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Condition monitoring and diagnostics of machines — Data interpretation and diagnostics techniques —

Part 1: General guidelines

Surveillance et diagnostic d'état des machines — Interprétation des données et techniques de diagnostic —

Partie 1: Lignes directrices générales

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Foreword

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ISO 13379-1 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machines*.

This first edition of ISO 13379-1 cancels and replaces ISO 13379:2003, which has been technically revised.

ISO 13379 consists of the following parts, under the general title *Condition monitoring and diagnostics of machines — Data interpretation and diagnostics techniques*:

— *Part 1: General guidelines*

The following parts are planned:

— *Part 2: Data-driven applications*

— *Part 3: Knowledge-based applications*

Introduction

This part of ISO 13379 contains general procedures that can be used to determine the condition of a machine relative to a set of baseline parameters. Changes from the baseline values and comparison to alarm criteria are used to indicate anomalous behaviour and to generate alarms: this is usually designated as condition monitoring. Additionally, procedures that identify the cause(s) of the anomalous behaviour are given in order to assist in the determination of the proper corrective action: this is usually designated as diagnostics.

Condition monitoring and diagnostics of machines — Data interpretation and diagnostics techniques —

Part 1: General guidelines

1 Scope

This part of ISO 13379 gives guidelines for the data interpretation and diagnostics of machines. It is intended to

— allow the users and manufacturers of condition monitoring and diagnostics systems to share common concepts in the fields of machine diagnostics;

— enable users to prepare the necessary technical characteristics that are used for the further diagnosis of the condition of the machine;

— give an appropriate approach to achieve a diagnosis of machine faults.

Since these are general guidelines, a list of the machine types addressed is not included. However, the machine sets covered by this part of ISO 13379 normally include industrial machines such as turbines, compressors, pumps, generators, electrical motors, blowers, gearboxes, and fans.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For undated references, the latest edition of the referenced document (including any amendments) applies.

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 13372 apply.

4 Condition monitoring set-up and diagnostics requirements

4.1 Role of diagnostics in operation and maintenance

Diagnostics have an essential role in decision making for operation and maintenance tasks. In order to be effective, diagnostics procedures should be set up according to the faults that can occur in the machine. Therefore, it is strongly recommended that a preliminary study be carried out when preparing the requirements for the condition monitoring and diagnostics system of a machine.

4.2 Establishing diagnostics needs

The principle of this study is shown in Figure 1. The V-shape has been intentionally chosen to represent the high-level concerns (maintenance: machine, risk assessment) and the “low level” ones (measurements: monitoring, periodical tests, data processing).

The left branch corresponds to the preliminary study, which prepares, for a particular machine, the necessary data for condition monitoring and diagnostics. The right branch of the sketch corresponds to the condition

monitoring and diagnostic activities that are normally undertaken after the machine has been commissioned. Each layer consists of a preparatory design phase (left) and a usage phase (right).

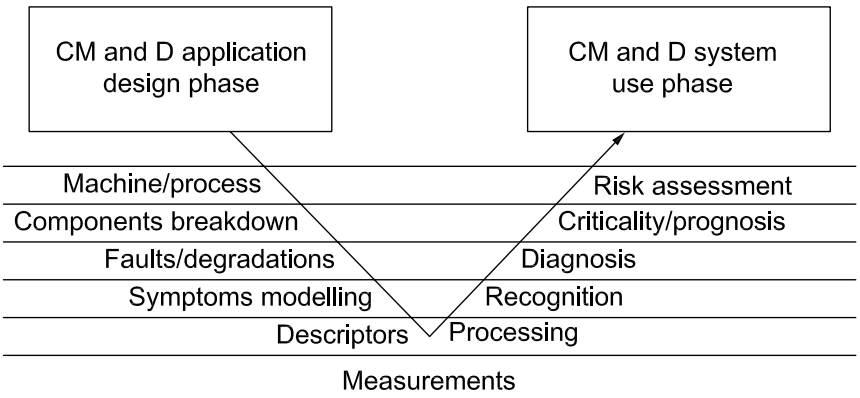

Figure 1 — Condition monitoring and diagnostics (CM and D) cycle: design and use of the application on a machine

The generic steps of the diagnostic study include the following:

a) analyse the machine availability, maintainability, criticality with respect to the whole process;

b) list the major components and their functions;

c) analyse the failure modes and their causes as component faults;

d) express the criticality, taking into account the significance (safety, availability, maintenance costs, production quality) and the occurrence;

e) decide accordingly which faults should be covered by diagnostics ("diagnosable");

f) analyse under which operating conditions the different faults can be best observed and define reference conditions;

g) express the symptoms that can serve in assessing the condition of the machine and that are used for diagnostics;

h) list the descriptors that are used to evaluate (recognize) the different symptoms;

i) identify the necessary measurements and transducers from which the descriptors are derived or computed.

The steps given in a), b), c) and d) may be followed using maintenance optimization such as FMEA (failure modes and effects analysis) or FMECA (failure modes, their effects and criticality analysis). They also may be accomplished within a more general process of maintenance optimization like RCM (reliability-centred maintenance).

NOTE The FMEA and FMECA procedures are outlined in IEC 60812[6].

The steps given in c), d), e), f), g), h) and i) may be followed using the FMSA (failure mode symptoms analysis) methodology explained in 4.3.

4.3 Failure mode symptoms analysis

4.3.1 Process of failure mode symptoms analysis

The aim of this process is to select monitoring technologies and strategies that maximize the confidence level in the diagnosis and prognosis of any given failure mode.

This methodology is designed to assist with the selection of monitoring techniques that provide the greatest sensitivity to detection and rate of change of a given symptom. Where the confidence in a technique's

sensitivity and resulting diagnosis/prognosis accuracy is questionable, the use of additional techniques for further correlation is recommended.

This process is essentially a modification of a FMECA process with a focus on the symptoms produced by each failure mode identified and the subsequent selection of the most appropriate detection and monitoring techniques and strategies.

This tool should be used in conjunction with an existing FMECA analysis that has already identified and ranked possible failure modes.

4.3.2 Guide for usage

This process is best represented by Table A.1. The essential items are as follows:

— listing the components involved;

— listing the possible failure modes for each component;

— listing the effects of each failure mode;

— listing the causes of each failure mode;

— listing the symptoms produced by each failure mode;

— listing the most appropriate monitoring technique;

— listing the estimated frequency of monitoring;

— ranking each failure mode by detection, severity, diagnosis confidence and prognosis confidence resulting in a monitoring priority number (MPN);

— listing the most appropriate correlation techniques;

— listing the frequency of monitoring for the correlation techniques.

The greatest difficulty arises in establishing the correct terms for failure mode, effect, and cause. The failure mode is a definition of how the failure would be observed, i.e. bent, corroded, etc. In the FMECA processes that should have been carried out prior to the FMSA process, there are areas of overlap between the terms used for the failure modes, effects and causes. An item may appear as a *cause of failure* in one line when considering a component and as a *failure mode* in another. A term may also appear as an *effect* in one line when dealing with a component and as a *failure mode* when dealing with an assembly. This also remains true for the FMSA process.

Care shall be taken to avoid duplication of failure mode and cause on the same line. For any one item the failure mode, effect, and cause shall read logically across the page. It can help to use the following form:

— a *failure mode* could result in an *effect* due to a *cause*.

When considering monitoring strategies, the following form can also be used:

— a *failure mode* produces *symptoms*, which are best detectable by a *primary monitoring technique* resulting in a high diagnosis and prognosis confidence when monitored at a given *monitoring frequency*;

— increased diagnosis and prognosis confidence can be gained by using “correlation techniques” when monitored at a given “monitoring frequency”.

4.3.3 Guide for rating

4.3.3.1 General

A rating which estimates the likelihood of detection, prognosis accuracy, and the degree of severity is assigned to each column. Provided that a user applies a consistent rating throughout all analyses, the higher risk categories reflect a higher MPN.

4.3.3.2 Rating detection (DET)

The likelihood of detection is rated from 1 to 5 and is designed to reflect the overall detectability of a failure mode irrespective of the following accuracy of diagnosis or prognosis. This rating is designed to highlight failure modes which:

— produce symptoms that are detectable but unrepeatable;

— produce symptoms that are undetectable;

— produce symptoms that are not measurable in practice; or

— produce symptoms that may be masked by other failure mode symptoms.

This is estimated on a scale of 1 to 5, where:

— 1 means “There is a REMOTE LIKELIHOOD that this failure mode will be detected.”

— 2 means “There is a LOW LIKELIHOOD that this failure mode will be detected.”

— 3 means “There is a MODERATE LIKELIHOOD that this failure mode will be detected.”

— 4 means “There is a HIGH LIKELIHOOD that this failure mode will be detected.”

— 5 means “It is VIRTUALLY CERTAIN that this failure mode will be detected.”

4.3.3.3 Severity of failure (SEV)

This ranking should reflect any previous FMECA analysis and is designed to rank individual failure modes by risk.

This is estimated on a scale of 1 to 4, where

— 1 means “Any event which could cause degradation of system performance function(s) resulting in negligible damage to either system or its environment, and no damage to life or limb.”

— 2 means “Any event which degrades system performance function(s) without appreciable damage to either system or life or limb.”

— 3 means “Any event which could potentially cause the loss of primary system function(s) resulting in significant damage to the said system or its environment and negligible hazard to life or limb.”

— 4 means “Any event which could potentially cause the loss of primary system function(s) resulting in significant damage to the system or its environment, and/or cause the loss of life or limb.”

4.3.3.4 Diagnosis confidence (DGN)

The predicted accuracy of the diagnosis is also rated from 1 to 5. This rating is designed to identify failure modes with:

— detectable, but unrepeatable, symptoms;

— unknown symptoms; or

— symptoms that are not distinguishable from other failure mode symptoms.

This is estimated on a scale of 1 to 5, where:

— 1 means “There is a REMOTE LIKELIHOOD that this failure mode diagnosis will be accurate.”

— 2 means “There is a LOW LIKELIHOOD that this failure mode diagnosis will be accurate.”

— 3 means “There is a MODERATE LIKELIHOOD that this failure mode diagnosis will be accurate.”

— 4 means “There is a HIGH LIKELIHOOD that this failure mode diagnosis will be accurate.”

— 5 means “It is VIRTUALLY CERTAIN that this failure mode diagnosis will be accurate.”

4.3.3.5 Prognosis confidence (PGN)

The predicted accuracy of the prognosis is also rated from 1 to 5. This rating is designed to identify failure modes with:

- detectable, but unrepeatable, symptoms;
- symptoms that are not sensitive to changes in degradation;
- unknown failure rates; or
- symptoms that are not distinguishable from other failure mode symptoms.

This is estimated on a scale of 1 to 5, where:

- 1 means “There is a REMOTE LIKELIHOOD that this failure mode prognosis will be accurate.”
- 2 means “There is a LOW LIKELIHOOD that this failure mode prognosis will be accurate.”
- 3 means “There is a MODERATE LIKELIHOOD that this failure mode prognosis will be accurate.”
- 4 means “There is a HIGH LIKELIHOOD that this failure mode prognosis will be accurate.”
- 5 means “It is VIRTUALLY CERTAIN that this failure mode prognosis will be accurate.”

The frequency of monitoring also contributes to the determination of the accuracy of expected prognosis, i.e. the greater the frequency of monitoring used, the higher the confidence in the expected failure rate and prognosis.

4.3.3.6 Monitoring priority number (MPN)

The ranking is the multiplication of the four preceding rankings and results in an overall rating of each failure mode.

A high MPN value indicates that the nominated technique is the most suitable for the detection, diagnosis, and prognosis of the associated failure mode.

It should be noted that a low MPN value does not imply that monitoring is not necessary but rather that a low confidence level for detection, analysis, and prognosis can be expected with the nominated monitoring technique and frequency.

The least favourable case is a failure mode with high severity, low detectability, low diagnosis confidence and low prognosis confidence.

The most favourable case is a failure mode with low severity, easily detectable, with known failure modes and associated patterns and, therefore, high diagnosis and prognosis confidence levels.

The implementation of a FMSA review and monitoring system design should therefore be carried out taking into consideration:

- safety risk of each failure mode;
- expected rate of deterioration of each failure mode;
- mean time between failures (MTBF) for each failure mode;
- secondary/subsequent failure modes;
- failure mode interrelationships;
- maintenance lead time required;
- availability of spare parts;

— required reliability and availability.

Continuous reassessment should be carried out when experience with a new installation has been gained or when a modification has been carried out.

4.4 Diagnostics requirements report

It is recommended that the synthesis of the preliminary study be stored in a “diagnostics requirements report”. This report should normally:

a) present the adopted breakdown of the machine into components;

b) list the faults associated with these components;

c) give the potentially observable symptoms for each fault;

d) name the condition monitoring descriptors that are to be used; and

e) indicate the method and parameters used for calculation of the descriptors.

It may arise that all the critical faults are not covered by condition monitoring and, as such, are not diagnosable. For this reason, it is strongly recommended that the faults which are addressed and those which are not be emphasized clearly in the report. It may be of use to re-evaluate the value of adding the capability to detect specific faults.

Formally, the diagnostics requirements report can be composed of two parts:

1) a machine description [corresponding to items a) to b) of 4.2]: identification, role in the process, components, criticality analysis;

2) a failure modes/symptoms analysis [corresponding to items c) to i) listed in 4.2]: failure modes, symptoms, descriptors and measurements that are to be used for diagnostics.

Item b) may be realized easily with the FMSA chart given in Annex A.

It is also recommended that the theoretical effectiveness of the diagnostics system be calculated. For this purpose, a proposal for a criterion for the effectiveness of a diagnostics system is given in Annex B.

5 Elements used for diagnostics

5.1 Condition monitoring data

5.1.1 Measurements

All the measurements used for condition monitoring are generally suitable for diagnostics. Descriptors are preferred instead of raw measurements for diagnostics as they offer greater selectivity with respect to faults.

Table 1 gives, as an example, a set of various measurements and parameters used for condition monitoring and diagnostics of a machine.

Table 1 — Example of measurements and parameters used for diagnostics

Performance	Mechanical	Electrical	Oil analysis, product quality and others
Power consumption	Thermal expansion	Current	Oil analysis
Efficiency	Position	Voltage	Ferrography wear debris analysis
Temperature	Fluid level	Resistance	Product dimensions
Pressure	Temperature	Inductance	Product physical properties
IR thermography	Vibration displacement	IR thermography	Product chemical properties
Flow	IR thermography	Capacitance	— colour
	Vibration velocity	Magnetic field	— visual aspect
	Vibration acceleration	Insulation resistance	— smell
	Audible noise	Partial discharge	— other non-destructive testing
	Ultrasonic waves		

5.1.2 Descriptors

Descriptors can be obtained from the condition monitoring system, either directly or after the processing of the measurements. Descriptors are often preferred to measurements for reasons of selectivity. The more selective the descriptors are, the more selective the symptoms and, therefore, the easier the diagnosis. The descriptor selectivity reduces the number of fault hypotheses when inferring from symptoms to fault.

EXAMPLES Amplitude of the first harmonic of the shaft displacement of vibration, crest factor of the acceleration of the vibration, oil total acid number, rotational speed, rolling element bearing damage factor, temperature gradient on an infrared thermography trace.

5.1.3 Symptoms

A symptom can be expressed in the following terms.

a) Time characteristic: the time constant of the evolution of the descriptor.

   EXAMPLES 1 h; 10 days; slow.

b) Type of evolution and magnitude change

   EXAMPLES Presence; absence; regular increase; decrease; stability; >10; <200; 40 µm cyclic evolution.

c) Descriptor: the descriptor used.

   EXAMPLES Temperature; first harmonic of the displacement of the vibration.

d) Location: where the symptom is observable on the machine.

   EXAMPLES Shaftline at bearing No. 3 vertical direction; bearing pedestal No. 4; high-pressure body (front left); bearing No. 2.

e) Circumstance: operating conditions in which the symptom is seen.

   EXAMPLES During run down; within 1 h after cold start-up; at 100 % power; any circumstance.

When preparing the selection of symptoms for a fault, care should be taken to avoid taking two or several symptoms that may be too dependent (highly correlated), as the evaluation of dependent symptoms does not give more information and, thus, does not allow the diagnosis to progress.

EXAMPLES Slow and regular evolution of first harmonic vector of shaft displacement; bearing temperature is 10 °C above usual value in nominal conditions; a 2 mm/s instantaneous change in pedestal vibration velocity; cyclic evolution of the first harmonic of the displacement of the vibration (>10 µm, after a change in power delivered by the machine); unusual noise; dark colour of the lubricant oil.