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Condition monitoring and diagnostics of machines — General guidelines

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

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machine systems*.

This third edition cancels and replaces the second edition (ISO 17359:2011), which has been technically revised.

The following changes have been made:

— reference to the ISO 55000 family of asset management standards has been included;

— power transformers have been added to Annex A and Annex B;

— Annex D has been updated;

— the Bibliography has been revised.

Introduction

This document provides guidelines for condition monitoring and diagnostics of machines using parameters such as vibration, temperature, tribology, flow rates, contamination, power, and speed typically associated with performance, condition, and quality criteria. The evaluation of machine function and condition may be based on performance, condition or product quality.

Condition monitoring forms a vital component of asset management and this document is the parent document of a group of standards which cover the field of condition monitoring and diagnostics. The range of condition monitoring standards are indispensable for the use and implementation of the ISO 55000 family of asset management standards. This document provides general procedures to be considered when setting up a condition monitoring programme for all types of machine, and includes references to other International Standards and other documents required or useful in this process.

An overview of the current status of condition monitoring International Standards is shown in Annex D.

This document 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 identifying and detecting symptoms of 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.

Condition monitoring and diagnostics of machines — General guidelines

1 Scope

This document gives 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. This document is applicable to all machines.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

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

ISO 13379-1, *Condition monitoring and diagnostics of machines — Data interpretation and diagnostics techniques — Part 1: General guidelines*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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

4 Overview of condition monitoring procedure

A generic procedure which may be used when implementing a condition monitoring programme is described in Clauses 5 to 11 and shown in diagrammatic form in Figure 1. Details on the key steps to be followed are provided. Condition monitoring activities should be directed towards identifying and avoiding root cause failure modes.

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

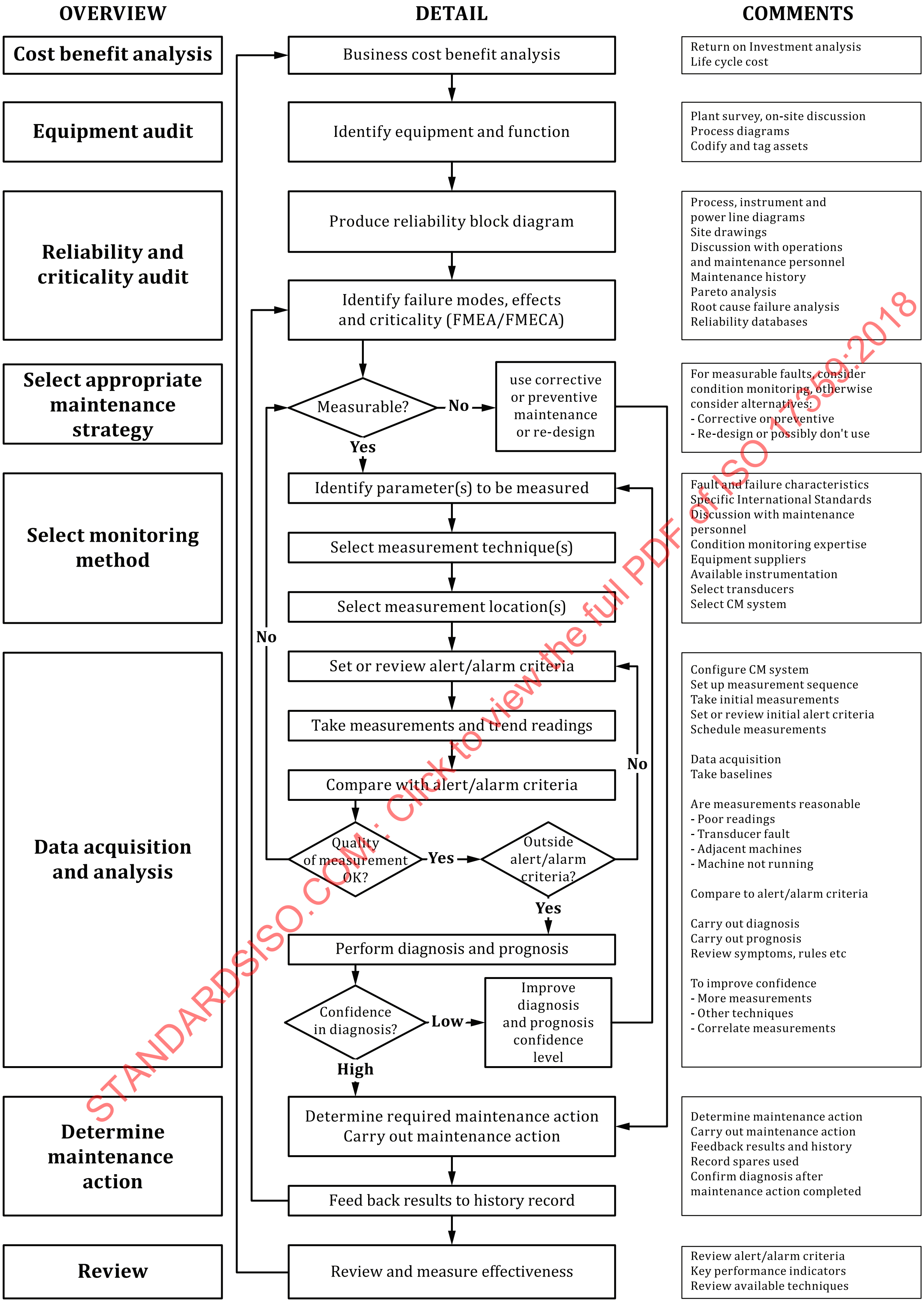

Figure 1 — Condition monitoring procedure flowchart

5 Cost benefit analysis

An initial feasibility and cost benefit analysis helps in establishing accurate key performance indicators and benchmarks to measure the effectiveness of any condition monitoring programme. Items to consider include the following:

a) life cycle cost;

b) cost of lost production;

c) consequential damage;

d) warranty and insurance.

6 Equipment audit

6.1 Identification of equipment

A generic machine schematic of the typical components and processes to be considered in the condition monitoring management process is shown in Figure 2.

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

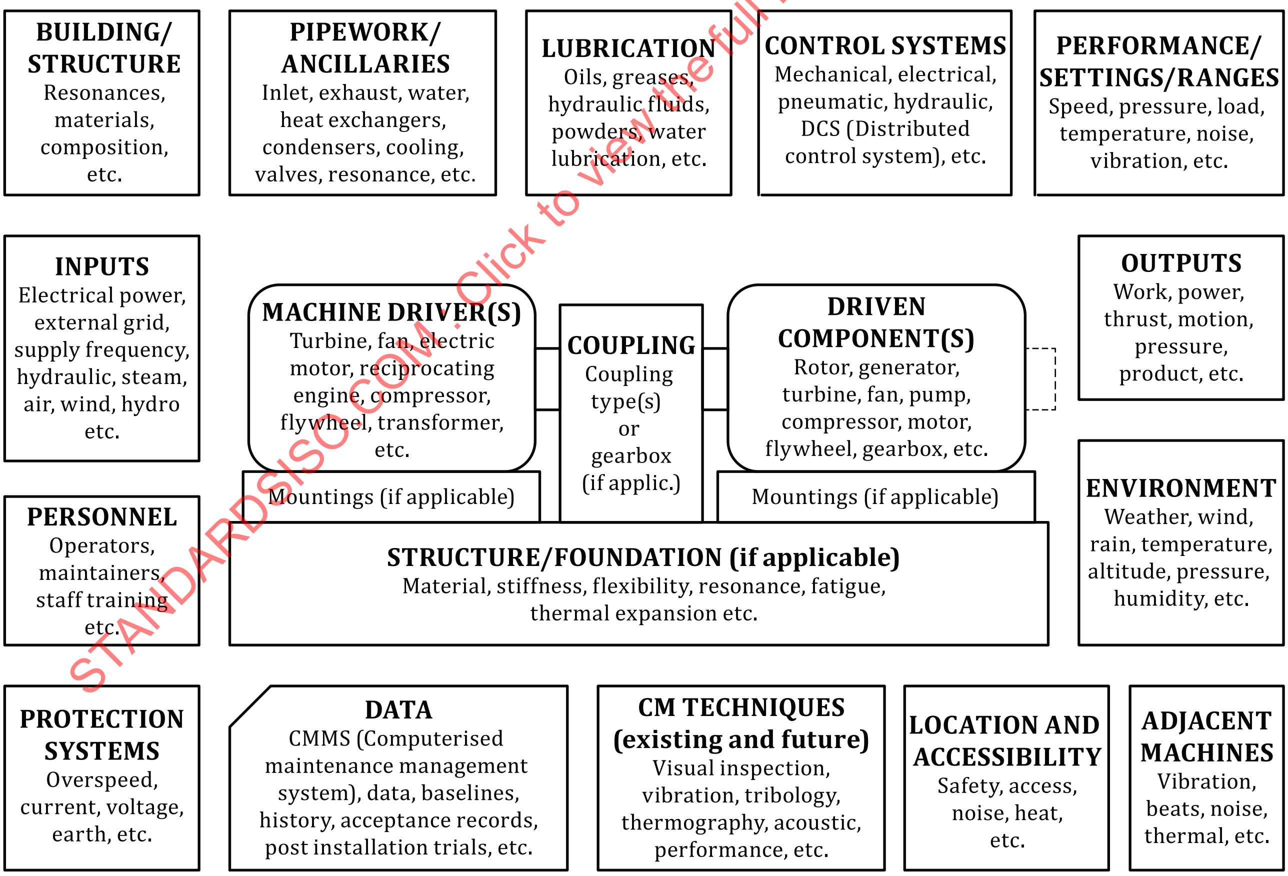

Figure 2 — System factors influencing condition monitoring

6.2 Identification of equipment function

Identify the following information.

a) What is the system, machine or equipment required to do?

b) What are the machine or system operating conditions or range of operating conditions?

7 Reliability and criticality audit

7.1 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.

7.2 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 the following:

a) cost of machine down-time or lost production costs;

b) failure rates and mean time to repair;

c) redundancy;

d) consequential or secondary damage;

e) replacement cost of the machine;

f) cost of maintenance or spares;

g) life cycle costs;

h) cost of the monitoring system;

i) 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 Clause 8).

7.3 Failure modes, effects and criticality analysis

It is recommended that a failure modes and effects analysis (FMEA) or failure mode effect and criticality analysis (FMECA) be performed 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 produce information on the range of parameters to be measured for particular failure modes. Parameters to be considered are generally those which indicate a fault condition, by either an increase or a decrease in the particular or characteristic measured value or by some other change to a characteristic value such as pump or compressor performance curves, reciprocating internal combustion engine pressure-volume performance curves and other efficiency curves.

Examples of measured parameters which can 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. Completed examples for the machine types shown in Annex A are included in Tables B.2 to B.11.

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

7.4 Alternative maintenance tasks

If the failure mode does not have a measurable symptom, it might be necessary to apply alternative maintenance strategies. These include burn-in (initial testing), run to failure, corrective maintenance, preventive maintenance or modification (design out).

8 Monitoring method

8.1 Measurement technique

For the particular measurable parameter considered to be applicable following the previous selection process, one or more measurement techniques can be appropriate. Measured parameters can be simple measurements of overall values or values averaged over time. For certain parameters, such as current, voltage, and vibration, simple measurements of overall values might not be sufficient to show the occurrence of a fault. Techniques such as time, spectral and phase measurement can be required to reveal changes caused by faults.

Examples of monitored parameters useful to consider for a number of machine types are given in Annex A. Examples of standards which can be useful in the identification of particular measurement methods and parameters for different machine types are included in the Bibliography.

The range and application area of International Standards relating to condition monitoring and diagnostics are shown in Annex D.

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

8.2 Accuracy of monitored parameters

In most cases, the accuracy required of the parameters to be used for machine condition monitoring and diagnosis is not necessarily as absolute as the accuracy which might 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, e.g. to standard atmospheric conditions of pressure and temperature, might not necessarily be required for routine condition monitoring. Where this is required, advice is given in the appropriate acceptance testing standard. A selection of International Standards relating to performance and acceptance testing is included in the Bibliography.

8.3 Feasibility of monitoring

Consideration should be given to the feasibility of acquiring the measurement, including ease of access, complexity of the required data acquisition system, level of required data processing, safety requirements, cost, and whether surveillance or control systems exist that are already measuring parameters of interest. Examples of faults and the parameters to be measured to detect them are given by machine type in Annex B. Although presented by machine type, it is recommended that the complete machine system be included in the decision and monitoring process.

8.4 Operating conditions during monitoring

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 can 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.

Measurements of different parameters should be taken wherever possible at the same time or under the same operating conditions. For variable duty or variable speed machines, it might be possible to achieve similar measurement conditions by varying speed, load or some other control parameter.

It is also important to be able to determine if a change in one or more parameters is due to the occurrence of a fault or is due to a change in duty or operating conditions.

8.5 Monitoring interval

Consideration should be given to the interval between measurements and whether continuous or periodic sampling is required. The monitoring interval primarily depends on the type of fault, its rate of progression and, thus, the rate of change of the relevant parameters. The elapsed time between the fault detection and actual failure is known as the lead time to failure (LTTF) and particularly influences the measurement interval (frequency of measurements) and type of monitoring system necessary to detect the particular fault syndrome.

However, the monitoring interval is also influenced by factors such as the operating conditions (e.g. duty cycles), cost, and criticality. It is useful to include these factors in the initial cost benefit analysis or criticality analysis.

8.6 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 might be necessary.

8.7 Record of monitored parameters

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

a) essential data describing the machine;

b) essential data describing operating conditions;

c) the measurement position;

d) the measured quantity units and processing;

e) 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 also be included. Annex C gives typical information which should be recorded when monitoring and Table C.1 shows an example of a typical form for recording asset and measurement data.

8.8 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 as follows:

a) safety;

b) sensor selection;

c) signal conditioning;

d) high sensitivity to change in fault condition;

e) reduced sensitivity to other influences;

f) repeatability of measurements;

g) attenuation or loss of signal;

h) accessibility;

i) environment;

j) costs.

Information on measurement locations is contained in technique and application standards listed in Annex D, and in some of the standards listed in the Bibliography.

1) For vibration condition monitoring, information on measurement locations is contained in ISO 13373-1, ISO 10816 (all parts), ISO 7919 (all parts), ISO 20816 (all parts), ISO 8528-9 and ISO 14694 (see Table D.1 and Bibliography).

2) For tribology-based condition monitoring, information on measurement locations will be contained in ISO 14830-1[1)] (see Table D.1).

8.9 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 can be single values or multiple levels, both increasing and/or decreasing. Step changes which occur within previously set alert boundaries, while not exceeding the alert boundaries, can still require investigation. Alert/alarm criteria can 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. Information on setting alert/alarm criteria is contained in Annex D, and in some of the standards listed in the Bibliography.

a) For vibration condition monitoring, information on alert/alarm criteria is contained in ISO 13373-1, ISO 10816 (all parts), ISO 7919 (all parts), ISO 20816 (all parts), ISO 8528-9 and ISO 14694 (see Table D.1 and Bibliography).

b) For tribology-based condition monitoring, information on alert/alarm criteria will be contained in ISO 14830-1[1)] (see Table D.1).

8.10 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 might be necessary to establish baselines for each of these states.

NOTE It is also possible for baselines to include more parameters and measurement points than those used for routine condition monitoring.

1) Under preparation.

For new and overhauled equipment, there can 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 or, for overhauled equipment, before re-establishing baselines.

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.

9 Data acquisition and analysis

9.1 Measurement and trending

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

9.2 Quality of measurements

The quality of any measurement needs to be established. There are many causes of poor measurements. These can include the following:

a) poor mounting of transducer;

b) transducer fault;

c) cable fault;

d) incorrect measurement range resulting in a saturated signal;

e) sampling rate insufficient to detect the actual rate of change of the measured parameter.

If poor quality measurements are detected or suspected, it might be necessary to repeat the measurements or to rectify the measurement system fault.

9.3 Measurement comparison to alert/alarm criteria

If the measured values are acceptable compared to the alert/alarm criteria, it might not be necessary to take any action 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, e.g. when carrying out a condition survey of equipment before a major shut-down. This could also be the case where other symptoms are noted which might have been outside the monitoring programme, but were detected by an alert operator, for example, noise, smell or visual symptoms.

9.4 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 or by comparison with similar machines or chosen from experience, from the specifications of the manufacturer, from commissioning tests, or computed from statistical data.

The possibility of carrying out diagnosis depends on the machine type, configuration and operating conditions. A fault may have been indicated by a change in one or more of the measured or derived parameters from the baseline values. For the machine types shown in Annex A, examples of faults and their associated symptoms or measured parameters are given for each machine type in Annex B. As and when circumstances permit, further examples of machine type and faults shown by performance parameter monitoring may be included in this document. Until such time, fault parameter identification can be found using experience or results of operation, and the interpretation agreed between manufacturer and customer.

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

a) the faults/symptoms approach, and

b) the causal approach.

Fault diagnosis procedures shall be in accordance with ISO 13379-1.

The condition monitoring process might show the expected progression of existing and future faults and indicate the estimated time to failure (ETTF). This is known as prognosis. Fault prognosis procedures should be in accordance with ISO 13381-1.

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

9.5 Improving diagnosis and/or prognosis confidence

In order to increase confidence in the diagnosis/prognosis, it might 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 diagnostic process or measurement technique;

f) use alternative techniques for correlation;

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

h) review symptoms and rules;

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

10 Determine maintenance action

The simplest action which can be taken in certain circumstances, e.g. for machines with low criticality, is to decide 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, e.g. the initiation of inspection or corrective work. If the alert/alarm criteria indicate a severe fault condition, it might be necessary to initiate an immediate shut-down.

Typical decisions include the following:

a) no action, continue routine monitoring;

b) reduce the interval to the next required measurement;

c) change (reduce or increase) the machine load, speed or throughput;

d) shut down the machine;

e) inspect the machine or bring forward routine planned maintenance;

f) carry out corrective maintenance.

When maintenance actions have been completed, it is recommended that any maintenance activities and changes to the machine be recorded, 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 which is also 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).

11 Review

Condition monitoring is an ongoing 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.) could, 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 could also need revision due to changes in the machine such as progressive wear, ageing, modification, operation or duty-cycle changes. Measured values and baselines could also change because of maintenance work, including component change, adjustment or duty change. In certain cases, the baseline may need to be re-established following such changes. It should be noted that changes in measured values can also be due to normal or controlled changes in the operating conditions, and not necessarily indicate a fault condition. Rule-based diagnostics could have to be modified to take these into account.

To ensure effective and sustainable data management, the following items require particular attention:

a) advisory reports should be issued within an appropriate timescale;

b) all data should be backed up in a secure and regular manner;

c) databases should be reviewed, updated and refined at regular specified intervals;

d) alarm settings should be reviewed and adjusted at regular specified intervals.

12 Training

Information on the requirements for qualification and assessment of personnel to carry out condition monitoring and diagnostics of machines is given in the relevant technique-based part of ISO 18436 (all parts) (see Annex D).

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	Compressor	Electric generator	RIC engine	Fan	Power transformer
Temperature	•	•	•	•	•	•	•	•	•	•
Pressure		•	•	•	•	•		•	•	•
Pressure (head)					•					
Pressure ratio			•	•		•				
Pressure (vacuum)		•			•					
Air flow			•	•		•		•	•	
Fuel flow			•	•				•		
Fluid flow		•			•	•				
Current	•						•			•
Voltage	•						•			•
Resistance	•						•			•
Electrical phase	•						•			
Input power	•				•	•	•		•	•
Output power	•	•	•	•			•	•		•
Noise	•	•	•	•	•	•	•	•	•	•
Vibration	•	•	•	•	•	•	•	•	•	•
Acoustic emission	•	•	•	•	•	•	•	•	•	•
Ultrasonics	•	•	•	•	•	•	•	•	•	•
Oil pressure	•	•	•	•	•	•	•	•	•	
Oil consumption	•	•	•	•	•	•	•	•	•	
Oil (tribology)	•	•	•	•	•	•	•	•	•	•
Thermography	•	•	•	•	•	•	•	•	•	•
Torque	•	•		•		•	•	•		
Speed	•	•	•	•	•	•	•	•	•	
Length		•								
Angular position		•	•	•		•				
Efficiency (derived)		•	•	•	•	•		•		

• Indicates condition monitoring measurement parameter is applicable.

Key

RIC: Reciprocating internal combustion

NOTE This table contains examples and is not an exhaustive list. Other parameters may be appropriate to consider.

Annex B
(informative)

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

An example of a blank form that may be completed for a particular machine type is given in Table B.1.

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

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

Tables B.2 to B.11 show examples of Table B.1 completed for the machine types shown in Annex A, listing some of the most common faults expected to occur, and matching them to the parameters or techniques that can be measured and monitored in order to show the occurrence of the faults.

Table B.2 — Example of electric motor faults matched to measurement parameters and techniques

Machine type: Electric motor	Symptom or parameter change												
Examples of faults	**Current**	**Voltage**	**Resistance**	**Partial discharge**	**Power**	**Torque**	**Speed**	**Vibration**	**Temperature**	**Coast down time**	**Axial flux**	**Oil debris**	**Cooling gas**
Rotor windings	•				•	•	•	•	•		•		•
Stator windings	•							•	•		•		•
Eccentric rotor	•							•			•		
Brush(es) fault	•	•			•	•			•				
Bearing damage	•					•		•	•	•		•	
Insulation deterioration	•	•	•	•									•
Loss of input power phase	•	•						•			•		
Unbalance								•					
Misalignment								•					

• Indicates symptom could occur or parameter could change if fault occurs.

Table B.3 — Example of steam turbine faults matched to measurement parameters and techniques

Machine type: Steam turbines	Symptom or parameter change									
Examples of faults	**Steam leakage**	**Length measurement**	**Power**	**Pressure or vacuum**	**Speed**	**Vibration**	**Temperature**	**Coast down time**	**Oil debris**	**Oil leakage**
Damaged rotor blade	•		•			•	•	•	•	
Damaged labyrinth	•		•	•	•	•	•	•		
Eccentric rotor	•					•		•		
Bearing damage		•	•	•		•	•	•	•	•
Bearing wear	•	•				•	•	•	•	•
Hogging or sagging rotor	•					•		•	•	
Unequal expansion	•	•				•	•			
Unbalance						•				
Misalignment						•				
• Indicates symptom could occur or parameter could change if fault occurs.										

Table B.4 — Example of aero gas turbine faults matched to measurement parameters and techniques

Machine type: Aero gas turbine	Symptom or parameter change											
Examples of faults	Compressor temperature	Compresor pressure/ Pressure ratio	Air flow	Fuel pressure/ Fuel flow	Speed	Gas generator temperature	Pressure/ Pressure ratio	Power turbine temperature	Exhaust temperature	Vibration	Oil debris	Oil leakage/ consumption
Air inlet blockage	•	•	•		•							
Compressor fouled	•	•	•	•	•	•	•	•	•	•	•	
Compressor damaged	•	•		•	•	•	•	•	•	•	•	
Compressor stall					•		•			•		
Fuel filter blockage		•		•	•		•					
Seal leakage						•	•				•	•
Combustion chamber holed				•	•				•			
Burner blocked				•	•		•					
Power turbine dirty	•	•	•		•		•	•		•		
Power turbine damage	•	•	•		•		•			•	•	
Bearing wear/ damage										•	•	•
Gear defects										•	•	
Unbalance										•		
Misalignment										•		

• Indicates symptom could occur or parameter could change if fault occurs.

Table B.5 — Example of industrial gas turbine faults matched to measurement parameters and techniques

Machine type: Industrial gas turbine	Symptom or parameter change											
Examples of faults	**Compressor temperature**	**Compressor pressure**	**Air flow**	**Fuel pressure/ Fuel flow**	**Speed**	**Exhaust temperature**	**Vibration**	**Output power**	**Compressor efficiency**	**Turbine efficiency**	**Oil debris/ contamination**	**Oil consumption**
Air inlet blockage		•	•		•			•				
Compressor fouled	•	•	•	•	•			•	•			
Compressor damaged	•	•	•	•	•		•	•	•		•	
Fuel filter blockage		•		•	•			•				
Combustion chamber holed				•	•			•				
Burner blocked				•	•	•		•				
Power turbine damaged					•	•	•	•		•	•	
Bearing wear							•				•	•
Unbalance							•					
Misalignment							•					

• Indicates symptom could occur or parameter could change if fault occurs.

Table B.6 — Example of pump faults matched to measurement parameters and techniques

Machine type: Pumps	Symptom or parameter change									
Examples of faults	**Fluid leakage**	**Length measurement**	**Power**	**Pressure or vacuum**	**Speed**	**Vibration**	**Temperature**	**Coast down time**	**Oil debris**	**Oil leakage**
Damaged impeller		•	•	•	•	•	•	•	•	
Damaged seals	•	•		•	•	•				
Eccentric impeller			•	•	•	•	•	•		
Bearing damage		•	•		•	•	•	•	•	•
Bearing wear		•				•	•	•	•	
Mounting fault						•				
Unbalance						•				
Misalignment		•				•				

• Indicates symptom could occur or parameter could change if fault occurs.

Table B.7 — Example of compressor faults matched to measurement parameters and techniques

Machine type: Compressors	Symptom or parameter change									
Examples of faults	Fluid leakage	Length measurement	Power	Pressure or vacuum	Speed	Vibration	Temperature	Coast down time	Oil debris	Oil leakage
Damaged impeller		•	•	•	•	•	•	•	•	
Damaged seals	•	•		•	•				•	
Eccentric impeller			•	•	•	•	•	•		
Bearing damage		•	•		•	•	•	•	•	•
Bearing wear		•				•	•	•	•	
Cooling system fault	•			•			•		•	
Valve fault	•			•		•	•			
Mounting fault						•				
Compressor stall		•			•	•				
Unbalance						•				
Misalignment		•				•				
• Indicates symptom could occur or parameter could change if fault occurs.										

Table B.8 — Example of reciprocating internal combustion (RIC) engine faults matched to measurement parameters and techniques

Machine type: RIC engine	Symptom or parameter change											
Examples of faults	Engine temperature	Cylinder pressure	Air flow	Fuel pressure	Fuel flow	Exhaust temperature	Exhaust pressure	Vibration	Output power	Oil consumption	Oil debris	Cooling fluid leak
Air inlet blockage	•	•	•				•					
Fuel injector fault	•	•	•		•	•		•	•	•		
Ignition fault	•	•			•	•		•	•	•		
Bearing wear								•			•	
Fuel filter blockage				•	•		•					
Seal leakage						•	•			•		
Piston ring fault		•							•	•	•	
Cooling system fault					•		•			•	•	•
Secondary balance gear fault								•				
Gear defects								•			•	
Flywheel damage								•			•	
Mounting fault								•				
Unbalance								•				
Misalignment								•				

• Indicates symptom could occur or parameter could change if fault occurs.

Table B.9 — Example of electric generator faults matched to measurement parameters and techniques

Machine type: Electric generator	Symptom or parameter change												
Examples of faults	**Current**	**Voltage**	**Resistance**	**Partial discharge**	**Power**	**Torque**	**Radio frequency emissions**	**Vibration**	**Temperature**	**Coast down**	**Axial flux**	**Oil debris**	**Cooling gas**
Rotor windings	•							•	•		•		•
Stator windings	•							•	•		•		•
Eccentric rotor	•							•			•		
Brush(es) fault	•	•			•	•	•		•				
Bearing damage						•		•	•	•		•	
Insulation deterioration	•	•	•	•									•
Loss of output power phase	•	•						•					
Unbalance								•					
Misalignment								•					

• Indicates symptom could occur or parameter could change if fault occurs.

Table B.10 — Example of fan faults matched to measurement parameters and techniques

Machine type: Fans	Symptom or parameter change									
Examples of faults	**Air leakage**	**Length measurement**	**Power**	**Pressure or vacuum**	**Speed**	**Vibration**	**Temperature**	**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 could occur or parameter could change if fault occurs.										

Table B.11 — Examples of power transformer faults matched to measurement parameters and techniques

Equipment type: Power transformer	Symptom or parameter change or detection technique															
Examples of faults	**Amps/ volts/ load**	**Visual**	**Oil condit ion**	**Temp erature**	**Partial discharge**	**DGA**	**Noise**	**Ultra sound**	**Vibration**	**Power Factor/ Tan δ**	**Resist ance**	**DFR/ PDC/ RVM**	**FRA**	**Excitation current**	**Leak re-actance flux**	**Bushing capacitance**
Insulation dete-rioration	•		•	•	•	•		○		•	•	•	•	•		
Moisture in-gress/ content			•			•				•	•	•				
On-load tap-changer condition/ fault	•		•	•	○	•	○	•	○		•		•	•		
De-energized tap-changer condition/ fault	•		•	•	○	•	○	•	○		•		•	•		
Oil quality dete-rioration			•			•				•		•				
Arcing/ electrical dis-charge		•	•		•	•	•	•		•						
Connection/ bushing faults				•	•	○	○	•		•	•					•
Overheating/ auxiliary cooling system fault		○	•	•		•		○								
Low oil level		•	○	○		○	○	○								

• Indicates symptom could occur or parameter could change if fault occurs. ○ Indicates less common symptom or parameter.

Key

DGA: Dissolved gas analysis

DFR: Dielectric frequency response

FRA: Frequency response analysis

PDC: Polarization and de-polarization current

RVM: Recovery voltage method

Tan δ (tan-delta): Tangent dissipation angle

NOTE For more details see ISO 18095.