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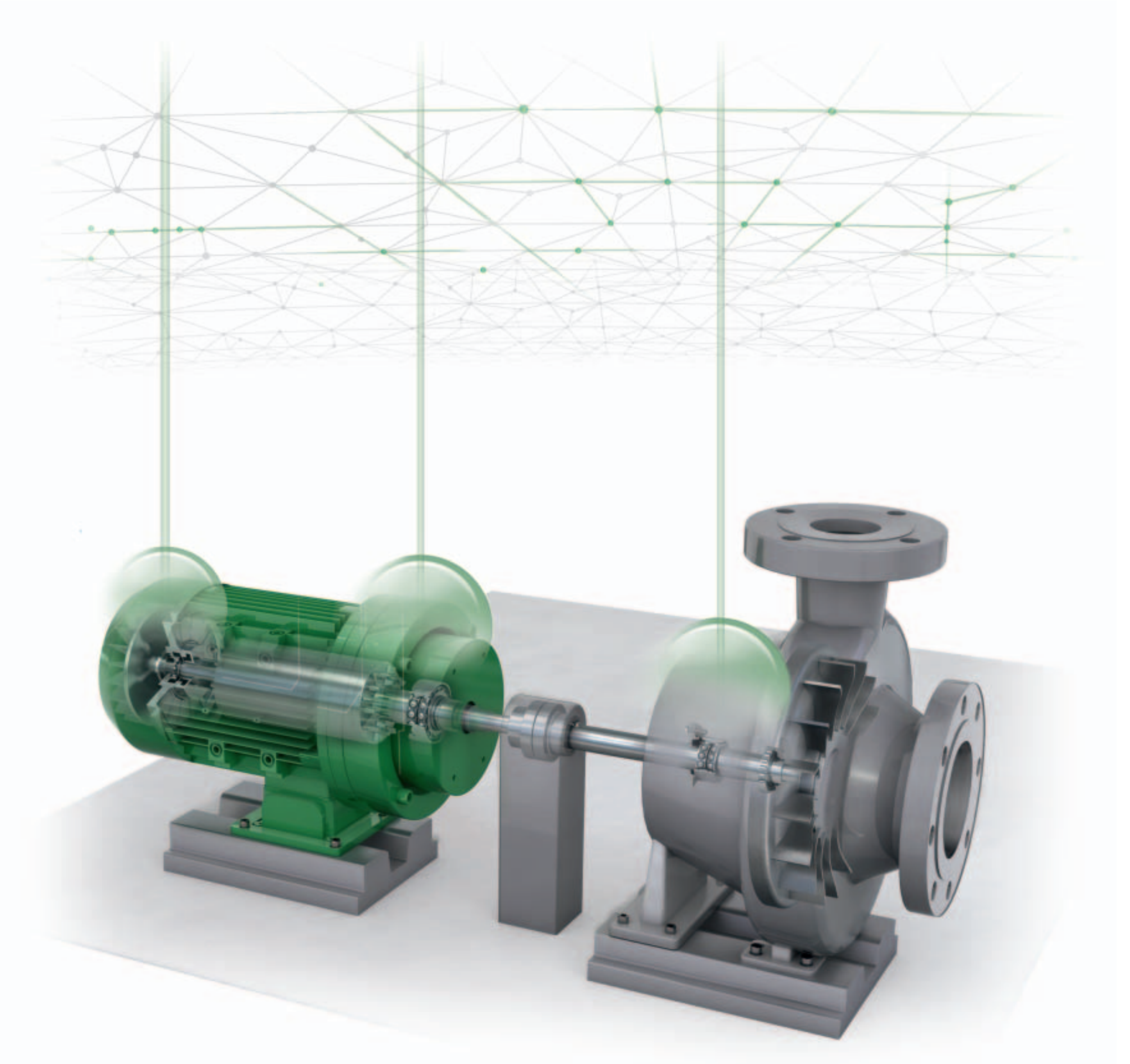

Condition Monitoring

Handbook on the vibration-based condition monitoring of industrial machines and plant

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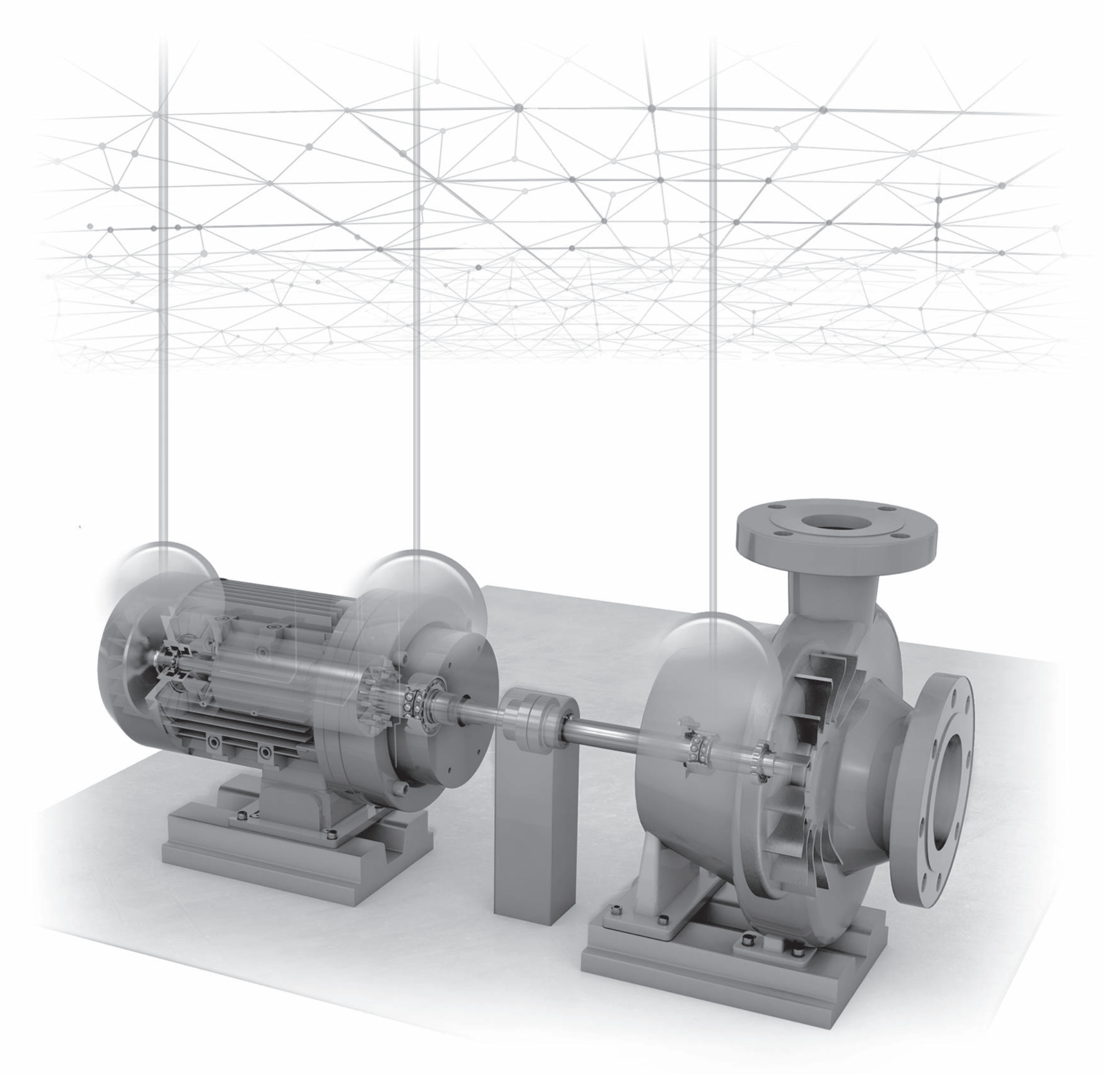


Condition Monitoring

Handbook on the vibration-based condition monitoring of industrial machines and plant

Contents

Foreword

The basis of this extensive work is the long-standing professional experience and specialist knowledge demonstrated by our employees in operations spanning a multitude of industrial sectors.

During the preparation of this book, we made a point of explaining even complex processes in comprehensible language and stayed true to the motto “Derived from practice for use in practice”. A deep and lasting understanding is also promoted through the use of various illustrative graphics and images.

These features render the Condition Monitoring Handbook a useful guide on the vibration condition monitoring of machinery and plant.

With the standard ISO 18436-2, the industry represents its interests in the comparable training and qualification of personnel who work in the vibration condition monitoring and diagnosis of machinery.

The content-related specifications from this standard in Category I and II are reflected comprehensively, in detail and with no relation to specific products, in this handbook. This makes the handbook particularly suitable for use in preparations for certification by an accredited certification institute. It also serves as a reference work and general guide in everyday practical maintenance.

As a result, this book fulfils both the practical requirements of industrial maintenance and the requirements governing theoretical explanations in a textbook, making it suitable for anyone wishing to acquire additional specialist knowledge in the field of vibration monitoring, but who is also required to maintain visibility of daily operations at all times.

Special thanks go to the employees in the project team from the Operational Service and Training departments, who, in addition to their daily work activities, demonstrated a high level of personal commitment and worked with great care on the creation of the text and graphics.

We wish you every success and an inspirational journey – be it in your daily work or exam preparations.

Schaeffler Monitoring Services GmbH

Introduction

Preventing unplanned downtime and thus increasing the availability of machinery represents an increasingly important challenge in the field of maintenance. As a result of detecting machine damage at an early stage, measures can be taken at the right time to reduce downtime periods and minimise repair costs. At the same time, the aim should be to replace components only when a defect occurs, rather than on a preventive basis, in order to make optimum use of their service life and achieve further cost savings. This not only gives the operator a high degree of investment security, but also provides active machinery protection.

Maintenance concepts which rely on monitoring the condition of machinery enable plant operators to plan, prioritise and consequently optimise maintenance in relation to personnel and replacement parts. Changes in machine performance and possible influences on quality and the production process can also be identified in this way.

Effective, condition-based maintenance requires personnel who, as a result of having received the appropriate training and gained the necessary level of experience, are qualified to plan measures, conduct measurements and evaluations and give recommendations for action. The qualification of personnel is defined in DIN ISO 18436 and can be certified in accordance with this standard.

This handbook adheres to the underlying standard DIN ISO 18436-2:2014-11 and can be used as an aid in the qualification of personnel in vibration analysis for monitoring and diagnosing the condition of machinery. In particular, it is aimed at those seeking certification to category I or II. Sections 4.2 to 4.5 of standard DIN ISO 18436-2 give an overview of the typical competencies and skills required in each category.

There are numerous standards that can be used to measure and assess machine vibrations. The best known standard, DIN ISO 10816, is currently being revised. Together with DIN ISO 7919, DIN ISO 10816 will be merged into, and superseded by, DIN ISO 20816. In order to incorporate existing knowledge relating to the standards, reference is made throughout this handbook to the corresponding parts of DIN ISO 10816 or DIN ISO 7919.

Condition monitoring

1

1 Condition monitoring

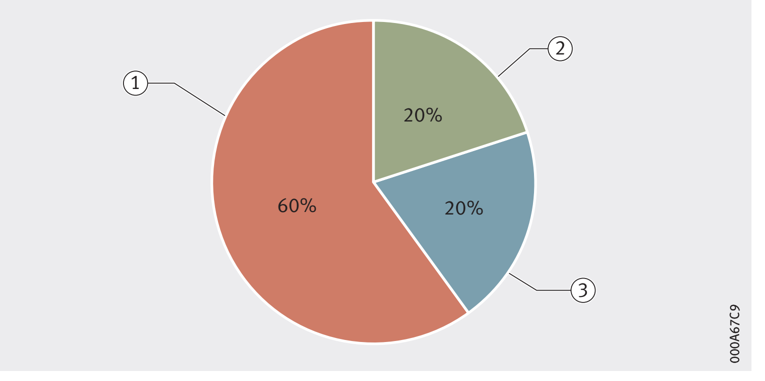
1 Condition monitoring

The field of condition monitoring has undergone significant developments from both a design and technology perspective over the past decades, with a resulting influence on maintenance. The technical development of machinery, plant and communication channels, which is also advancing at a constant rate, calls for ongoing adjustments to measurement technology and maintenance strategies. While maintenance primarily focusses on the operational capability or restoration of a technical system, condition monitoring predominantly pursues two objectives: guaranteeing safety and increasing efficiency. This means, for example, optimising the technical availability of machinery and plant while simultaneously increasing quality and productivity and additionally seeking to avoid consequential damage by detecting changes in condition at an early stage.

The actual service life of machines and machine elements is usually significantly shorter than the basic rating life. Unbalance, misalignment and bearing damage are cited as the three main causes which can lead to unforeseen plant failures and production downtime. Other common causes include structural problems, mounting issues and resonance. ***Figure 1-1*** shows the relative rate of occurrence for the various causes of failure.

Figure 1-1
Rate of occurrence of failure causes

① *Unbalance and misalignments*
② *Rolling bearing damage*
③ *Other*



Lubricant starvation and incorrectly designed or loaded components can also cause damage. For example, a lack of lubricant, unsuitable or aged lubricant, contamination of the lubricant, mounting errors, overloading or fatigue can be proven as causes of failure for rolling bearings.

In the event of a failure, immediate repair costs are initially incurred for the replacement of the defective component. The costs caused by secondary damage can also be considerable, however, and may even exceed the repair costs for the originally defective machine component.

Machine failures can occur at any time, although the likelihood of such failures is particularly great at the start and end of a machine's anticipated operating life. Premature failures are largely caused by material defects as well as by errors in production and assembly. Most failures occurring towards the end of the operating life are attributable to wear and fatigue. Failures occurring between these timeframes tend to be random in nature and are promoted by errors in machine operation or maintenance.
This time profile of the failure rate is illustrated using the so-called bathtub curve, see ***Figure 1-2***, page 15.

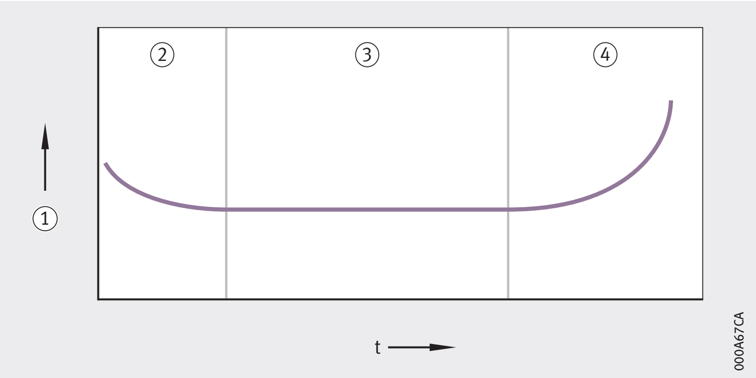


Figure 1-2
Bathtub curve

① *Failure rate*
② *Running-in phase*
③ *Usable operating phase*
④ *End phase of the operating life*

t = *time*

The curve shows how the failure rate is initially relatively high at the start of the life cycle, but then decreases. The failure rate is constant in the middle of the curve, but rises sharply towards the end.

Measures which decisively influence the maintenance procedure can then be derived from the information provided by this bathtub curve and with the aim of minimising the probability of failure.

1.1 Maintenance strategies

The basic measures involved in maintenance are servicing, inspection, repair and improvement (DIN 31051). The priorities associated with the maintenance of technical systems, plant and machinery vary across different industries and companies. For this reason, maintenance strategies must be selected accordingly. This also applies in terms of the various machine and plant types and their respective types of use. For example, process-critical plant usually require different maintenance activities to auxiliary units, which can be dispensed with temporarily in the event of a failure or are quick and relatively inexpensive to replace. Production systems that are in continuous operation and have a highly sophisticated start-up process are a particular area of emphasis. In some volume production processes, it is crucial that plant remain in constant operation. In such cases, any unexpected suspension of operation leads to very high downtime costs and the costly waste of production material.

The necessary technical and administrative measures and activities are derived from the maintenance strategy applied in each case. Four strategies are cited in Sheet 1 of standard DIN ISO 17359:

- breakdown maintenance
- preventive maintenance
- condition-based maintenance
- predictive maintenance

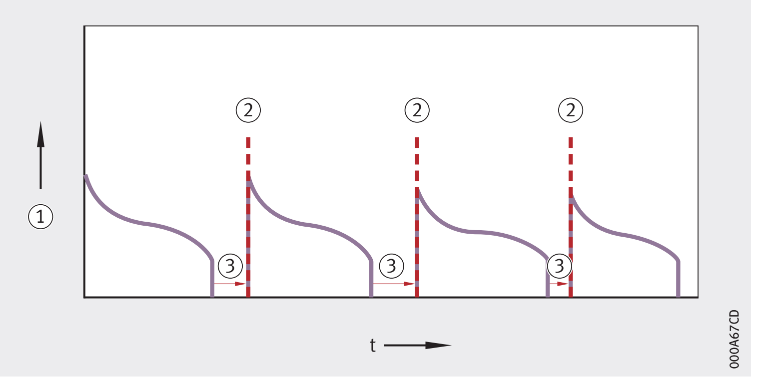
1.1.1 Breakdown maintenance

Breakdown maintenance is also often referred to as failure-based maintenance and is a passive strategy. In this instance, a maintenance measure is only implemented following the failure of a plant or damage to a machine element, see ***Figure 1-3***, page 16. This means that no information on the condition of the plant is obtained or evaluated during plant operation. Components or operating materials are only replaced if the situation requires it, in order to restore operational capability.

Figure 1-3
Breakdown maintenance

① *Wear reserve*
② *Repair measure*
③ *Repair time*

t = *time*



Since it is not possible to predict a point in time when the failure will occur, the extent of the damage and the repair time required are undetermined in advance. This generally means that increased time and work is required for the repair and that consequential damage to adjacent or connected equipment may occur.

The major advantage of this method is the fact, however, that no costs are incurred during problem-free operation and the full wear reserve of the machine is utilised. This is of particular interest in the case of machinery whose operation has no direct influence on processes critical to production or where complete replacement is more economical than one of the active maintenance strategies cited below.

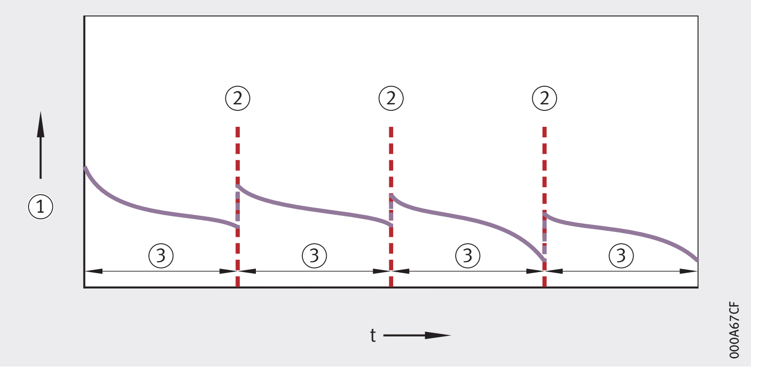
1.1.2 Preventive maintenance

With the aid of active maintenance planning, the operator can acquire a certain degree of control over the condition of his operating facilities. In the case of preventive maintenance, it is assumed that a machine or plant requires particular maintenance expenditure at defined time intervals, see ***Figure 1-4***. The definition of the time intervals is based on the average operating life of the system and on empirical values.

Figure 1-4
Preventive maintenance

① *Wear reserve*
② *Maintenance measure*
③ *Fixed maintenance interval*

t = *time*



Since the time intervals in preventive maintenance are fixed, they can be integrated in a targeted manner into existing production operations or downtime planning. However, they do not necessarily correlate with the actual condition of the system. It is therefore possible that maintenance measures will be carried out prematurely, thus making an unnecessary claim on resources such as material and working time.

The use of preventive maintenance does not provide a means of either identifying or specifically preventing the occurrence of non-plannable random damage that is due, for example, to material defects or incorrect use. It must also be borne in mind that any maintenance intervention in a machine can, in turn, constitute a risk of a mounting error. Indeed, regular maintenance measures can cause premature component wear due to wear of the shaft seat or bearing housing, for example.

1.1.3 Condition-based maintenance

In condition-based maintenance, machinery and plant no longer undergo maintenance work on the basis of failures or times but on the determined component condition. With this strategy, condition monitoring is used to carry out maintenance and repair work which is based on the actual wear status of a plant or machine, see ***Figure 1-5***. Various methods can be used individually or in combination to determine the current condition of a plant, see ***Section 1.2***, page 18.

The outcome of the condition monitoring is incorporated into the planning of targeted maintenance measures, taking account of various parameters. The efficiency of the monitored machine is increased and the overall downtime costs are reduced.

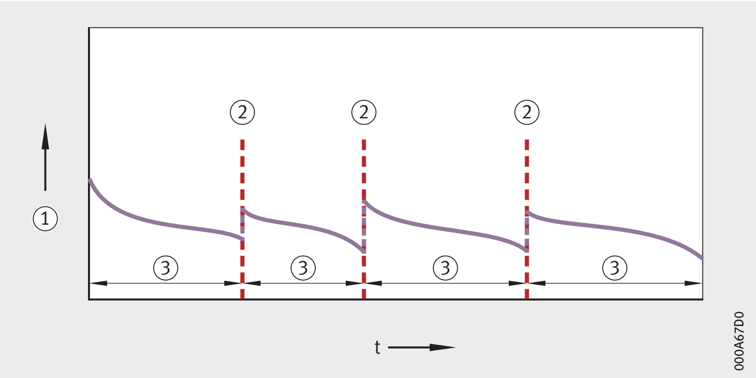


Figure 1-5
Condition-based maintenance

① *Wear reserve*
② *Maintenance measure*
③ *Variable maintenance interval*
t = *time*

Condition-based maintenance offers the following advantages:

- The failure of plant and machinery due to component damage and the resulting consequential damage are avoided.
- As a result of the early detection of fault conditions and damage, the replacement of the affected components, and thus the downtime required for this process, can be planned.
- Downtimes can be minimised due to customised planning of the repair measures and timely procurement of the necessary replacement parts.
- In some cases, the development of detected damage can be retarded by implementing specifically tailored measures such as relubrication, speed or load reduction, and by rotating stationary bearing rings through 180°.
- Components are only replaced if their condition necessitates this, meaning that the availability of plant and machinery is increased through optimal utilisation of the wear reserve.

The following disadvantages show that condition-based maintenance is a costly form of maintenance that is not the most economical solution for every machine:

- Technical equipment in the form of measuring devices, sensors and software is required for condition monitoring.
- The recording and analysis of measurement data is time-consuming and requires appropriate human resources.
- The knowledge required to record and analyse measurement data must be developed among personnel through training and experience.

1.1.4 Predictive maintenance

From the starting point of condition-based maintenance, increasing importance is now being attached to predictive maintenance planning. Here, a fault analysis and causal investigation not only take the current condition of the plant into account but also help to optimise this with the aid of accompanying measures. This is intended to further reduce the probability of a future failure in the long term.

The measures used can include an analysis of the machine history, special measurements to determine natural frequencies or phase relationships as well as improvements to the operating condition in the form of precision balancing and alignment.

1.2 Condition monitoring methods

The malfunction-free and optimised operation of complex plant and machinery can be achieved effectively by means of condition monitoring, which calls for the regular recording of data and evaluation of the particular variables that provide information about the condition of a machine or plant.

The basis of such condition monitoring is knowledge of the plant and the machine parts together with their structure and function, and the resulting defect and failure possibilities. A condition-based monitoring program prioritises objectives and should be tailored to the needs of the specific application, see ***Chapter 5***. Depending on the type of plant or machine and its importance for the production process, continuous (online) monitoring or regular (offline) monitoring can be used.

Various methods are available for recording the condition of a machine during operation, which can essentially be divided into destructive and non-destructive methods. Since the objective in condition monitoring is always to achieve increased availability of the plant, destructive test methods are encountered extremely rarely and are normally only used retrospectively in root cause analysis.

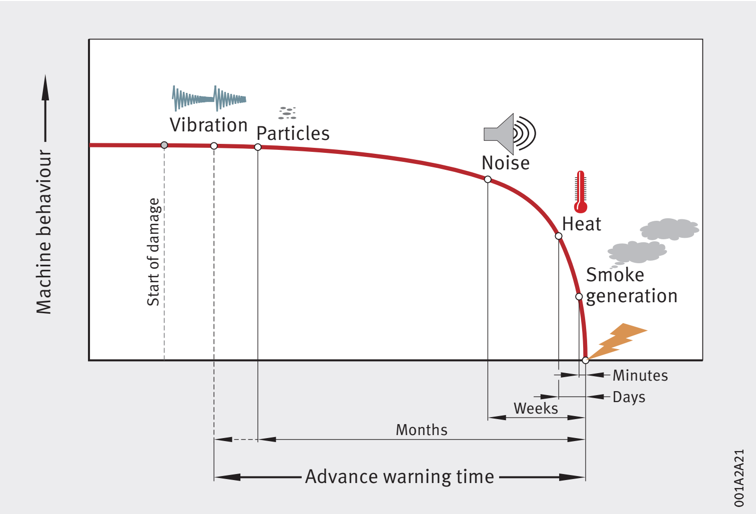
The non-destructive methods and techniques presented in the following sections for the realisation of effective condition monitoring are intended as a guide for achieving an overview of some of the various options and areas of application.

1.2.1 Vibration analysis

Vibration analysis began with the observations of machine operators, who used the “human sensory system”, i.e. hearing, touch and sight, to detect abnormalities and assess these to a certain extent.
With the advancement of measurement technology came the ability to not only identify conspicuous machine vibrations subjectively, but also more comprehensively and objectively, leading in turn to continuous improvements in the quality of the knowledge gained.

Today, vibration-based machine monitoring is an established and reliable tool for detecting and identifying the root causes of machine problems at an early stage, and thus supports the timely planning of necessary maintenance measures. Vibration measurement and vibration analysis can be used to detect fault conditions such as unbalance and misalignment as well as rolling bearing damage and gear tooth defects. Depending on the application, advance warning times of several months can be achieved, see ***Figure 1-6***.

Figure 1-6
Damage curve and detectability as a function of time



Vibrations are induced by occurring forces. Every machine in operation will have a certain basic vibration that reflects its mechanical condition. If the forces acting in the machine change, for example as a result of unbalance, damaged machine components or electrical issues, the vibration behaviour of the machine will also change. If the vibration level increases while the operating parameters remain unchanged, this can indicate a deterioration in the condition of the machine.

With vibration analysis, various machine faults and damage types can be identified on the basis of characteristic vibration patterns in the measurement signals, see ***Chapter 6*** to ***Chapter 8***. Early detection of the changed condition may indeed render further operation of the machine permissible in the first instance. This method of condition monitoring offers considerable cost-saving potential provided that the service life of the plant and machinery can be almost fully utilised and their availability can be increased.

In most cases, attention is focussed on the measurement and analysis of structure-borne sound. This involves recording vibrations at the surface of a solid body, for example a machine housing, which are transmitted within the body from their point of origin to the measurement location. Alternatively, measurement methods which involve observing the vibration motion of an entire body, such as a shaft, can also be used.

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