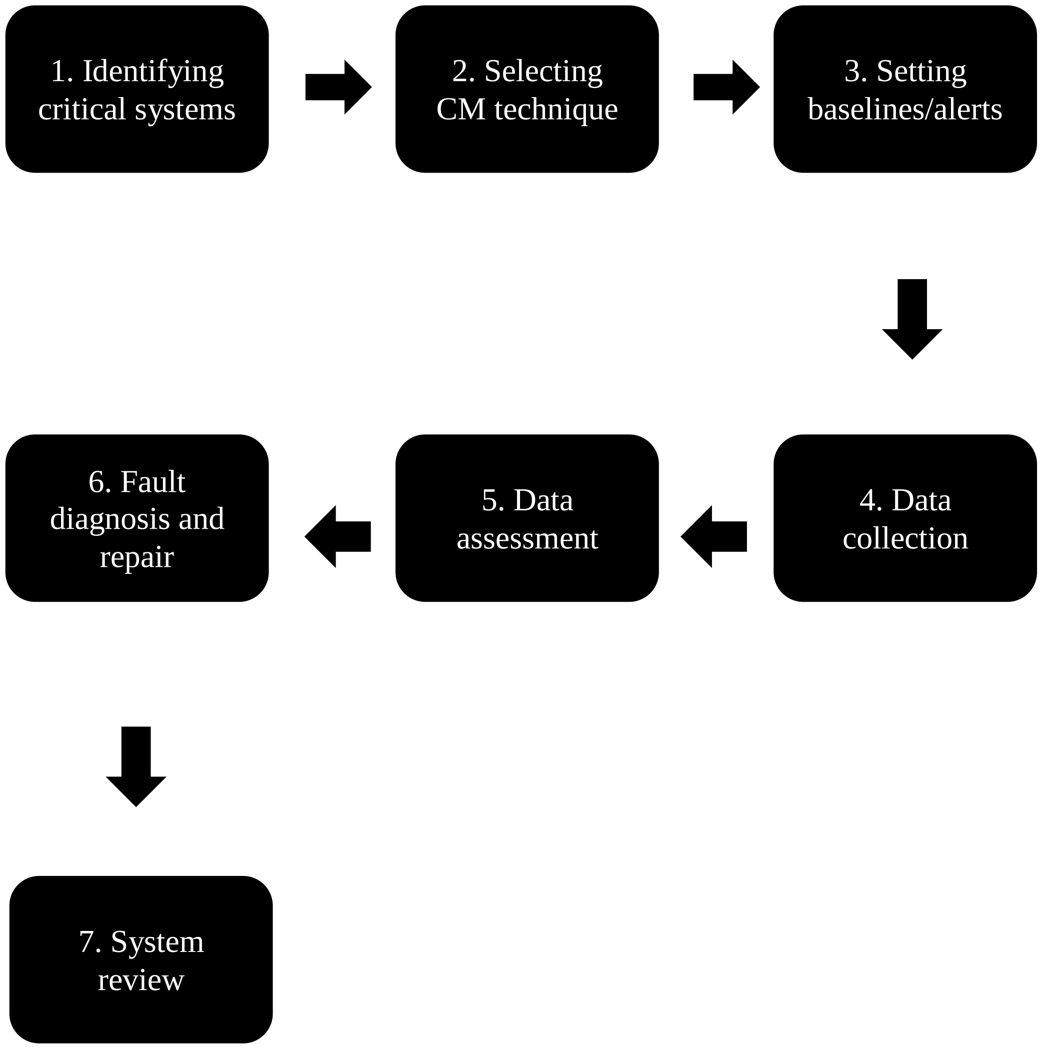


Figure 11 - The CM process (MOM350, 2010)

According to (Meland et al., 2009) the most frequently failure of implementation of CBM is companies that purchase advanced and expensive monitoring systems, then gathers large quantities of data, but does not know what to do with this data. With use of CBM, the equipment will be fixed when needed, and not as a part of a scheduled plan. To eliminate the root cause of a failure is one of the key elements of CBM.

### *3.6.1 Condition monitoring techniques*

There are many CM methods and techniques. Common for all the different CM methods and techniques are that they are used to monitor different equipment and machines based on failure modes. Extern experts can be used to describe failure modes and decide the criticality of the equipment and machines, and how the system shall be monitored. CM methods are divided into the different methods shown in Table 1. An essential activity to ensure integrity and facilitate continuous improvement is Risk Based Inspection (RBI), which also can be used as an input to CBM.

**Table 1 – CM methods (MOM350, 2010)**

| Condition methods |
|---|
| **Vibration monitoring** |
| **Process parameter monitoring** |
| **Thermography** |
| **Thermodynamic** |
| **NDT – Non-destructive testing** |
| **Tribology** |
| **Visual inspection** |

#### *3.6.1.1 Vibration monitoring*

Vibration monitoring is the most frequently used technique to monitor equipment and systems. It can be used to detect material fatigue, wear and loose parts and so on in rotating equipment. This method is used to detect the vibration energy which in its simplest form can be considered to be the oscillation or repetitive motion of an object around its equilibrium position (MOM350, 2010). Systems that is in, for example unbalance will give some kind of vibration energy, and the frequencies from the energy makes it possible to trace the origin of the vibration. According to Tsang (1995), it is possible to characterize vibration by using amplitude, speed and acceleration, and according to MOM350 (2010) it is possible to measure these parameters with the sensors shown in Table 2.

**Table 2 – Vibration sensors (MOM350, 2010)**

| Vibration sensors |
|---|
| **Displacement Sensor** |
| **Velocity Sensor** |
| **Acceleration Sensor** |

The energy created by mechanical systems are acquired, managed, trended and evaluated by microprocessor-based, single-channel data collectors and Windows®-based software. Measurements when the equipment was new will be compared with the measured data. This will give an indication of the integrity of the equipment. Appendix A shows a flow chart from ISO (2002) of the procedure of CM with vibration.

#### *3.6.1.2 Thermography*

When using thermography, an infrared camera is used to detect the thermal energy and converts it to a visible image, which then allows a thermographer to analyse abnormalities in the image, such as Figure 13 shows. Energy emitted, transmitted and reflected from an object are the three sources of thermal energy, and only the emitted energy is of importance for a predictive maintenance program (MOM350, 2010).The abnormalities are located and can define incipient failures. The intensity of infrared radiation from an object is a function of its surface temperature.

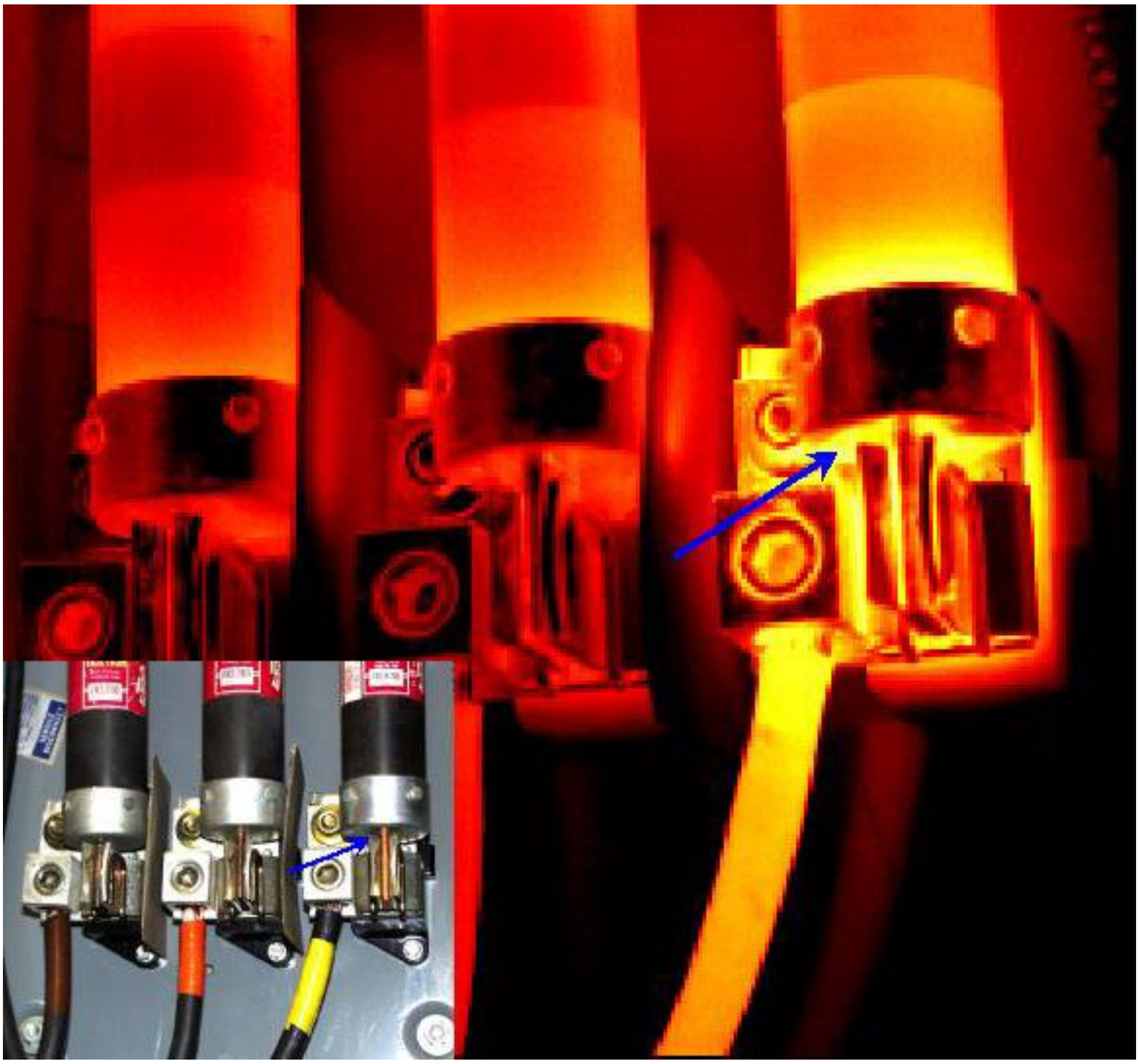


**Figure 12 – Abnormalities shown by use of thermal imaging device (Services 2012)**

#### *3.6.1.3 Tribology*

Tribology is the science to understand the interaction between surfaces. Friction, wear and lubrication are central parts of tribology. Tribology applies for equipment and machines where there is interaction. Tribology-analyses can give information about the condition of the machine or equipment. Analyses of lubrication oil can reveal particles from the machine, and from the particles one can find information about their origin. The result from the analysis can give a recommendation to change the oil, change the type of oil, change parts of the equipment and so further. Today, oil analysis has become an important aid to preventive maintenance (MOM350, 2010).

#### ***3.6.1.4 NDT – Non-destructive Testing***

NDT is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage to it. Because NDT does not permanently alter the article being inspected, it is a highly-valuable technique that can save both money and time in product evaluation, troubleshooting, and research. Common NDT methods include ultrasonic, magnetic-particle, liquid penetrant and radiographic testing.

##### 3.6.1.4.1 Ultrasonic testing

Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization, and more. According to (Larson 2012a), a typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. Driven by the pulser, the transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen.

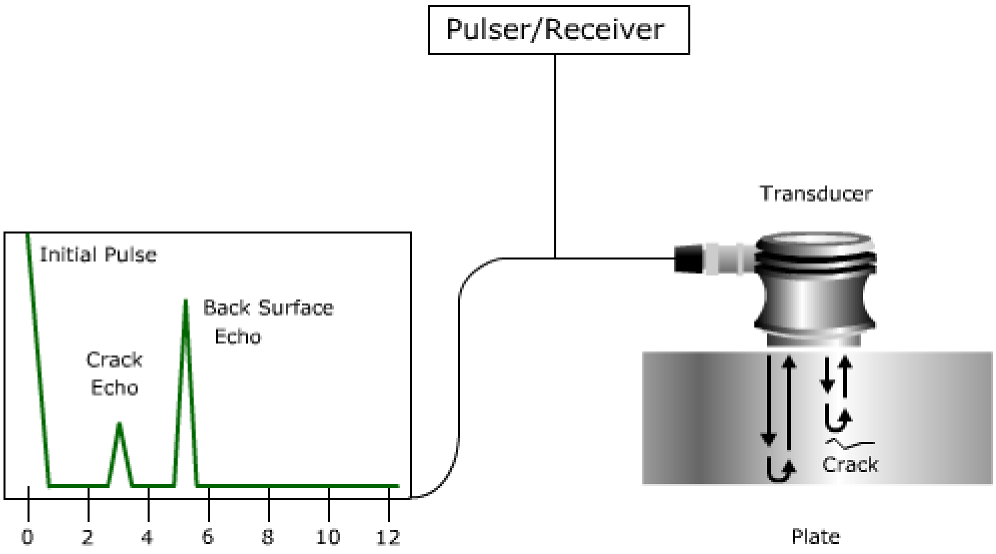



**Figure 13 - A typical pulse/echo inspection configuration (Larson 2012a)**

Ultrasonic Inspection is a very useful and versatile NDT method. Some of the advantages of ultrasonic inspection that are often cited include:

**Table 3 – Advantages of ultrasonic inspection (Larson 2012a)**

| Advantages |
|---|
| **Only single-sided access is needed when the pulse-echo technique is used.** |
| **High sensitivity, permitting the detection of extremely small flaws.** |
| **The depth of penetration for flaw detection or measurement is superior to other NDT methods.** |

As with all NDT methods, ultrasonic inspection also has its limitations, which include:

**Table 4 – Disadvantages of ultrasonic inspection (Larson 2012a)**

| Disadvantages |
|---|
| **Manual operation requires careful attention by experienced technicians.** |
| **It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.** |
| **Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.** |

#### 3.6.1.4.2 Magnetic Particle Inspection

The following description of the basics of magnetic particle inspection in general is largely retrieved from (Larson 2012b).

The first step in a magnetic particle inspection is to magnetize the component that is to be inspected. If any defects on or near the surface are present, the defects will create a leakage field. If the component is just cracked but not broken completely in two, a north and south pole will form at each edge of the crack. As Figure 15 shows, the magnetic field exits the north pole and re-enters at the south pole. The magnetic field spreads out when it encounters the small air gap created by the crack because the air cannot support as much magnetic field per unit volume as the component can.

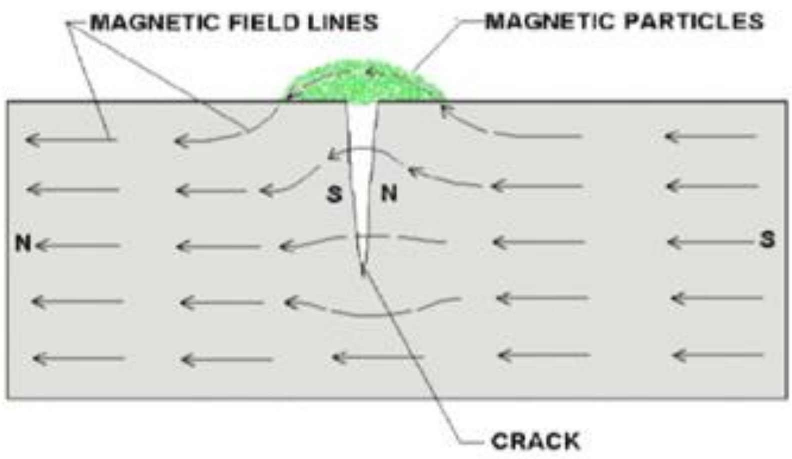



**Figure 14 – Illustration on how the magnetic field reacts to a crack in a magnetized component (Larson 2012b)**

After the component has been magnetized, iron particles, either in a dry or wet suspended form, are applied to the surface of the magnetized part. The particles will be attracted to and cluster not only at the poles at the ends of the magnet, but also at the poles at the edges of the crack. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspection.

### 3.6.1.4.3 Radiographic Testing

As stated in (EngineersHandbook 2006), this technique involves the use of penetrating gamma or X-radiation to examine parts and products for imperfections. An X-ray machine or radioactive isotope is used as a source of radiation. Radiation is directed through a part and onto film or other media. The resulting shadowgraph shows the internal soundness of the part. Possible imperfections are indicated as density changes in the film in the same manner as X-ray shows broken bones, as shown in Figure 16.

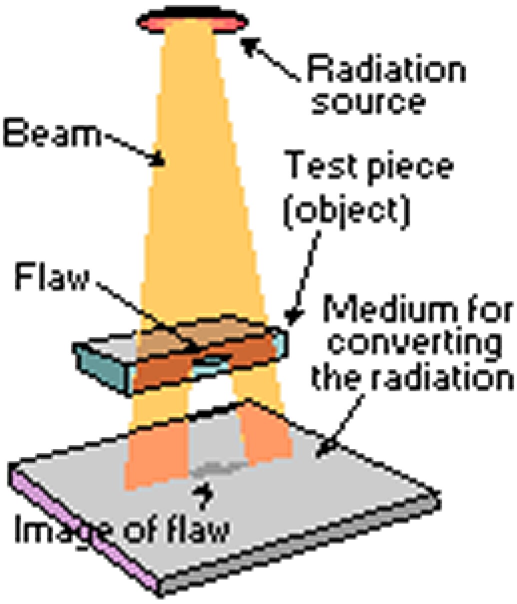



**Figure 15 – Example of a typical radiographic test (EngineersHandbook 2006)**

According to (EngineersHandbook 2006), radiographic applications fall into two distinct categories evaluation; of material properties and evaluation of manufacturing and assembly properties. Material property evaluation includes the determination of composition, density, uniformity, and cell or particle size. Manufacturing and assembly property evaluation is normally concerned with dimensions, flaws (voids, inclusions, and cracks), bond integrity (welds, brazes, etc.), and verification of proper assembly of component pieces.

## *3.7 Risk based maintenance and consequence classification*

The following description of risk based maintenance in general is largely retrieved from NORSOK Z-008 Risk based maintenance and consequence classification (NORSOK 2011).

The NORSOK Z-008 standard is applicable for different purposes and phases such as operational phase, where it is used to update and optimize existing maintenance programmes. As a basis for preparation and optimisation of maintenance programmes for new and in service facilities, all risk elements shall be taken into account, i.e. risks related to

- Personnel
- Environment
- Production loss
- Direct or indirect cost including reputation

Risk assessment shall be used as the guiding principle for maintenance decisions. The key elements of this methodology are as follows:

a) consequence classification of functional failure;

b) the application of the consequence classification and additional risk factors for decision making related to corrective maintenance and handling of spare parts.

As important as the risk assessment, is having well defined work processes and company/management commitment.

### *3.7.1 Safety functions*

Establishment of function requirements for the safety functions should be based on risk evaluations of accidental events, which will determine the safety systems and their performance. The overall performance shall be documented in the form of PSs or equivalent. The PS will set requirements with respect to availability, capacity and performance of safety functions.

One of the most important tasks for the maintenance organisation is to maintain this performance during the lifecycle of the plant. Availability requirements should be used to determine the programme for PM activities and the required contingency plans in the event of failure. The inherent availability of the safety functions should be controlled and documented. The development of failure rate and system unavailability should be used as the basis for changing of test intervals and other mitigating actions to ensure compliance with function requirements.

### *3.7.2 Risk decision criteria*

Risk based decisions have to be done against defined criteria. The definition of the criteria should be done in accordance with overall company policy for HSE, production and cost. The criteria shall be properly defined and communicated.

The following principles should apply:

- the risk matrix should as far as possible be the same for all operation for a company in order to aid common companywide optimisation and devote resources accordingly as well as having a common language for communicating risk;
- further, the same criteria should be used for all equipment and systems. This is in particular important for topside maintenance and inspection planning which are handling basically the same hardware;
- the consequence of loss of functionality (both loss of MF and sub functions) should take into account the standby redundancy and reduce the impact accordingly.

### *3.7.3 Consequence classification*

Consequence classification expresses what effect loss of function can have on HSE, production and cost/other. The classification is done according to a consequence scale which is a part of the risk model.

The consequence classification together with other key information and parameters gives input to the following activities and processes:

- selection of equipment where detailed RCM/RBI/FMECA analysis is recommended (screening process);
- establish PM programme;
- preparation and optimisation of GMCs;
- design evaluations;
- prioritisation of work orders;
- spare part evaluations.

Figure 17 shows an overall workflow related to classification. The following principles apply:

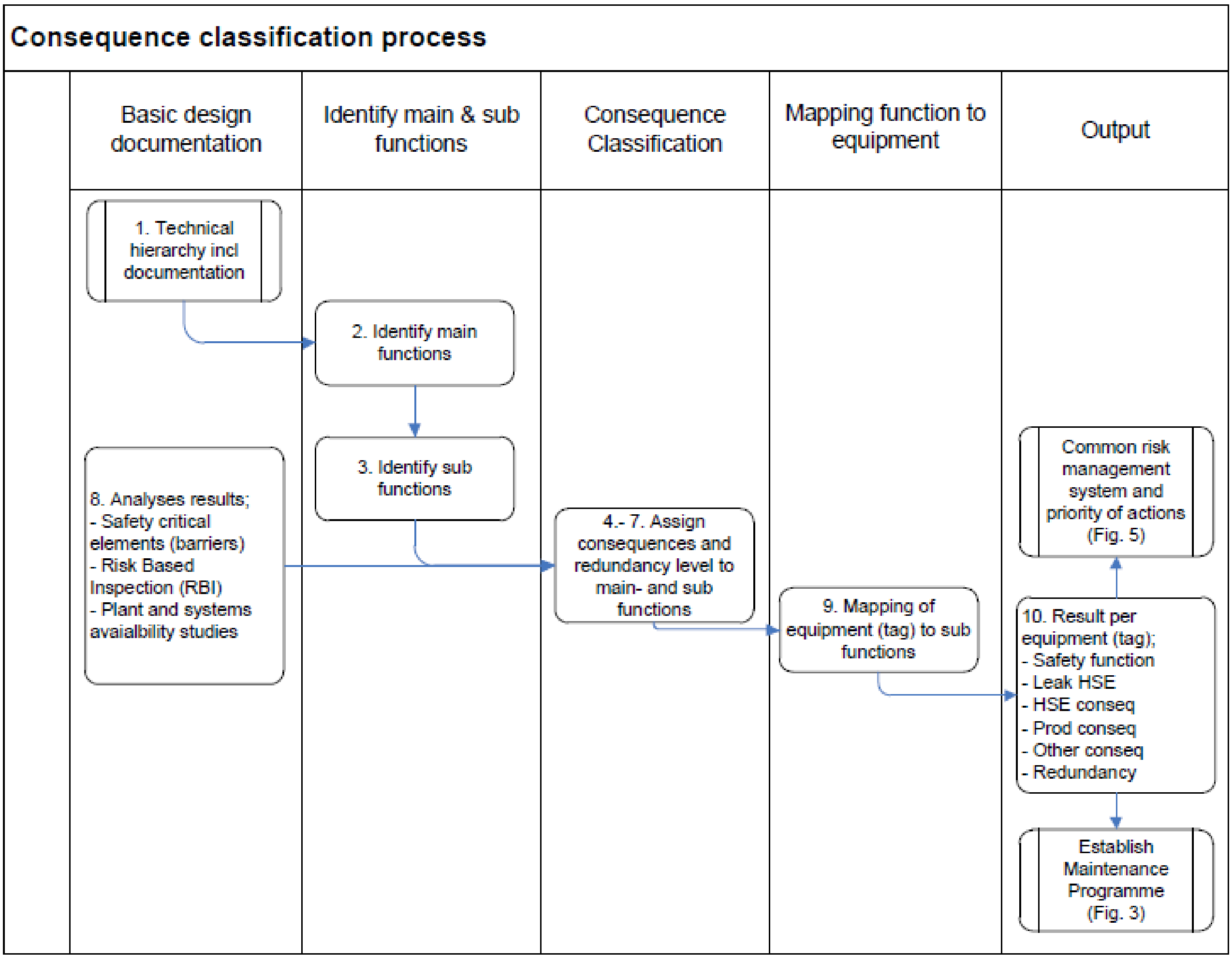



**Figure 16 – Consequence classification process (NORSOK 2011).**

- The consequence classification is done to identify critical equipment for HSE, production and cost.
- All systems and/or tags related to an installation should be classified using the same classification scale – regardless which method and standard is used for the classification.
- A functional hierarchy is established (MFs and sub functions). This is normally not stored in the CMMS but used during the classification process. Sub functions are linked to equipment/maintenance object in the technical hierarchy
- The classification feeds in to a common risk model used for operational decision making, thus they need to be comparable.
- The static process equipment consisting of pipes, vessels, valves are normally consequence classified via an RBI analysis. The classification of HSE leakage may be done as a part of the RBI analysis or as a separate activity together with the overall classification of all functions and equipment. The containment has a dual function, i.e. a safety system with a PS and a production system with its production functions.
- Safety functions are defined via safety analysis (e.g. quantitative risk analysis) in the design or modification process. As such these systems and equipment are already identified and its function defined, normally with high consequence for HSE.
- The outcome of the classification will be a set of attributes assigned to each tag. The set of parameters should be aligned to the decision model. Examples of information to be assigned to each tag are

    - safety function identifier,
    - leakage HSE consequence,
    - functional failure/loss of function – HSE consequence,
    - functional failure/loss of function – production consequence,
    - functional failure/loss of function – cost/other consequence,
    - redundancy.

The functional classification work process is described stepwise below:

1) Technical hierarchy

- The established technical hierarchy including documentation is used to identify systems and equipment which is subject to consequence classification.

2) Identify MFs
   - Each plant system should be divided into a number of MFs covering the entire system.
   - The MFs are characterised by being the principal tasks in the process such as heat exchanging, pumping, separation, power generation, compressing, distributing, storing, etc. Appendix B gives an overview of typical MFs for an oil and gas production plant.
   - Each MF is given a unique designation consisting of a number (if appropriate a tag number) and a name that describes the task and the process.

3) Identify sub functions
   - MFs are split into sub functions. In order to simplify the consequence assessment, the sub function level can be standardised for typical process equipment with pre-defined terms. See Appendix C.
   - The standard list of sub functions has to be supplemented with other sub functions relevant for the system configuration.

4) Assign MF redundancy
   - MF redundancy shall be specified, see Appendix D, Table 9 for example of redundancy definitions.
   - In case of safety systems or protective functions with redundancy due to functional reliability or regulatory requirements, the redundancy effect should not be counted for.

5) Assign MF consequences
   - The entire MF failure consequence is assessed in terms of the state where the MF no longer is able to perform its required functions.
   - Assuming that other adjacent functions and equipment are operating normally
   - In this assessment any redundancy within the function is disregarded, as the redundancy will be treated separately.

- Other mitigating actions are not considered at this stage, i.e. like spares, manning, and tools.
- The most serious, but nevertheless realistic effects of a function fault shall be identified according to set risk criteria.

6) Assign sub function redundancy
   - If there is redundancy within a sub function, the number of parallel units and capacity per unit shall be stipulated, see Table 9 for example of redundancy definitions.

7) Assign sub function consequences
   - The consequence on system/plant of a fault in a sub function is assessed with respect to HSE, production and cost according to the same principles as outlined for MF.

8) Input from other analyses
   - Safety functions: Dedicated safety functions shall be identified via a risk assessment where performance requirements are defined such as reliability and survivability. In the classification process these systems are mapped to the tag hierarchy for readily identification in the CMMS system. The functional requirements are carried forward to the maintenance programme to maintain these functions, primarily in the form of functional testing.

9) Equipment mapping to function
   - The equipment (identified by its tag numbers) carrying out the sub functions shall be assigned to the respective sub functions.
   - If equipment performs more than one sub function (e.g. some instrument loops), it should be assigned to the most critical sub function.
   - All equipment (identified by its tag number) will inherit the same description, consequence classification and redundancy as the sub function of which they are a part.

10) Result per equipment

- The documentation of consequence analysis should as a minimum include the following details and the key data stored in CMMS readily available:
    - decision criteria;
    - definition of consequence classes;
    - MF description;
    - sub function description;
    - assignment of equipment (tags) to sub function;
    - assessment of the consequences of loss of MFs and sub functions for all consequence categories, including necessary arguments for assignment of consequence classes;
    - assessment of MF and sub function redundancy;
    - any deviations should be documented and explained.

### *3.7.4 Maintenance programme*

The purpose of a maintenance program is to control all risks associated with degradation of equipment. Maintenance includes e.g. calendar based activities, inspection, condition monitoring and testing. The program shall include activities and maintenance intervals per equipment.

A maintenance programme needs updating at regular intervals. The triggers for such updating can be one or more of the following:

- the observed failure rate is significantly different from what was expected, i.e.:
    - higher failure rate is observed requiring a change in maintenance strategy or frequency – or replacement of the unit;
    - lower failure rate, or no observed damage at PM may point towards extension of intervals or omitting certain tasks.
- the operational environment has changed causing different consequence and probability:
    - less or more production;
    - change in product composition.

- cost of maintenance different from expected;
- new technology that could make the maintenance more efficient (like new methods for condition monitoring) is available;
- updated regulations;
- information from vendor;
- modifications.

The evaluation should be based on historical data and experience. A process diagram to update a maintenance programme is shown in Figure 18. If it is a safety system, an evaluation of number of failures per tests versus PS requirements should be performed. If there is a significant change in the safety system performance stated in the PS, this information should be feedback to the overall risk assessment for the plant.

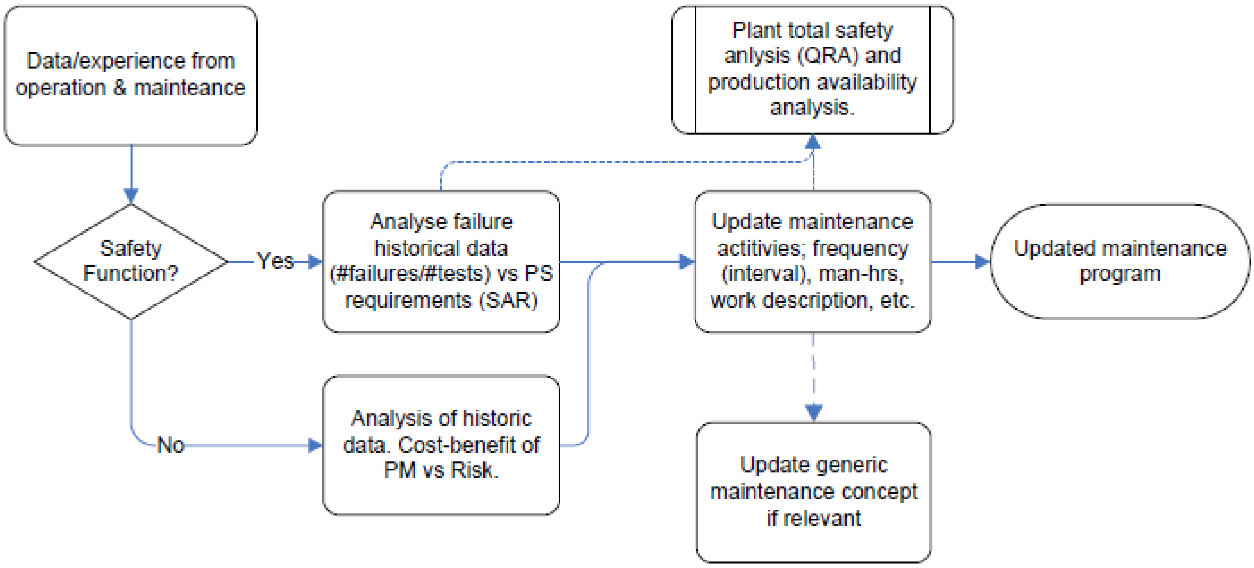



**Figure 17 – Process for updating maintenance program (NORSOK 2011).**

For non-safety systems a cost-benefit analysis based on experience should be performed. Based on this evaluation maintenance programme and GMC (if relevant) should be updated, and implemented in the maintenance plan.

Most maintenance programmes are based on a relatively constant failure rate not considering the ageing development that systems can suffer, see Figure 9. However, the maintenance function should at any time have an overview of the ageing development for its components, and do maintenance and upgrading to ensure safe and reliable operation. This may require dedicated efforts beyond what is said above when approaching the intended lifetime for the plant. Such an effort involves the following:

a) evaluate operational and degradation history. Any incidents with large degradation, abnormal operation, etc should be identified as well as any detrimental effect of modifications done to the unit. Collection and verification of system documentation and "as-build" documentation;
b) assessment of current condition/"as-is" condition;
c) evaluate the future ageing in view of the planned future operation and load planned for the asset:
    1) are there any ageing phenomena that have not been seen so far but are under development?
    2) are the safety function status and development according to requirements?
    3) will any equipment/system become obsolete so that spares no longer can be purchased?
d) based on c) decisions need to be made regarding
    1) updated/more intensive maintenance programme as well as change in spares holding strategy;
    2) replacement or modifications of single components or larger units;
    3) any operational constrains for the unit in view of ageing;
    4) dedicated analysis for e.g. structure.
e) finally, classification and maintenance programme should be updated, if relevant.

## *3.8 Spare parts evaluation*

The spare part assessment defines the need for spares, both number of spares/consumables, location and lead time, and shall be based on results from the consequence classification. Further, the PM programme should state the needed spares for its activity giving estimate of the demand rate for spare parts used for PM.

Parameters such as procurement lead time and transportation time will have significant impact on the ultimate quantities of spare parts to be hold, as well as location.

Figure 19 gives an overview of the work flow for evaluation of spare parts.

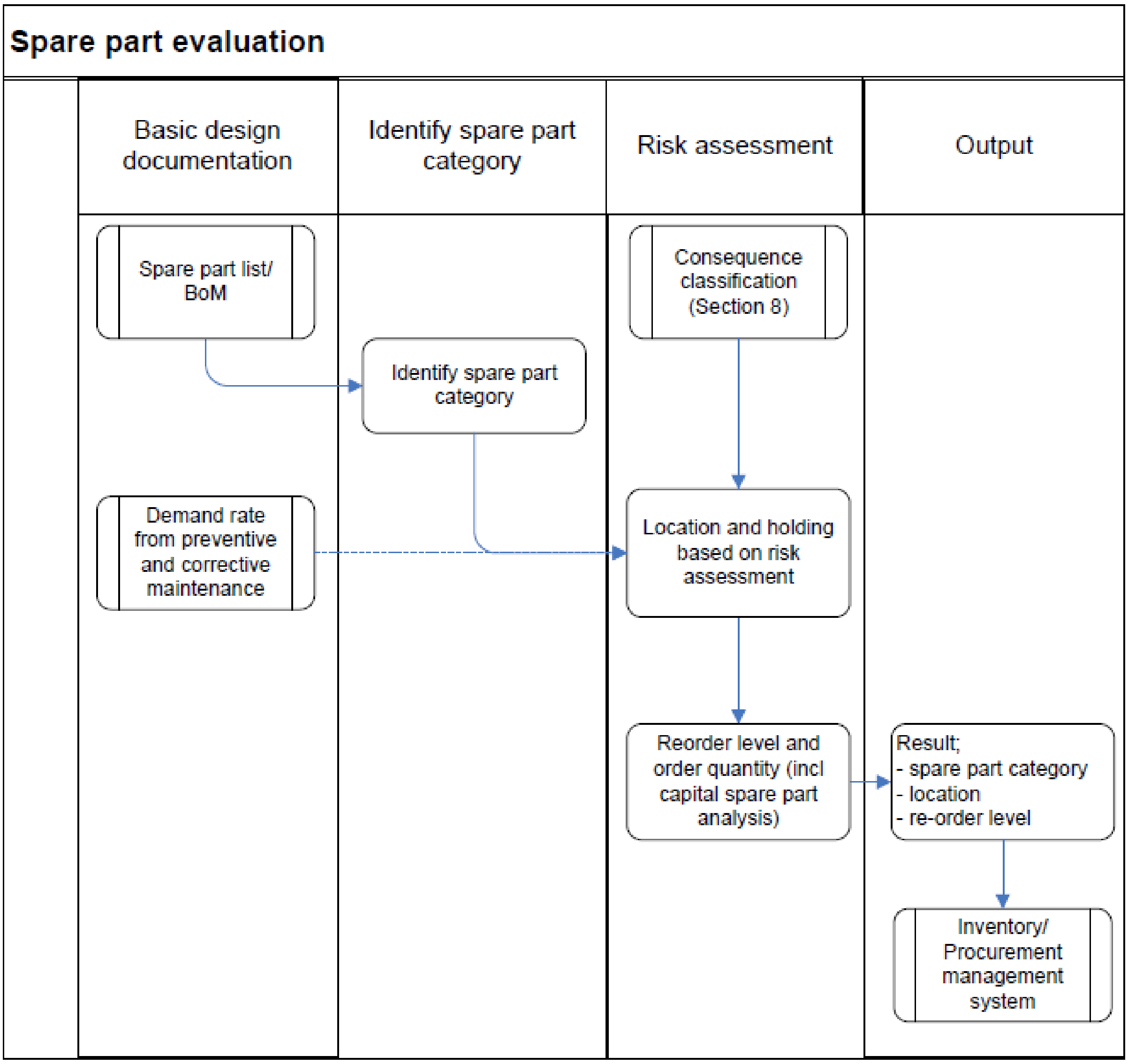



**Figure 18 – Evaluation of spare parts (NORSOK 2011).**

### 3.8.1 *Spare part categories*

Spare parts can be categorised as follows (NORSOK 2011):

- capital spare parts:
    - vital to the function of the plant, but unlikely to suffer a fault during the lifetime of the equipment;
    - delivered with unacceptably long lead time from the supplier and usually very expensive;
    - often these spare parts are characterised by a substantially lower cost if they are included with the initial order of the system package.
- operational spare parts;

    Spare parts required to maintain the operational and safety capabilities of the equipment during its normal operational lifetime.
- consumables.

    Item or material that is not item specific and intended for use only once (non-repairable).

### 3.8.2 *Location and holding*

Spare parts are normally held at various locations. Determining the optimum location for a spare part can be done by use of a risk model where the dimensions are consequence of not having the spare parts in place and the demand rate. See Appendix D for an example of a risk matrix for use to determine location (NORSOK 2011). Demand rate can be estimated from preventive and corrective maintenance. The consequence of not having the spare part in place can be established for this purpose.

### 3.8.3 *Reorder level and order quantity*

The re-order level and order quantity are important parameters to control that spare parts are available without under- or overstocking. Traditional inventory methods and formulas can be used to estimate these parameters for operational spare parts and consumables. Capital spare parts are evaluated case by case based on a risk assessment. The output is a level of spare parts which incurs the minimum combination of costs and risks.

Reorder level is based on demand rate and delivery time, adjusted by a safety factor due to uncertainty. Order quantity is estimated based on demand rate, cost per order, and holding cost.

# 4 Results

## *4.1 Existing maintenance program*

The existing maintenance program for the portal cranes consists of a yearly control, where a third part is performing the control. This is actually the only requirement by law. Recent years, Munck Cranes AS has done these controls. Figure 23 gives an example of what Munck Cranes emphasize during their controls.

In addition to the yearly control, the maintenance plan includes a lubrication check sheet. Figure 24 gives an example of such a check sheet for crane 548 Wisbeck. The check sheet looks identical for the cranes 519 and 520 Hensen, except the latter one also include a checkpoint for the tension rods. This is not relevant for crane 548 as it does not have these parts. The lubrication check sheet is reviewed every second month and is performed by BGR maintenance personnel. This year BGR has implemented that the results from the lubrication check list is to be logged in the CMMS records. This to make it easier to keep track of what has been done from previous months, and to see what uses most resources.

Besides having these visual inspections every second month and a more thorough control once a year, there is no condition monitoring of the cranes. Most of the maintenance on the cranes is based on corrective maintenance. Should a problem occur besides those that can be solved with lubrication and small parts like lining, bearings and electrical parts, there is no safety function to pick up on that before it is too late.

## 4.2 The current condition of the cranes

An inspection of cranes where performed as well as interviewing of key personnel. CMMS and incident records were investigated.

The cranes show good proof of their old age. During the inspection rounds there were discovered a lot of corrosion on different parts of the cranes. In general, there is a lot of rust on the portal cranes and their legs. The bolts around the slewing ring and on the block concerning the main lift hook were all covered with rust, and a lot of rust on ladders and hand rails, see Figure 20. Dust is another problem concerning the engine rooms seeing that the motors were covered with it. Cables hanging on the outside of the cranes are breaking up, see Figure 21.

Another observation was how bad the condition of the control cabins is. The ergonomics are terrible and there is no air condition, making a warm summer a big challenge working there. In addition, the roof is leaking. The most important thing here, though, was that the control system does not go back to "0" position after releasing the stick. This is a safety requirement on newer systems and can cause serious problems should something happen to the crane operator while operating the crane. While writing this thesis, the management at BGR had decided to change the control cabins for all the three portal cranes for completely new ones.

After investigating the incident record at BGR, 25 incidents were recorded regarding the cranes during the last 6 years. The most recent and hazardous incident happened last year and was about a 3,1 kg nut that loosened and fell down from the tension rod at portal crane 519. The height is approximately 45 meters. An explanation is given in Figure 22 of the incident:

1. The nut is loosen from the tension rod
2. Falls down on control cabinet
3. Rolls off the edge of the control cabinet
4. Hits the ground below the crane

An investigation group was put together in order to find the underlying cause for this incident. Even though it is difficult to state the exact reason why the nut loosened, it is fair to assume that vibration may have played an important part here. The nut did not show any signs of material fatigue.

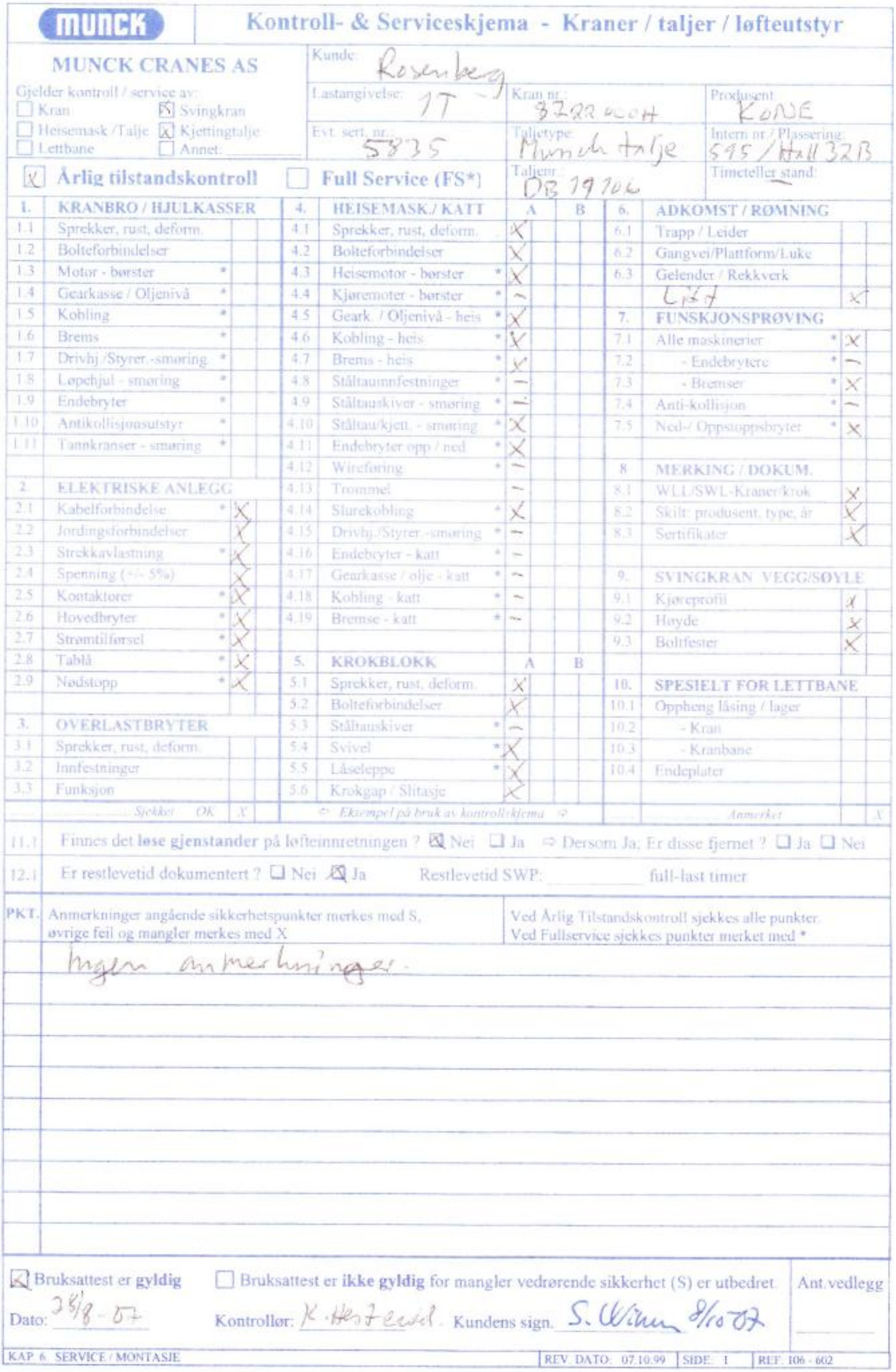
The corrective measures performed after the incident was to install safety barriers beneath the nut and around the tension rods on both the Hensen cranes, see Figure 23, and daily routines for observation of the nut were implemented.

The total downtime for the cranes has actually been decreased recent years. This is due to the lower activity on the cranes compared to before. The most frequently used crane is the 519 Hensen due to its strategic position close to GMC's area. They rent the crane service quite frequently for their projects, and should anything break down on 519, 520 works as a spare part inventory for 519.

**Figure 19 – an example of the corrosion on top of crane 520 Hensen (BGR, 2012)**

**Figure 20 – An example of cables breaking up on crane 520 Hensen (BGR, 2012)**


**Figure 21 – Incident Crane 519 Hensen where a nut falls down from the tension rod (BGR, 2012)**



MUNCK

Kontroll- & Serviceskjema - Kraner / taljer / løfteutstyr

MUNCK CRANES AS

Kunde: Rosenberg

Gjelder kontroll / service av: ☐ Kran ☒ Svingkran ☐ Heisemask./Talje ☒ Kjettingtalje ☐ Lettbane ☐ Annet:

Lastangivelse: 1T

Kran nr.: 3222 W.O.H

Produsent: KONE

Evt. sert. nr.: 5835

Taljetype: Munch talje

Intern nr./Plassering: 595 / Hall 32B

☒ Årlig tilstandskontroll ☐ Full Service (FS*)

Taljenr.: DB 19706

Timeteller stand:

| 1. | KRANBRO / HJULKASSER | | | 4. | HEISEMASK./KATT | | A | B | 6. | ADKOMST / RØMNING | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | Sprekker, rust, deform. | | | 4.1 | Sprekker, rust, deform. | | X | | 6.1 | Trapp / Leider | | |
| 1.2 | Bolteforbindelser | | | 4.2 | Bolteforbindelser | | X | | 6.2 | Gangvei/Plattform/Luke | | |
| 1.3 | Motor - børster | * | | 4.3 | Heisemotor - børster | * | X | | 6.3 | Gelender / Rekkverk | | |
| 1.4 | Gearkasse / Oljenivå | * | | 4.4 | Kjøremotor - børster | * | – | | | Lift | | X |
| 1.5 | Kobling | * | | 4.5 | Geark. / Oljenivå - heis | * | X | | 7. | FUNSKJONSPRØVING | | |
| 1.6 | Brems | * | | 4.6 | Kobling - heis | * | X | | 7.1 | Alle maskinerier | * | X |
| 1.7 | Drivhj./Styrer.-smøring | * | | 4.7 | Brems - heis | * | X | | 7.2 | - Endebrytere | * | – |
| 1.8 | Løpehjul - smøring | * | | 4.8 | Ståltaufestninger | * | – | | 7.3 | - Bremser | * | X |
| 1.9 | Endebryter | * | | 4.9 | Ståltauskiver - smøring | * | – | | 7.4 | Anti-kollisjon | * | – |
| 1.10 | Antikollisjonsutstyr | * | | 4.10 | Ståltau/kjett. - smøring | * | X | | 7.5 | Ned-/ Oppstoppsbryter | * | X |
| 1.11 | Tannkranser - smøring | * | | 4.11 | Endebryter opp / ned | * | X | | | | | |
| | | | | 4.12 | Wireføring | * | – | | 8. | MERKING / DOKUM. | | |
| 2. | ELEKTRISKE ANLEGG | | | 4.13 | Trommel | | – | | 8.1 | WLL/SWL-Kraner/krok | | X |
| 2.1 | Kabelforbindelse | * | X | 4.14 | Slurekobling | * | X | | 8.2 | Skilt: produsent, type, år | | X |
| 2.2 | Jordingsforbindelser | | X | 4.15 | Drivhj./Styrer.-smøring | * | – | | 8.3 | Sertifikater | | X |
| 2.3 | Strekkavlastning | * | X | 4.16 | Endebryter - katt | * | – | | | | | |
| 2.4 | Spenning (+/- 5%) | | X | 4.17 | Gearkasse / olje - katt | * | – | | 9. | SVINGKRAN VEGG/SØYLE | | |
| 2.5 | Kontaktorer | * | X | 4.18 | Kobling - katt | * | – | | 9.1 | Kjøreprofil | | X |
| 2.6 | Hovedbryter | * | X | 4.19 | Bremse - katt | * | – | | 9.2 | Høyde | | X |
| 2.7 | Strømtilførsel | * | X | | | | | | 9.3 | Boltfester | | X |
| 2.8 | Tablå | * | X | 5. | KROKBLOKK | | A | B | | | | |
| 2.9 | Nødstopp | * | X | 5.1 | Sprekker, rust, deform. | | X | | 10. | SPESIELT FOR LETTBANE | | |
| | | | | 5.2 | Bolteforbindelser | | X | | 10.1 | Oppheng låsing / lager | | |
| 3. | OVERLASTBRYTER | | | 5.3 | Ståltauskiver | * | – | | 10.2 | - Kran | | |
| 3.1 | Sprekker, rust, deform. | | | 5.4 | Svivel | * | X | | 10.3 | - Kranbane | | |
| 3.2 | Innfestninger | | | 5.5 | Låseleppe | * | X | | 10.4 | Endeplater | | |
| 3.3 | Funksjon | | | 5.6 | Krokgap / Slitasje | | X | | | | | |
| | Sjekket OK | | X | | ⇐ Eksempel på bruk av kontrollskjema ⇒ | | | | | Anmerket | | X |

11.1 Finnes det løse gjenstander på løfteinnretningen? ☒ Nei ☐ Ja ⇒ Dersom Ja; Er disse fjernet? ☐ Ja ☐ Nei

12.1 Er restlevetid dokumentert? ☐ Nei ☒ Ja Restlevetid SWP: ______ full-last timer

PKT. Anmerkninger angående sikkerhetspunkter merkes med S, øvrige feil og mangler merkes med X

Ved Årlig Tilstandskontroll sjekkes alle punkter. Ved Fullservice sjekkes punkter merket med *

Ingen anmerkninger.

☒ Bruksattest er gyldig ☐ Bruksattest er ikke gyldig for mangler vedrørende sikkerhet (S) er utbedret. Ant.vedlegg

Dato: 28/8-07 Kontrollør: K. Hestenes Kundens sign. S. Wiium 8/10 07

KAP. 6 SERVICE / MONTASJE REV. DATO: 07.10.99 SIDE: 1 REF: 106 - 602

**Figure 22 – Control and service form Munck Cranes AS (BGR, 2012)**

**PERIODISK VEDLIKEHOLD AV PORTALKRAN 548 WISBECH** **Mnd / År**

| Beskrivelse | Kontrollert | Smørt | Etterfylt | Skiftet olje/fett | Justert | Kommentar |
|---|---|---|---|---|---|---|
| Kjørehjul/boggier | | | | | | |
| Oljenivå gearkasser nede | | | | | | |
| Oljenivå gearkasser oppe | | | | | | |
| Bom/jibb | | | | | | |
| Tårn | | | | | | |
| Maskinrom | | | | | | |
| Svingkrans | | | | | | |
| Bremser nede | | | | | | |
| Bremser oppe | | | | | | |
| Kroker | | | | | | |
| Endebrytere kontrollert | | | | | | |
| Generell sjekk Trapper / Rekkverk | | | | | | |
| Krane er kontrollert for løse gjenstander | | | | | | |
| Generell Orden & Ryddighet | | | | | | |
| Frie Rømningsveier | | | | | | |
| Årets farge provosorisk løfteutstyr | | | | | | |
| Korrosjon | | | | | | |
| Oppheng lys / lyskastere | | | | | | |

**Signatur** **Dato**

**Figure 23 – Periodic maintenance of portal crane 548 Wisbeck (BGR, 2012)**

## *4.3 The current spare part inventory at BGR*

An inspection of the spare part inventory where performed as well as interviewing of key personnel.

The spare part inventory contains parts that have in some cases been stored there since 1960. These parts, besides being checked before use, do not get maintained much. Some of the parts do not get produced anymore and has to be custom-made through data sheets. The delivery time may be as long as 6 months.

The following parts are currently in BGRs spare part inventory:

- One set of bogies for crane 548 Wisbeck and one set for crane 519/520 Hensen
- Electrical equipment/parts for the engine room
- A couple of bearings for the engine room
- Oil for the gearboxes
- Several limit-switches/sensors
- Several split-lock washers for the tension rods
- Consumables:
  - Several different lubricants
  - Several different oils

Parts available from close by suppliers:

- Brake bands.
  - Need external help to replace the old bands with new ones. This is often done within an hour, depending on the supplier’s capacity that day.
- Different linings made at IKM at Forus.

## 4.4 Consequence classification

Documentation of the cranes was difficult to find due to their old age. The following was to be found of the Wisbeck 548 crane, see Figure 25. As one can see from the documentation the crane has a support lift in addition to the main lift. This goes for the Hensen cranes, as well.

The application certificates for the portal cranes can be found in Appendix E.

BGR could not provide a sufficient technical hierarchy of the cranes. To be able to identify the equipment that was subject to consequence classification experienced personnel were interviewed. This included the crane operator and maintenance people responsible for the cranes.

Following equipment on the cranes is subject to consequence classification:

- The crane's wheels/bogies
- The gearboxes (6 in total on each crane)
- The jib boom
- The tower of the crane
- The engine room
- The slewing ring
- The tension rods (Hensen)
- The breaks
- The hooks
- The sensors/limit-switches
- The headlights and their suspension

The following classification was used:

**Table 5 – General consequence classification**

| Class | Health, safety and environment (HSE) | Production | Cost (exclusive production loss) |
|---|---|---|---|
| **High** | Potential for serious injuries.<br>Render safety critical systems inoperable.<br>Potential for fire in classified areas.<br>Potential for large pollution. | Stop in production exceeding one week | Substantial cost - exceeding 1 mill NOK |
| **Med.** | Potential for injuries requiring medical treatment.<br>Limited effect on safety systems.<br>No potential for fire in classified areas.<br>Potential for moderate pollution. | Brief stop in production lasting less than a week, but more than a day. | Moderate cost between 0.1 - 1 mill NOK |
| **Low** | No potential for injuries.<br>No potential for fire or effect on safety systems<br>No potential for pollution | No effect on production, problem fixed within the day. | Insignificant cost less than 100 000 NOK |

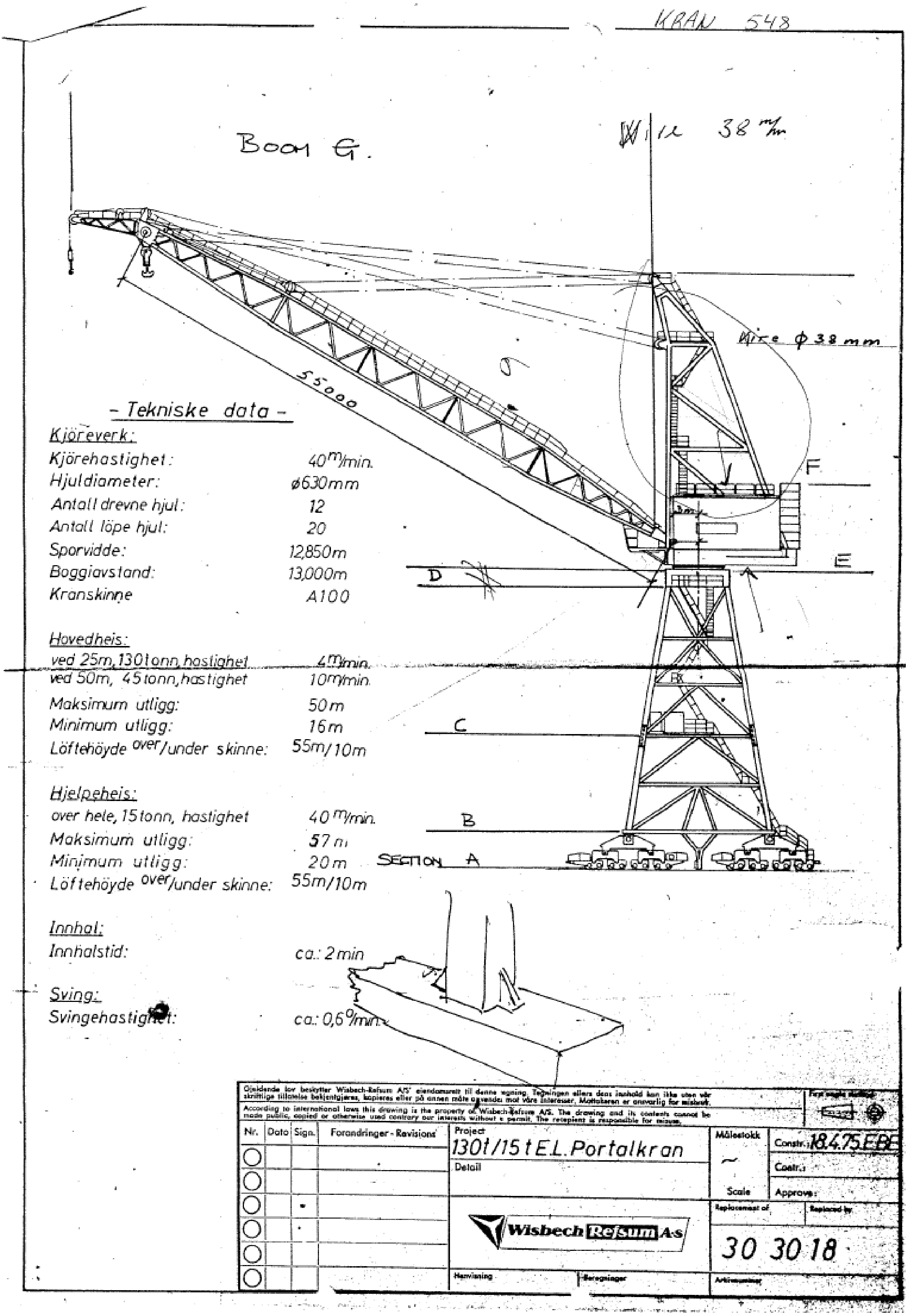



**Figure 24 – Documentation of the Wisbeck Refsum crane (BGR, 2012)**

An overall redundancy for the cranes is that should one crane lose function or break down, there are always two cranes in backup. In addition, two of the cranes are identical meaning they share the same identical equipment and structure (the two Hensen cranes). If the Yard had only one portal crane the situation would be changed, meaning less availability and capacity.

During the following classification each crane will be looked into isolated from the other two cranes. The reason for that is to see if there is any redundancy within each crane.

1. **The crane's wheels/bogies**
   MF: Manoeuvring/transporting the crane from A to B.
   HSE consequence: **Low**. No immediate danger here should one of the wheels break down. The crane will not be able to move.
   Production consequence: **High**. Time to change the wheels: Approximately 4 weeks. Getting the old one fixed takes the same amount of time.
   Cost consequence: **High**.
   Redundancy: **A**. If one of the wheels breaks down the crane has to stop.

2. **The gearboxes**
   MF: Manoeuvring the crane.
   HSE consequence: **Low**.
   Production consequence: **Low**. Should one of the gearboxes break down the crane could still move, as the crane has six of them. In order to be able to do that the gearbox needs to be detached which is done in less than an hour. This can go on until a new gearbox is being prepared.
   Cost consequence: **High**.
   Redundancy: **B.**

3. **The jib boom**
   MF: Lifting

Sub function: Wire rope sheave. Feed wire during lifting operation.

HSE consequence: **MF: High**. Should the jib boom fail during a lifting operation people might get seriously injured. **Sub function: Med.** The wire rope sheave can crack.

Production consequence: **High.** Lots of work should the jib boom lose function.

Cost consequence: **High.** Need to use a neighbouring crane in order to get equipment down.

Redundancy: **A.**

4. **The tower of the crane**

   MF: Lifting

   Sub function: Wire rope sheave. Load cell. Keeping track of the weight of the load that is being lifted.

   HSE consequence: **MF: Med. Sub function: High.**

   Production consequence: **Med.** Should the main lift lose function the support lift can be used given that the load is within the support lifts capacity.

   Cost consequence: **Low.**

   Redundancy: **A.** If the support lift can be used: **B.**

5. **The engine room**

   MF: Lifting

   Sub function: the driving gear for main and support lift. Bearings on reel. Electrical installation.

   HSE consequence: **MF: Low. Sub function: Med.**

   Production consequence: **Med.** Similar consequence to the tower.

   Cost consequence: **Med.**

   Redundancy: **A.** If the support lift can be used: **B.**

6. **The slewing ring**

   MF: Manoeuvring

   HSE consequence: **Low.**

   Production consequence: **High.** Changing a driving wheel supporting the slewing ring would be classified as a medium consequence.

   Cost consequence: **High.**

Redundancy: **A.**

7. **The tension rods**

   MF: Lifting

   HSE consequence: **Low.**

   Production consequence: **High.** Bearing, lining and spring failure will all cause long downtime due to long repair time.

   Cost consequence: **Med.**

8. **The breaks**

   MF: Manoeuvring and lifting. Two sets of breaks, one for manoeuvring the crane and the other for the lifting operation. Each break system has two sets of breaks with reduced break force should one fail.

   HSE consequence: **High.**

   Production consequence: For manoeuvring: **Low.** For lifting: **Med.** Main and support lift.

   Cost consequence: **Low.**

   Redundancy: **B.**

9. **The hooks**

   MF: Lifting

   HSE consequence: **Low.**

   Production consequence: **Med.** Should there be any signs of cracks or other defects on the hook a new hook would be needed. No spare part at site.

   Cost consequence: **Med.**

   Redundancy: **A.** If the support lift can be used: **B.**

10. **The sensors/limit-switches**

    Sub function: Indicator/controlling. Controlling the position of the jib boom and the position of the crane when it is getting near the end of the rails.

    HSE consequence: **Low.** The load cell will also give indication should the sensors lose function.

    Production consequence: **Med.** If one of the sensors breaks down the crane will not be able to operate. In most cases the sensors just need to be reset (lightning).

Cost consequence: **Low.**

Redundancy: **A.**

**11. The headlights and their suspension**

Sub function: Illuminate the area around the crane.

HSE consequence: **Low.**

Production consequence: Season dependent. During summer period: **Low.** During winter period: **Med.**

Cost consequence: **Low.**

Redundancy: **B.** Losing more than one of the headlights will reduce the visibility around the crane considerably.

# 5 Discussion

The current maintenance program is based on visual inspections with a more thorough control each year, carried out by Munck Cranes AS. This is a good foundation for good maintenance, but as the crane gets older problems that cannot be discovered by the naked eye starts to appear. Cracks and other material fatigues caused by corrosion, wear and tear is difficult to detect with just visual inspection. With reference to the consequence classification, there would be recommended to implement condition monitoring to the maintenance program. For high consequence parts like the slewing ring, the tension rods and the jib boom, which all are parts of the load carrying structure, vibration monitoring would be an excellent technique (ref. Section 3.6.1.1).

For parts like the bogies, the hooks and different bolts located on the cranes, NDT would be e good technique (ref. Section 3.6.1.4). To implement NDT every second month may be to overdo it, but as an annual control could be wise.

Regarding the increasing corrosion on the portal cranes this is maybe the most expensive part of the maintenance program. But not dealing with it sooner rather than later will just add to the expenses and increase the probability for failure. There is no easy solution for this.

Management has to agree on taking the bill and to make sure it is solved properly. This way it will get easier to implement simple surface treatments to the lubrication check sheet, should any new corrosion be discovered. A good advice is to do NDT on the welded joints before surface treatment.

The spare parts inventory at BGR needs improvements. Too much time is being spent on waiting for the right part to arrive instead of having the right part in stock. With reference to the consequence classification, it is recommended to have the right spares for the jib boom, the tension rods and the slewing ring at site. These parts are operational spare parts, like bearings, linings and wire rope sheaves. The yard has room for it.

Extra capital spare parts like gearboxes and wire line spools would prevent unnecessary downtime, as an old gearbox needs to be sent to Denmark for repair. The total number of gearboxes at BGR is 18 (6 for each crane) and given their old age, the probability for one of them to fail during a year is quite high. Each crane has two wire line spools and they have an expected lifetime for 10-12 years. The problem with keeping an extra spool in stock is that they are date stamped. Here, a new spool should be ordered to be ready in time to replace one of the old ones. The delivery time is app. 6 months.

# 6 Conclusion

The following improvements to the maintenance program are suggested:

Suggestion 1:

Implement vibration monitoring to detect material fatigue, wear and loose parts on the following parts: the slewing ring, the tension rods and the jib boom.

Suggestion 2:

Implement NDT to the annual control to detect material fatigue to the following parts: the bogies, the hooks and the different bolts located on the cranes.

Suggestion 3:

Put in sufficient resources to handle the corrosion problem. This way it will get easier to implement simple surface treatments to the lubrication check sheet, should any new corrosion be discovered.

Suggestion 4:

Keep one extra gearbox for each crane at site. Prepare a new wire line spool a year in advance to when the old one is to expire.

Suggestion 5:

Keep enough operational spare parts for the following equipments: the jib boom, the tension rods and the slewing ring. This includes bearings, linings and wire rope sheaves as well as gear wheels.

# 7 References

Arbeids- og administrasjonsdepartementet, 2001. *St.meld. nr. 7 Om helse, miljø og sikkerhet i petroleumsvirksomheten.* [online] Oslo: Arbeids- og administrasjonsdepartementet. Available at: <http://www.regjeringen.no/Rpub/STM/20012002/007/PDFA/STM200120020007000DDDPDFA.pdf>. [Accessed 14 April 2012].

BGR, 2012. *Internal archive Bergen Group Rosenberg*

EngineersHandbook (2006). "*Radiography Testing*." from http://www.engineershandbook.com/MfgMethods/ndtrt.htm

ISO, 2006. *NS-EN ISO 14224:2006 Petroleums- og naturgassindustri - Samling og utveksling av pålitelighets- og vedlikeholdsdata for utstyr.* Lysaker: Standard Online AS.

ISO, 2010. *NS-EN 13306:2010 Maintenance terminology.* Lysaker: Standard Online AS.

Larson, B. (2012a). "*Basic Principles of Ultrasonic Testing*." from http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/Introduction/description.htm.

Larson, B. (2012b). "*Basic Principles of Magnetic Particle Inspection*." from http://www.ndt-ed.org/EducationResources/CommunityCollege/MagParticle/Introduction/basicprinciples.htm

Liyanage, J. P., 2007. *Integrated eOperations-eMaintenance: Applications in North Sea offshore assets.* Springer: Kobbacy, K. A. H. and Murthy, D. N. P.

Meland, O., Schølberg, P., Vatn, J. and Rødseth, H., 2009. *Forskning og utvikling innen vedlikehold med relevans for petroleumsvirksomheten.* Trondheim: Sintef Teknologi og Samfunn.

Mobley, R. K. ed., 2002. *An introduction to predictive maintenance*. London: Butterworth Heinemann.

MOM350, 2010. *Condition monitoring and management.* [lecture notes] Professor Tore Markeset. Stavanger: University of Stavanger.

MOM460, 2010. *Drift og vedlikeholdsstyring.* [lecture notes] Professor Tore Markeset. Stavanger: University of Stavanger.

NIST (2012). *The Bathtub Curve*, http://www.itl.nist.gov/div898/handbook/apr/section1/apr124.htm.

NORSOK (2011). "*NORSOK Z-008 Risk based maintenance and consequence classification*." **Edition 3**.

Services, S. E.-T. (2012). *Thermography*, Spark Electro-Techinical Services.

Piltelton, L., Gelders, L. and Puyvelde, F. van., 1997. *Maintenance management*. Leuven: Acco.

Tsang, A. H. C., 1995. *Condition-based maintenance: tools and decision making*. Hong Kong: The Hong Kong Polytechnic University.

## List of figures

## List of tables

# Appendix A

Flow diagram for vibration monitoring

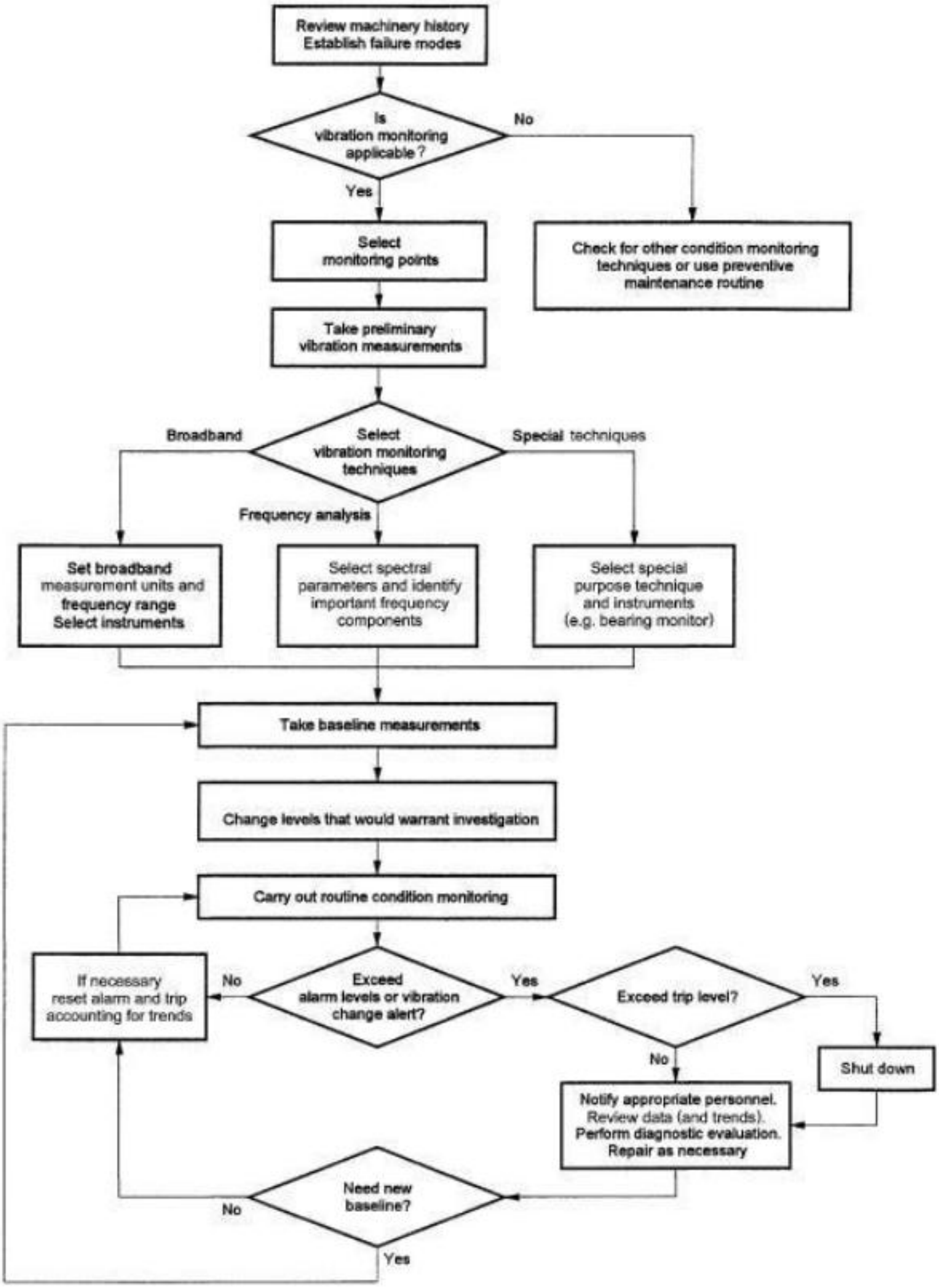



**Figure 25 – Flow diagram for vibration monitoring (ISO, 2002)**

# Appendix B

Main function (MF) description and boundaries

Descriptions of MFs should aim to describe an active function (i.e. "Pumping" instead of "Pump"). Descriptions commonly used for MFs are shown in Table 5. Normally a further specification is required to describe the MF sufficiently. If relevant, the availability, capacity and performance should be specified.

**Table 6 – Examples of MF descriptions (NORSOK 2011)**

| MF description | Sub title, examples |
|---|---|
| Accumulation | Instrument/plant air, heating/cooling medium |
| Cementing | |
| Circulating | Heating/cooling medium |
| Compressing | Gas export/injection |
| Cooling | |
| Detecting | Fire and gas |
| Distributing | (Main/emergency) power, hydraulic, tele |
| Drying | Air, gas |
| Expanding | |
| Filling | Lubrication oil |
| Filtering | |
| Fire fighting | Sprinkler, deluge, water spray, foam, aqueous film foaming foam, hydrants |
| Generating | (Main/emergency) power |
| Heating | |
| Injecting | Chemicals, gas, water |
| Life Saving | Mob, lifeboat, basket, raft, escape chute |
| Lifting | Deck crane, personnel, goods |
| Logging | Well, production, mud |
| Manoeuvring | |
| Metering | Fiscal (gas/oil), $CO_2$ |
| Pumping | Oil/gas export, bilge, seawater |
| Regenerating | Glycol |
| Scrubbing | |
| Separating | Production, test, cyclone- (water/sand/oil), centrifuge |
| Storing | Chemicals, potable water, lubrication/seal oil |
| Transferring | Oil/gas pipe (riser) |

# Appendix C

Simplifying consequence assessment of standard sub functions

The consequence assessment of the MF already performed may be used as a basis for establishing the consequence assessment for the standard sub functions. It is recommended that these evaluations are verified by experienced process personnel and adjusted individually, if needed.

An example of guidelines for the standardised sub functions for one project is shown in Table 6.

**Table 7 - Project guideline example of consequence assessment of standardized sub functions, based on the MF consequence assessment (NORSOK 2011).**

| Standard sub function | Classification of loss of function | | | | Comment |
|---|---|---|---|---|---|
| | RED | HSE | PROD | Other | |
| Main task | MF | MF | MF | MF | |
| Pressure, relief | Configu ration | H | L | L | **RED:** No redundancy for the failure mode 'Fail to operate on demand' |
| Shut down, process | A | H | L | L | **RED:** No redundancy for the failure mode 'Fail to operate on demand'. |
| Shut down, equipment | MF | M | L | MF | **Other:** Inherits the highest consequence from the MF |
| Controlling | MF | MF | MF | MF | |
| Monitoring | MF | M | L | L | |
| Local indication | MF | L | L | L | |
| Manual shutoff | MF | (MF) | (MF) | (MF) | |

H/M/L Consequence "high", "medium" and "low"
MF Will inherit MFs
RED Redundancy
() Reduce with one level from MF

# Appendix D

Risk assessment criteria

## D.1 Risk decisions based on risk assessment

As important as the risk scale is the use of the risk for decision making. Table 7 shows a set of criteria for prioritising time to repair connected to corrective work. The scale for time to repair should be based on company standard for maximum allowable time to complete repair and the mean time to failure.

Example: A failure is observed and the development time to critical failure (fully functional outage) for this function is expected to be 2 years. The time to repair should be some fraction of this time, like 9 months for the highest consequence C3 and 18 months for the lower consequence C1.

**Table 8 - Example of priority of time to repair based on risk (NORSOK 2011)**

| Risk | Priority/time to repair | Comment |
|---|---|---|
| H | 5 days | Always highest priority for safety function failure. |
| M | 30 days | |
| L | 180 days | |
| VL | 360 days | |

**Table 9 - Example of redundancy definitions (NORSOK 2011)**

| RED | Redundancy degree definition |
|---|---|
| A | No redundancy i.e. the entire system is required to avoid any loss of function. |
| B | One parallel unit can suffer a fault without influencing the function. |
| C | Two or more parallel units can suffer a fault at the same time without influencing the function |

## D.2 Risk assessment of spare parts

An example of consequence classes which can be used to determine the optimum location for spare parts is given in Table 9. Input from the consequence classification can be used or modified for this purpose. The consequence classes combined with demand rate gives location of spare parts as shown in Table 10.

**Table 10 - Example of consequence classes for spare parts (NORSOK 2011)**

| Consequence | Description |
|---|---|
| High | Equipment of a system that shall operate in order to maintain operational capability in terms of safety, environment and production. |
| Medium | Equipment of a system that have installed redundancy, of which either the system or its installed spare must operate in order to maintain operational capability in terms of safety, environment and production. |
| Low | No consequence for safety, production or environment. |

**Table 11 - Example of risk matrix for spare parts (NORSOK 2011)**

| Consequence / Demand rate | Low | Medium | High |
|---|---|---|---|
| **First line spare parts, frequently used.** | Minimum stock at site | Minimum stock at site and any additional spare parts at central warehouse | Adequate stock at site |
| **Not frequently used.** | No stock | Central warehouse, no stock at site | Central warehouse and minimum stock at site if convenient |
| **Capital spare parts. Seldom or never used.** | No stock | No stock | Holding optimized by use of risk assessment case by case |

# Appendix E

Application certificate for the portal cranes

Wisbeck Refsum 548

MUNCK

MUNCK CRANES AS

**BRUKSATTEST**
**FOR LØFTEINNRETNING OG FAST TILBEHØR**

I HENHOLD TIL FORSKRIFT OM BRUK AV ARBEIDSUTSTYR (555)

| | |
|---|---|
| Produsent / Leverandør: **Wisbeck Refsum** | Bruksattest nr.: *332-967* |
| Sluttbruker: **Kværner Oil & Gas** | Prod.nr.: |
| Adresse: P. O. Box 8006<br>4003 STAVANGER | Prod. år.: 1975 |

Vi bekrefter hermed at følgende utstyr oppfyller de grunnleggende kravene til helse og sikkerhet ifølge EUs retningslinjer med hensyn til design og produksjon. Denne bekreftelsen bortfaller hvis utstyret endres på noen måte uten at vi konsulteres på forhånd. Vi bekrefter også at oppstilling og sammenmontering er OK. Videre bekreftes at vi har kontrollert CE-merket instruksjonsbok og samsvarserklæring ihht. maskinforskrift best. nr. 522. Vedlikehold utføres i henhold til leverandørens manualer. Vedlikehold skal journalføres.

| Løfteinnretningens art, plassering, beskrivelse og eventuelle nummer eller andre merker | | Kranens bomlengde bomvinkel arbeidsradius | Anvendt prøvelast ved 1 gangs kontroll | Tillatt arbeidsbelastning ved angitte bomlengde bomvinkel arbeidsradius |
|---|---|---|---|---|
| PORTALKRAN | | Meter / grader | Tonn | Tonn |
| Konstruksjon | : Portalkran | 25 m | 143,0 | 130,0 |
| Beregnet etter norm | : Svensk standard IKH | 57 m | 18,75 | 15,0 |
| Hovedløft | : 130 t inntil 25 m radius | | | |
| Hjelpeløft | : 15 t inntil 57 m radius | | | |
| Eiers maskinnummer | : 548 | | | |
| Plassering hos eier | : NORDSIDEN AV DOKK II | | | |

Ovenstående test dokumenterer at løfteinnretningen inklusiv fundament er funksjonsprøvet og belastet i henhold til gjeldende regelverk for å kontrollere sikkerheten under bruk.

Denne bruksattesten er kun gyldig for en kontrollperiode av gangen. For gyldighetsperiode – se bakside.

Bekrefter at utstyr som beskrevet ovenfor har blitt inspisert, testet og dersom ikke noe annet er bestemt ovenfor, er i overensstemmelse med innholdet i kontrakten eller ordren.
Kvalitetskontrollen er utført i overensstemmelse med vår kvalitetssikring.

1. Original: Kunde 1. Kopi: Avd.kontor

**Figure 26 – Application certificate for crane 548 Wisbeck, page 1 (BGR, 2012)**

# BRUKSATTEST

ATTESTASJON FOR GYLDIGHET

Denne bruksattest er gyldig dersom mangler påvist etter periodisk kontroll og som berører sikkerhet er utbedret (ref. Munck kontrollskjema).

**Attestasjon for gyldighet gjelder for en kontrollperiode av gangen.**

| **Kontrolltype** | **Bruksattest gyldig fra:** | **Bruksattest gyldig til:** | **Sign.:** |
|---|---|---|---|
| 1. gangs kontroll med last og bremseprøve | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | 09.2001 | 09.2002 | MUNCK CRANES AS [illegible] |
| Periodisk kontroll i henhold til forskrifter | 09.2002 | 09.2003 | MUNCK CRANES AS [illegible] |
| | | | |
| Periodisk kontroll med last og bremseprøve | 09.2003 | 09.2004 | MUNCK CRANES AS [illegible] |
| Periodisk kontroll i henhold til forskrifter | 09.2004 | 09.2005 | Munck Service AS [illegible] |
| Periodisk kontroll i henhold til forskrifter | 08.2005 | 08.2006 | Munck Service AS [illegible] |
| Periodisk kontroll i henhold til forskrifter | 11.2006 | 11.2007 | Munck Service AS [illegible] |
| | | | |
| Periodisk kontroll med last og bremseprøve | 11.2007 | 11.2008 | MUNCK CRANES AS [illegible] |
| Periodisk kontroll i henhold til forskrifter | 07.2008 | 07.2009 | MUNCK CRANES AS [illegible] |
| Periodisk kontroll i henhold til forskrifter | 10.7.2009 | 10.7.2010 | MUNCK CRANES AS O. Nilsen |
| Periodisk kontroll i henhold til forskrifter | 7/7.2010 | 7/7.2011 | Munck Service AS For O. Nilsen [illegible] |
| | 28/7 2011 | 28/7 2012 | [illegible] |
| Periodisk kontroll med last og bremseprøve | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| | | | |
| Periodisk kontroll med last og bremseprøve | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| | | | |

For tekniske data og produktinformasjon, se forside

**Figure 27 - Application certificate for crane 548 Wisbeck, page 2 (BGR, 2012)**

Stork Hensen 519 & 520

munck

MUNCK CRANES AS

# BRUKSATTEST
# FOR LØFTEINNRETNING OG FAST TILBEHØR

I HENHOLD TIL FORSKRIFT OM BRUK AV ARBEIDSUTSTYR (555)

| | |
|---|---|
| Produsent / Leverandør: **Stork Hensen** | Bruksattest nr.: *332-970* |
| Sluttbruker: **Kværner Oil & Gas** | Prod.nr.: |
| Adresse: P. O. Box 8006<br>4003 STAVANGER | Prod. år.: 1960 |

Vi bekrefter hermed at følgende utstyr oppfyller de grunnleggende kravene til helse og sikkerhet ifølge EUs retningslinjer med hensyn til design og produksjon. Denne bekreftelsen bortfaller hvis utstyret endres på noen måte uten at vi konsulteres på forhånd. Vi bekrefter også at oppstilling og sammenmontering er OK. Videre bekreftes at vi har kontrollert CE-merket instruksjonsbok og samsvarserklæring ihht. maskinforskrift best. nr. 522. Vedlikehold utføres i henhold til leverandørens manualer. Vedlikehold skal journalføres.

| Løfteinnretningens art, plassering, beskrivelse og eventuelle nummer eller andre merker | | Kranens bomlengde bomvinkel arbeidsradius | Anvendt prøvelast ved 1 gangs kontroll | Tillatt arbeidsbelastning ved angitte bomlengde bomvinkel arbeidsradius |
|---|---|---|---|---|
| PORTALKRAN | | Meter / grader | Tonn | Tonn |
| | : | | | |
| Konstruksjon | : Portalkran | 19,5 | 110,0 | 100,0 |
| Last Løfteevne | : 100 t | | | |
| Type | : Portalkran | 45 | 12,5 | 10,0 |
| | : | | | |
| Beregnet etter norm/ | : | | | |
| tilfredsstiller klasse | : Nederlandske | | | |
| | : normaliseringsbestemmelser | | | |
| | : N1018 | | | |
| | : | | | |
| Eiers maskinnummer | : 520 | | | |
| Plassering hos eier | : NORDSIDEN, DOKK II | | | |

Ovenstående test dokumenterer at løfteinnretningen inklusiv fundament er funksjonsprøvet og belastet i henhold til gjeldende regelverk for å kontrollere sikkerheten under bruk.

Denne bruksattesten er kun gyldig for en kontrollperiode av gangen. For gyldighetsperiode – se bakside.

Bekrefter at utstyr som beskrevet ovenfor har blitt inspisert, testet og dersom ikke noe annet er bestemt ovenfor, er i overensstemmelse med innholdet i kontrakten eller ordren.
Kvalitetskontrollen er utført i overensstemmelse med vår kvalitetssikring.

1. Original: Kunde 1. Kopi: Avd.kontor

**Figure 28 - Application certificate for crane 520 Hensen, page 1 (BGR, 2012)**

# BRUKSATTEST

## ATTESTASJON FOR GYLDIGHET

Denne bruksattest er gyldig dersom mangler påvist etter periodisk kontroll og som berører sikkerhet er utbedret (ref. Munck kontrollskjema).

**Attestasjon for gyldighet gjelder for en kontrollperiode av gangen.**

| Kontrolltype | Bruksattest gyldig fra: | Bruksattest gyldig til: | Sign.: |
|---|---|---|---|
| 1. gangs kontroll med last og bremseprøve | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | 05.2001 | 05.2002 | MUNCK CRANES AS |
| Periodisk kontroll i henhold til forskrifter | 05.2002 | 05.2003 | MUNCK CRANES AS |
| | | | |
| Periodisk kontroll med last og bremseprøve | 05.2003 | 05.2004 | MUNCK CRANES AS |
| Periodisk kontroll i henhold til forskrifter | 06.2004 | 06.2005 | Munck Service AS |
| Periodisk kontroll i henhold til forskrifter | 08.2005 | 08.2006 | Munck Service AS |
| Periodisk kontroll i henhold til forskrifter | 11.2006 | 11.2007 | Munck Service AS |
| | | | |
| Periodisk kontroll med last og bremseprøve | 11.2007 | 11.2008 | MUNCK CRANES AS |
| Periodisk kontroll i henhold til forskrifter | 07.2008 | 07.2009 | MUNCK CRANES AS |
| Periodisk kontroll i henhold til forskrifter | 10.7.2009 | 10.7.2010 | MUNCK CRANES AS |
| Periodisk kontroll i henhold til forskrifter | 7/7-2010 | 7/7-2011 | Munck Service AS |
| | 28/7 2011 | 28/7 2012 | [illegible] |
| Periodisk kontroll med last og bremseprøve | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| | | | |
| Periodisk kontroll med last og bremseprøve | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| Periodisk kontroll i henhold til forskrifter | | | |
| | | | |

For tekniske data og produktinformasjon, se forside

**Figure 29 - Application certificate for crane 520 Hensen, page 2 (BGR, 2012)**