INTERNATIONAL STANDARD

ISO 17359

First edition
2003-07-01

Condition monitoring and diagnostics of machines — General guidelines

Surveillance et diagnostic d'état des machines — Lignes directrices générales

Reference number
ISO 17359:2003(E)

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Published in Switzerland

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17359 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 5, *Condition monitoring and diagnostics of machines*.

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Introduction

This International Standard provides guidance for condition monitoring and diagnostics of machines. It is the parent document of a group of standards which cover the field of condition monitoring and diagnostics. It sets out general procedures to be considered when setting up a condition monitoring programme for all machines, and includes references to other International Standards and other documents required or useful in this process.

This International Standard presents an overview of a generic procedure recommended to be used when implementing a condition monitoring programme, and provides further detail on the key steps to be followed. It introduces the concept of directing condition monitoring activities towards root cause failure modes, and describes the generic approach to setting alarm criteria, carrying out diagnosis and prognosis and improving the confidence in diagnosis and prognosis, which are developed further in other International Standards.

Particular techniques of condition monitoring are only introduced briefly, and are covered in more detail in other International Standards referenced in the Bibliography.

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Condition monitoring and diagnostics of machines — General guidelines

1 Scope

This International Standard sets out guidelines for the general procedures to be considered when setting up a condition monitoring programme for machines, and includes references to associated standards required in this process. It is applicable to all machines.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1925, *Mechanical vibration — Balancing — Vocabulary*

ISO 2041, *Vibration and shock — Vocabulary*

ISO 13372, *Condition monitoring and diagnostics of machines — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1925, ISO 2041, ISO 13372 and the following apply.

3.1
equipment
machine or group of machines including all machine or process control components

3.2
fault
⟨in a machine⟩ condition occurring when any of the components of a machine or their assembly is degraded or exhibits abnormal behaviour

NOTE This may lead to failure of the machine.

3.3
failure
⟨of a machine⟩ condition occurring when one or more of the principle functions of a machine are no longer available

NOTE This generally happens when one or more of its components is in a fault condition.

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4 Overview of condition monitoring procedure

A generic procedure which may be used when implementing a condition monitoring programme is described, and further details on the key steps to be followed is provided. Condition monitoring activities should be directed towards identifying and avoiding root cause failure modes.

Particular techniques of condition monitoring are only introduced briefly, and are covered in more detail in other International Standards referenced in the Bibliography.

A typical condition monitoring programme flowchart is shown in Figure 1. The sections of the flowchart are detailed in Clauses 5 to 10.

5 Equipment audit

5.1 Identification of equipment

List and clearly identify all equipment and associated power supplies, control and existing surveillance systems.

5.2 Identification of equipment function

Identify the following information.

— What is the equipment required to do?

— What are the operating conditions?

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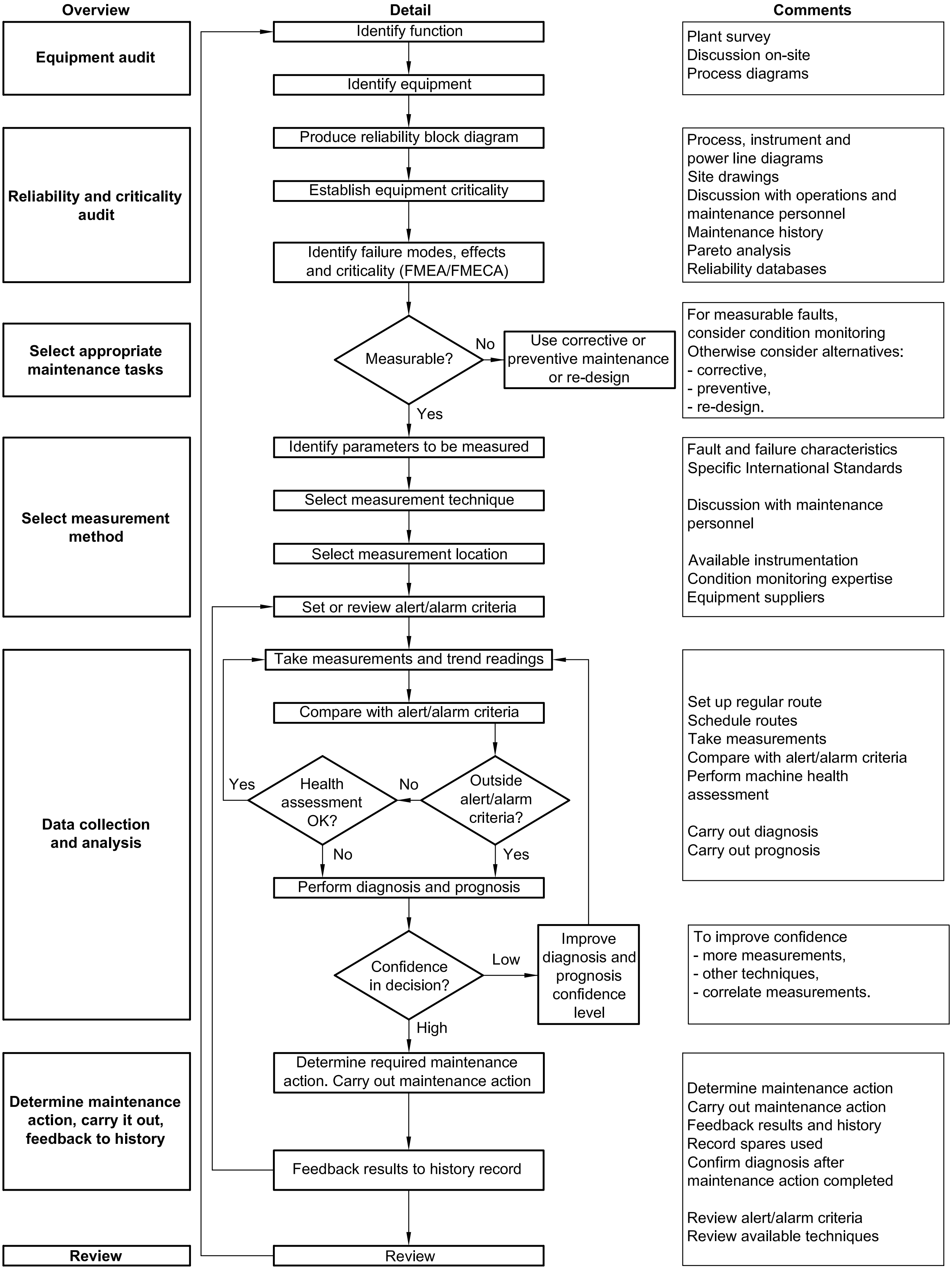

Figure 1 — Condition monitoring procedure flowchart

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6 Reliability and criticality audit

6.1 Reliability block diagram

It can be useful to produce a simple high-level reliability block diagram, including whether the equipment has a series or parallel reliability effect. The use of reliability and availability factors is recommended to improve the targeting of the condition monitoring processes.

Detailed information on producing reliability block diagrams is contained in references in the Bibliography.

6.2 Equipment criticality

A criticality assessment of all machines is recommended in order to create a prioritized list of machines to be included (or not) in the condition monitoring programme. This may be a simple rating system based on factors such as

- cost of machine down-time or lost production costs,
- failure rates and mean time to repair,
- consequential or secondary damage,
- replacement cost of the machine,
- cost of maintenance or spares,
- life-cycle costs,
- cost of the monitoring system, and
- safety and environmental impact.

One or more of the above factors may be weighted and included in a formula to produce the prioritized list.

The results of this process may be used when selecting methods of monitoring (see 8.1).

6.3 Failure modes, effects and criticality analysis

It is recommended to perform a failure modes and effects analysis (FMEA) or failure mode effect and criticality analysis (FMECA) in order to identify expected faults, symptoms and potential parameters to be measured which indicate the presence or occurrence of faults.

The FMEA and FMECA audits will produce information on the range of parameters to be measured for particular failure modes. Parameters to be considered are generally those which will indicate a fault condition either by an increase or decrease in the overall measured value, or by some other change to a characteristic value such as pump or compressor curves, reciprocating internal combustion engine pressure-volume curves and other efficiency curves.

Examples of measured parameters which it may be useful to consider for a range of typical machine types are given in Annex A.

Annex B contains an example of a form (Table B.1) which can be completed for each machine type, linking each fault to one or more symptoms or measured parameters showing the occurrence of the fault. A completed example is also included in Table B.2.

References to more detailed methods of carrying out FMEA and FMECA are given in the Bibliography.

Guidance on the selection of performance parameters which may be useful to indicate faults for a range of machine types is contained in ISO 13380.

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6.4 Alternative maintenance tasks

If the failure mode does not have a measurable symptom, alternative maintenance strategies may have to be applied. These include corrective maintenance, preventive maintenance or modification (design out).

7 Measurement method

7.1 Measurement technique

For the particular measurable parameter considered to be applicable following the previous selection process, one or more measurement techniques may be appropriate. Annex A shows a range of parameters measurable using appropriate measurement techniques.

Condition monitoring systems can take many forms. They may utilize permanently installed, semi-permanent, or portable measuring instrumentation, or may involve methods such as sampling fluids or other materials for local or remote analysis.

7.2 Accuracy of monitored parameters

In most cases, the accuracy required of the measured parameters to be used for machine condition monitoring and diagnosis is not necessarily as absolute as the accuracy which may be required for other measurements such as performance testing. Methods using trending of values can be effective where repeatability of measurement is more important than absolute accuracy of measurement. Correction of measured parameters, for example to standard conditions of pressure and temperature, is not necessarily required for routine condition monitoring.

7.3 Feasibility of measurement

Consideration should be given to the feasibility of acquiring the measurement, including ease of access, complexity of required data acquisition system, level of required data processing, safety requirements, cost, and whether surveillance or control systems exist which are already measuring parameters of interest. It is recommended that the complete machine system be included in the decision and monitoring process.

7.4 Operating conditions during measurements

If possible, monitoring should be carried out when the machine has reached a predetermined set of operating conditions (e.g. normal operating temperature) or, for transients, a predetermined start and finish condition and operating profile (e.g. coast down). These are also conditions which may be used for a specific machine configuration to establish baselines. Subsequent measurements are compared to the baseline values to detect changes. The trending of measurements is useful in highlighting the development of faults.

7.5 Measurement interval

Consideration should be given to the interval between measurements, and whether continuous or periodic sampling is required. The measurement interval primarily depends on the type of fault, its rate of progression (and thus the rate of change of the relevant parameters). However, the measurement interval is also influenced by factors such as duty cycles, cost and criticality.

7.6 Data acquisition rate

For steady-state conditions, the data acquisition rate should be fast enough to capture a complete set of data before conditions change. During transients, high-speed data acquisition may be necessary.

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7.7 Record of monitored parameters

Records of monitored parameters should include, as a minimum, the following information:

a) essential data describing the machine;

b) the measurement position;

c) the measured quantity units and processing;

d) date and time information.

Other information useful for comparison includes details of the measuring systems used, and the accuracy of each measuring system. It is recommended that details of machine configuration and any component changes are also included. Annex C gives typical information which should be recorded when monitoring.

7.8 Measurement locations

Measurement locations should be chosen to give the best possibility of fault detection. Measurement points should be identified uniquely. The use of a permanent label or identification mark is recommended.

Factors to take into consideration are

— safety,

— high sensitivity to change in fault condition,

— reduced sensitivity to other influences,

— repeatability of measurements,

— attenuation or loss of signal,

— accessibility,

— environment, and

— costs.

For vibration condition monitoring, information on measurement locations is contained in ISO 13373-1.

For tribology-based condition monitoring, information on measurement locations is contained in ISO 14830-1.

7.9 Initial alert/alarm criteria

The initial alert/alarm criteria should be set to give the earliest possible indication of the occurrence of a fault. The alarms may be single values or multiple levels, both increasing and decreasing. Step changes which occur within previously set alert boundaries, whilst not exceeding the alert boundaries, may still require investigation. Alert/alarm criteria may also result from the processing of several measurements, or be set as envelopes on dynamic signals.

Alert/alarm criteria should be optimized over time as an iterative process.

For vibration condition monitoring, information on alert/alarm criteria is contained in ISO 13373-1, ISO 10816 (all parts) and ISO 7919 (all parts).

For tribology-based condition monitoring, information on alert/alarm criteria is contained in ISO 14830-1.

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7.10 Baseline data

Baseline data are data or sets of data as measured or observed when the equipment operation is known to be acceptable and stable. Subsequent measurements can be compared to these baseline values to detect changes. Baseline data should accurately define the initial stable condition of the machine, preferably operating in its normal operating state. For machines with several operational states, it may be necessary to establish baselines for each of these states.

For new and overhauled equipment, there may be a wear-in period. As a result, it is common to see a change in measured values during the first few days or weeks of operation. Therefore, time should be allotted for wear-in before acquiring baseline data.

For equipment which has been operating for a significant period, and monitored for the first time, a baseline can still be established as a trending reference point.

8 Data collection and analysis

8.1 Measurement and trending

The general procedure for data collection is to take measurements and compare them to historical trends, baseline or representative data for the same or similar machines. Management of the condition monitoring data collection procedure is often done by arranging the measurements to be taken into a route or tour of a plant. The routes are then scheduled to be carried out at an initial regular periodicity which is more frequent than the expected failure mode. For many condition monitoring techniques, computer-based systems are available which assist in the management of data-collection routes, recording and trending of measurements.

8.2 Measurement comparison to alert/alarm criteria

If the measured values are acceptable compared to the alert/alarm criteria, no action may be required, other than to record the values and to continue to monitor them. If the measured values are not acceptable compared to the alert/alarm criteria, then the diagnosis process should be initiated. There can be occasions when no anomalies are suspected or detected, but diagnosis and prognosis is still carried out because of a requirement for a machine health assessment decision, for example when carrying out a condition survey of equipment before a major shut down.

8.3 Diagnosis and prognosis

The diagnosis process is generally triggered by anomaly detection. This detection is carried out by making a comparison between the present descriptors of a machine and reference values (generally called baseline values or data) chosen from experience, from the specifications of the manufacturer, from commissioning tests, or computed from statistical data (e.g. long-term average).

Different approaches may be used for diagnosing a machine. Two such approaches are

— the faults/symptoms approach, and

— the causal approach.

These are described in ISO 13379.

The condition monitoring process may show the expected progression of existing and future faults. This is known as prognosis. Fault prognosis procedures should be in accordance with ISO 13381.

If confidence in the diagnosis and/or prognosis is low, then further verification may be required. If the confidence is high, it may be possible to initiate maintenance or corrective action immediately.

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8.4 Improving diagnosis and/or prognosis confidence

In order to increase the confidence in the diagnosis/prognosis, it may be necessary to carry out one or more of the following actions:

a) retake the measurement(s) to confirm the measurement(s) and alarm conditions;

b) compare the measurement(s) to past historical trends;

c) reduce the interval between the successive intended measurements;

d) take additional measurements at the same and/or at extra locations;

e) use a more sophisticated process or technique;

f) use alternative techniques for correlation;

g) modify operating conditions or machine configuration to assist in diagnosis;

h) call in other expertise in the particular machine/mode of failure.

9 Determine maintenance action

The simplest action, which may be taken in certain circumstances such as machines with low criticality, is to carry out no immediate action and to continue to monitor at normal intervals.

Generally, depending on the level of confidence in the diagnosis/prognosis of fault occurrence, a maintenance decision and action should be carried out, such as to initiate inspection or corrective work. If the alert/alarm criteria indicate a severe fault condition, it may be necessary to initiate an immediate shutdown. Other options may include reducing the machine load, speed or throughput.

When maintenance actions have been completed, it is recommended to record any maintenance activities and changes to the machine, including details of spares used, skills used and other faults discovered during the repair/restoration. These should be fed back to form a historical record, which can assist in future diagnosis and prognosis, and will also be useful when the condition monitoring process is reviewed.

When maintenance actions have been carried out, it is useful to inspect components to confirm that the initial diagnosis or prognosis was correct.

Repetitive failures can reduce system reliability and increase operating cost. If the root cause of failures can be identified, the maintenance action can be reviewed and optimized in order to avoid or reduce the impact of the failures. The appropriate maintenance action may include more sophisticated condition monitoring techniques, additional maintenance tasks, discussion with the manufacturer and modification (design out).

10 Review

The condition monitoring process is an on-going process, and techniques that may not have been available, or considered to be too costly at the time, or too complicated, or unfeasible in some other way (lack of access, safety problems, etc.), may on review become feasible. It is recommended that the condition monitoring procedure include a review process to allow such re-evaluations to be made. Similarly, the effectiveness of techniques currently being undertaken in the programme should be assessed, and any techniques considered no longer necessary removed.

Alert/alarm criteria may also need revision due to changes in the machine, such as progressive wear, ageing, modification, operation or duty-cycle changes. Measured values and baselines may also change because of maintenance work, including component change, adjustment or duty change. In certain cases, the baseline

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may need to be re-established following such changes. It should be noted that changes in measured values may also be due to normal or controlled changes in the operating conditions, and not necessarily indicate a fault condition.

11 Training

Information on the training and certification requirements for personnel to carry out condition monitoring and diagnostics of machines are given in ISO 18436-1 and ISO 18436-2.

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Annex A
(informative)

Examples of condition monitoring parameters

Table A.1 — Examples of condition monitoring parameters by machine type

Parameter	Machine type								
	Electric motor	**Steam turbine**	**Aero gas turbine**	**Industrial gas turbine**	**Pump**	**Com-pressor**	**Electric generator**	**RIC engine**	**Fan**
Temperature	•	•	•	•	•	•	•	•	•
Pressure		•	•	•	•	•		•	•
Pressure (head)					•				
Pressure ratio			•	•		•			
Air flow			•	•		•		•	•
Fuel flow			•	•				•	
Fluid flow		•			•	•			
Current	•						•		
Voltage	•						•		
Resistance	•						•		
Input power	•				•	•	•		•
Output power	•	•	•	•			•	•	
Noise	•	•	•	•	•	•	•	•	•
Vibration	•	•	•	•	•	•	•	•	•
Acoustic techniques	•	•	•	•	•	•	•	•	•
Oil pressure	•	•	•	•	•	•	•	•	•
Oil consumption	•	•	•	•	•	•	•	•	•
Oil (tribology)	•	•	•	•	•	•	•	•	•
Torque	•	•		•		•	•	•	
Speed	•	•	•	•	•	•	•	•	•
Length		•							
Efficiency (derived)		•	•	•	•	•		•	

• Indicates condition monitoring measurement parameter is applicable.

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Annex B
(informative)

Matching fault(s) to measured parameter(s) or technique(s)

Table B.1 — Example of form for matching fault(s) to measurement parameter(s) or technique(s)

Machine type:	**Symptom or parameter change**											
Fault												
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
• Indicates symptom may occur or parameter may change if fault occurs.												

Table B.2 shows the form in Table B.1 completed for a typical machine, listing some of the most common faults expected to occur, and matching them to the parameters or techniques possible to measure and monitor in order to show the occurrence of the faults.

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Table B.2 — Fan faults matched to measurement parameters and techniques

Machine type: Fans	Symptom or parameter change									
Fault	Air leakage	Length measure-ment	Power	Pressure or vacuum	Speed	Vibration	Temp.	Coast down time	Oil debris	Oil leakage
Damaged impeller		•	•	•	•	•	•	•	•	
Damaged oil seals		•		•	•				•	•
Damaged bellows	•									
Eccentric impeller			•	•	•	•	•	•		
Bearing damage		•	•		•	•	•	•	•	•
Bearing wear		•				•	•	•	•	
Mounting fault						•				
Rotor fouled						•				
Unbalance						•				
Misalignment		•				•				
• Indicates symptom may occur or parameter may change if fault occurs.										

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Annex C
(informative)

Typical information to be recorded when monitoring

C.1 Machine details

As a minimum for each machine being monitored, the following information should be recorded.

ITEM	EXAMPLE
Unique machine identifier:	equipment code or tag number
Machine type:	motor/gen./turbine/compressor/pump/fan
Rated speed:	r/min or Hz
Rated power:	kW
Configuration:	direct, belt or shaft driven
Machine support:	rigid or resiliently mounted
Shaft coupling:	rigid or flexible

It may also be useful to record the following information.

Powered:	electric/steam/gas/reciprocating/diesel/hydraulic
Function:	driver or driven
Component:	bearing/seal/gearing/impeller
Fluid types:	lubricant/coolant/hydraulic

C.2 Measurements

For each measuring or sampling system, the following information should be recorded.

ITEM	EXAMPLE
Date, time (including time zone) of measurement/sample:	
Instrument type:	
Location, orientation:	description or code
Value:	numerical quantity, or data range
Units:	mm/s, m/s^2, ml
Units qualifier:	peak, peak-peak, r.m.s, parts per million, etc.
Measurement type:	volume/overall/amplitude /spectrum/sample/etc.

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The following additional information may also be recorded.

ITEM	EXAMPLE
Transducer type:	eddy current/velocity/accelerometer/particle counter, etc.
Transducer method of attachment:	probe/magnet/stud/adhesive, etc.
FFT or other processing:	filter/number of lines/number of averages/number of samples/windowing
Speed during measurement:	r/min or Hz
Power during measurement:	kW
Sampling method:	on-line/off-line
Other significant operating parameters:	temperature, pressure
Calibration requirement, type and date of last or next required calibration:	

C.3 Other information

Extra information on the machine and the measurements may be recorded in addition to the above, for example historical maintenance data.

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