INTERNATIONAL STANDARD

ISO 13379

First edition
2003-08-15

Condition monitoring and diagnostics of machines — General guidelines on data interpretation and diagnostics techniques

Surveillance et diagnostic d'état des machines — Lignes directrices générales sur l'interprétation des données et les techniques de diagnostic

Reference number
ISO 13379:2003(E)

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Published in Switzerland

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Foreword

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

Introduction

This International Standard 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 — General guidelines on data interpretation and diagnostics techniques

1 Scope

This International Standard gives guidance for 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,

— to enable users to prepare the necessary technical characteristics that will be used for the further diagnosis of the condition of the machine, and

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

Since it gives general guidelines, a list of the machine types addressed is not included. However, the machine sets covered by this International Standard will normally include industrial machines such as turbines, compressors, pumps, generators, electrical motors, blowers and fans.

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 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 2041, ISO 13372 and the following apply.

3.1
alarm
operational signal or message designed to notify personnel when a selected anomaly, or a logical combination of anomalies, requiring corrective actions is encountered

NOTE An alarm is a more severe anomaly zone than an alert and should be identified with a red indicator.

3.2
anomaly
irregularity or abnormality in a system

3.3
descriptor
condition monitoring descriptor
data item derived from raw or processed parameters or an external observation

NOTE Descriptors are used to express symptoms and anomalies. The descriptors used for diagnostics are generally those obtained from the condition monitoring systems. However, operational parameters, like any other measurement, can be considered as descriptors.

3.4
failure
〈of a machine〉 termination of the ability of an item to perform a required function

NOTE Failure is an event as distinguished from fault, which is a state.

3.5
fault
〈of a component of a machine, in a machine〉 condition of a component that occurs when one of its components or assembly degrades or exhibits abnormal behaviour, which may lead to the failure of the machine

NOTE 1 Fault can be the result of a failure, but may exist without a failure.

NOTE 2 An event is not a fault if it is a result of planned actions or lack of external resources.

3.6
root cause
set of conditions and/or actions that occur at the beginning of a sequence of events that result in the initiation of a failure mode

3.7
symptom
〈of a fault〉 perception, made by means of human observations and measurements (descriptors), which may indicate the presence of one or more faults with a certain probability

3.8
syndrome
group of signs or symptoms that collectively indicate or characterize an abnormal condition

3.9
diagnosis confidence level
estimate of the likelihood that a calculated reliability will be achieved or bettered

NOTE 1 Reliability calculations are made on the basis of available evidence. The degree of trust that can be placed on the calculation is a function of the extent of the sample size.

NOTE 2 The diagnostic confidence level is a figure of merit that indicates the degree of certainty that the diagnosis is correct.

NOTE 3 The diagnostic confidence level is determined by the diagnostic confidence factor.

4 Condition monitoring set-up and diagnostics requirements

4.1 Role of diagnostics in operation and maintenance

Diagnostics has an essential role in decision making in operational and maintenance tasks. Hence, in order to be effective, diagnostics procedures should be set up according to the potential faults that may happen 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 right branch of the sketch corresponds to the condition monitoring and diagnostics activities that are normally undertaken after the machine has been commissioned. The left branch corresponds to the preliminary study which prepares, for a particular machine, the necessary data for condition monitoring and diagnostics. Each layer consists of a preparatory design phase (left) and a usage phase (right).

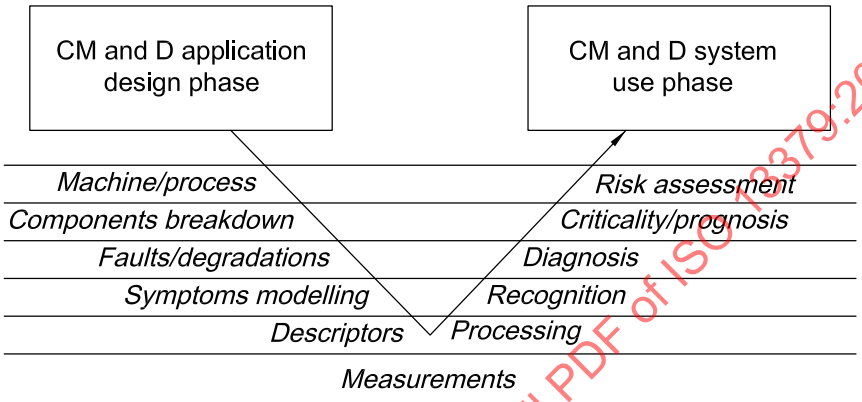


Figure 1 — Condition monitoring and diagnostics (CM and D) cycle: Design and use of the application on a machine

The generic steps of the diagnostics study include the following:

a) analyse the machine availability, maintainability and 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 gravity (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 will be used for diagnostics;

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

i) identify the necessary measurements and transducers from which the descriptors will be 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), FMECA (Failure Modes, their Effects and Criticality Analysis). They may be also accomplished within a more general process of maintenance optimization like RCM (Reliability Centred Maintenance).

NOTE FMEA and FMECA procedures are outlined in BS 5760 and IEC 60812.

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 (FMSA)

4.3.1 FMSA process

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 will 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, then the use of additional techniques for further correlation should be recommended.

This process is essentially a modification of an FMECA process with a focus on the symptoms produced by each identified failure mode 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;

— ranking each failure mode by detection, severity, diagnosis confidence and prognosis confidence resulting in the Monitoring Priority Number;

— listing the most appropriate monitoring technique;

— listing the estimated frequency of monitoring;

— 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 is also true for the FMSA process.

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

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

When considering monitoring strategies, the following format 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 is assigned to each column which estimated the probability of detection and prognosis accuracy, and the degree of severity. Provided that a user applies a consistent rating throughout all analyses, the higher risk categories reflect a higher Monitoring Priority Number.

4.3.3.2 Rating detection (DET)

The probability 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 that

— 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, as follows.

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

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

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

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

5 means “It is 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, as follows.

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, as follows.

1 means “There is a REMOTE PROBABILITY of this failure mode diagnosis being accurate.”

2 means “There is a LOW PROBABILITY of this failure mode diagnosis being accurate.”

3 means “There is a MODERATE PROBABILITY of this failure mode diagnosis being accurate.”

4 means “There is a HIGH PROBABILITY of this failure mode diagnosis being accurate.”

5 means “It is 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, as follows.

1 means “There is a REMOTE PROBABILITY of this failure mode prognosis being accurate.”

2 means “There is a LOW PROBABILITY of this failure mode prognosis being accurate.”

3 means “There is a MODERATE PROBABILITY of this failure mode prognosis being accurate.”

4 means “There is a HIGH PROBABILITY of this failure mode prognosis being accurate.”

5 means “It is 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)

This 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 an FMSA review and monitoring system design should therefore be carried out taking the following into consideration:

— the safety risk of each failure mode;

— the expected rate of deterioration of each failure mode;

— mean time between failure for each failure mode;

— secondary/subsequent failure modes;

— failure mode inter-relationships;

— maintenance lead time required;

— availability of spare parts;

— required reliability and availability.

Continuous re-assessment 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 will 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 to emphasize clearly in the report the faults that are addressed and those that are not.

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

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

b) failure mode/symptom analysis [corresponding to items c) to i) listed in 4.2]: failure modes, symptoms, descriptors and measurements that will be used for diagnostics.

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

It is also recommended to calculate the theoretical effectiveness of the diagnostics system. For this purpose, a proposal for a criterion of 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
IR thermography	Vibration displacement	Inductance	Product physical properties
Pressure	Vibration velocity	Capacitance	Product chemical properties
Flow	Vibration acceleration	Magnetic field	— colour
	Audible noise	Insulation resistance	— visual aspect
	Ultrasonic waves	Partial discharge	— smell
			— other non-destructive testing

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 reason of selectivity. The more selective the descriptors, the more selective the symptoms and, therefore, the easier the diagnosis. The descriptor selectivity reduces the number of fault hypothesis 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.

5.1.3 Symptoms

A symptom can be expressed in the following terms.

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

EXAMPLES 1 h; 10 days; slow.

b) Type of evolution and magnitude change (compulsory)

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

c) Descriptor (compulsory): the descriptor used.

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

d) Location (compulsory): 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 (compulsory): 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 will not give more information and, thus, will not allow the diagnosis to progress.

EXAMPLES OF SYMPTOMS Slow and regular evolution of first harmonic vector of shaft displacement, bearing temperature is 10 °C above usual value under 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.

5.1.4 Fault

A fault can be expressed in the following terms.

a) Machine (compulsory): the name or the identifier of the machine.

EXAMPLES Unit No. 1 turbine; boiler feed water pump No. 2; BFW PU2; circulation pump; coal crusher No. 5.

b) Component (compulsory): name or identifier of the component of the machine on which the fault occurs.

EXAMPLES Bearing No. 3; shaft; piston; low-pressure body; seal No. 2.

c) Failure mode (compulsory): type of degradation of the component of the machine.

EXAMPLES Wear; transverse crack; rubbing; spalling; unbalance; misalignment.

d) Severity (optional): integer number, for example defined in 4.3.3.3, representative of the magnitude of the degradation or failure mode.

5.1.5 Operational parameters

Operational parameters are often used for diagnostics. They are used both for

— establishing some descriptors, and

— establishing the operating conditions in which the symptoms appears (circumstance).

Care should be taken when considering operational parameters. When it is a descriptor, or enters the computation of a descriptor, the parameter is an output. It is an input when it characterizes an operating condition. This should be considered in order to avoid using an operating condition as a descriptor. For example, the turbine body temperature is a descriptor when monitoring and diagnosing the body. It becomes an operating condition when monitoring the bearing as it has an influence on the work of the bearing, but is no longer descriptive of bearing faults.

5.2 Machine data

Knowledge of specific data of the machine is often necessary for diagnostics. This is the case, for example:

— for vibrations: data regarding the kinematics of the components of the machine such as rotational speeds, number of teeth on gears, ball bearings characteristic frequencies;

— for oil analysis: data regarding the oil path of the machine, flows, metal composition, filters disposition and fineness, etc.;

— for thermography: IR emissivity of a surface.

A distinction should be made between data related to the techniques used for processing descriptors and data related to the configuration of the machine. It is important to record both for the purpose of diagnostics. Data related to the configuration of the machine will normally be recorded in the machine file, as it is preferable to record machine data related to condition monitoring techniques within diagnostics requirements, when specifying the descriptors.

5.3 Machine history

Fault occurrence can be linked to operation but also to maintenance of the machine. It may arise that a fault has been introduced during an overhaul or a particular situation. Therefore, it is important to keep a record of the fault history, operational history and maintenance history of the machine in order to take into account these facts for diagnostics.

6 Diagnostic approaches

6.1 Selection of diagnostic approach

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

Two main approaches can be used for diagnosing a machine.

a) **Numerical methods** (neural network, pattern recognition, statistical, histographic Pareto approach, or other numerical approaches). These methods are generally automatic, do not need deep knowledge of the mechanism of initiation and fault propagation, but require a learning period with a large set of observed fault data.

b) **Knowledge-based methods** which rely on the use of fault models, correct behaviour models or case description.

This Clause presents two possible approaches to fault models.

a) **Faults/symptoms approach** is generally used when the objective is only to diagnose the current fault(s). For this purpose, an in-depth knowledge of the mechanism of initiation and fault propagation is not necessarily required. However, a basic knowledge of the machine's mechanical mechanisms and processes is required.

b) **Causal tree approach** is generally used when the objective is the identification of a root cause or the development of a prognosis. For this purpose, an in-depth knowledge of the mechanism of initiation and fault propagation is required.

6.2 Fault/symptom approach

6.2.1 General description

This approach is based on the exploitation of fault/symptom relationships. This is known as an associative knowledge model since the relationships between faults and symptoms are associations. The diagnostic activity results from different tasks, each of which being devoted to a particular aspect. The main tasks are listed and explained below. Figure 2 gives an illustration of the phases of the faults/symptoms association approach.

The starting point for the diagnosis is taken to be either

— the presence of a real anomaly, alarm or abnormal behaviour, or

— a suspicion expressed as an anomaly in order to assess the condition of the machine.

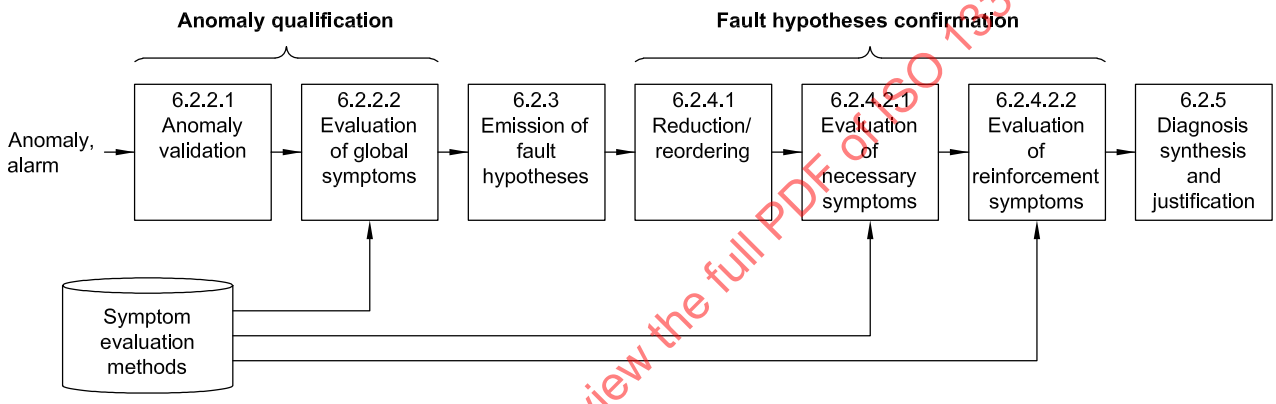


Figure 2 — Fault/symptom approach

6.2.2 Qualification of the detected anomaly

6.2.2.1 Anomaly validation

The anomaly can be

— derived from descriptors,

— an abnormal change in the data without reaching alarm levels, or

— a human perception of a change on the machine (noise, smell, temperature, moisture, leaking, etc.).

The process generally consists of validating the data from which the anomaly is derived (plausibility of the measurement, correlation with other measurements, alarm criterion check, transducer verification, etc.).

6.2.2.2 Evaluation of global symptoms

This step is intended to enable the production of fault hypotheses. A small set of global symptoms is evaluated. These symptoms, called macrosymptoms (grouping of symptoms), are evaluated using specified methods as for symptoms.

6.2.3 Emission of fault hypotheses

Once macrosymptoms have been evaluated, the macrosymptoms/faults association is used to produce a list of fault hypotheses.

6.2.4 Confirmation of fault hypotheses

6.2.4.1 Reduction/reordering of the fault hypothesis list

This step is optional. It consists of reducing the diagnostic time. From the exhaustive list of fault hypotheses that has been found, a reduction or reordering can be made regarding the following:

— the probability of occurrence of the fault, from the feedback data, on the same type of machine, under the same service and operating conditions;

— the severity of the fault, from the criticality analysis.

When reducing the number of fault hypotheses, great expertise is needed as the result can be an initial rejection of a fault hypothesis (this is particularly the case for rare faults, which may be critical, nevertheless).

6.2.4.2 Evaluation of the fault hypotheses

6.2.4.2.1 Evaluation of necessary symptoms

All the necessary (i.e. required or must be present) symptoms are examined first. If all the necessary symptoms have been validated, then the fault hypothesis is validated. If one (or more) of the necessary symptoms has been invalidated, then the fault hypothesis is rejected.

When several methods exist to evaluate a symptom, the best performance method will be preferred.

6.2.4.2.2 Evaluation of reinforcement symptoms

Once all the necessary symptoms have been validated, the reinforcement symptoms should be evaluated. These may reinforce the presumption of a particular fault at the final diagnostic step. Unlike the necessary symptoms, if one or more of the reinforcement symptoms has not been validated, the fault is not rejected.

6.2.5 Diagnosis synthesis and justification

This is the last step in the diagnostics process. The objective is to summarize the realized diagnosis.

The elements that have been evaluated and validated should be included in a formal diagnosis report. These elements include

a) the anomaly that triggered the diagnostic,

b) the global symptoms that has been validated,

c) the rejected faults with the invalidated symptoms, and

d) the validated faults with their respective probabilities.

The report should also state other elements considered during the final stage of the synthesis phase. These elements are used to weight the validated hypotheses according to

a) the machine history,

b) similar cases encountered, and

c) the probability and criticality of faults.

A conclusion should be reached. In this, the faults should be given in the reverse order of plausibility. A confidence factor (subjective but based on all the objective previous elements) may be given for each one.

Corrective operation or maintenance actions should be proposed or, if a maintenance work is needed but can be delayed, the delay should be given and recommendations regarding operation should be formulated, if required.

An example of diagnosis report is given in Annex C.

6.2.6 Determination of confidence factor

This figure of merit essentially represents the cumulative effect of error sources on the final certainty of confidence in the accuracy of the diagnosis. It can be determined algorithmically or via a weighted assessment system. An example of a weighted assessment is given in Annex D.

The confidence factor should be determined from the following elements:

— maintenance history, including experience of same faults on similar machines;

— design and failure modes assessment;

— analysis technique or descriptor used;

— severity limits used;

— measurement interval;

— database set-up;

— data acquisition;

— severity assessment process;

— trend assessment;

— diagnosis process.

6.3 Causal tree approach

6.3.1 Limit of fault/symptom approach

When an in-depth knowledge of the mechanism of initiation and fault propagation is required, the simple fault/symptom approach is no longer satisfactory.

A causal tree diagnostic approach should then be used.

6.3.2 Causal tree modelling

The fault tree analysis method, when used in diagnostics, is a process of determining the root cause based on an existing set of failure modes. Causal tree analysis flowcharting is normally used in the retrospective (diagnostic) sense in that the method is used to look at the “caused by” or “influenced by” relationship between failure modes. The data for this process already exist and therefore are not estimated. In the prognosis process, the method differs as the data have to be forecast.

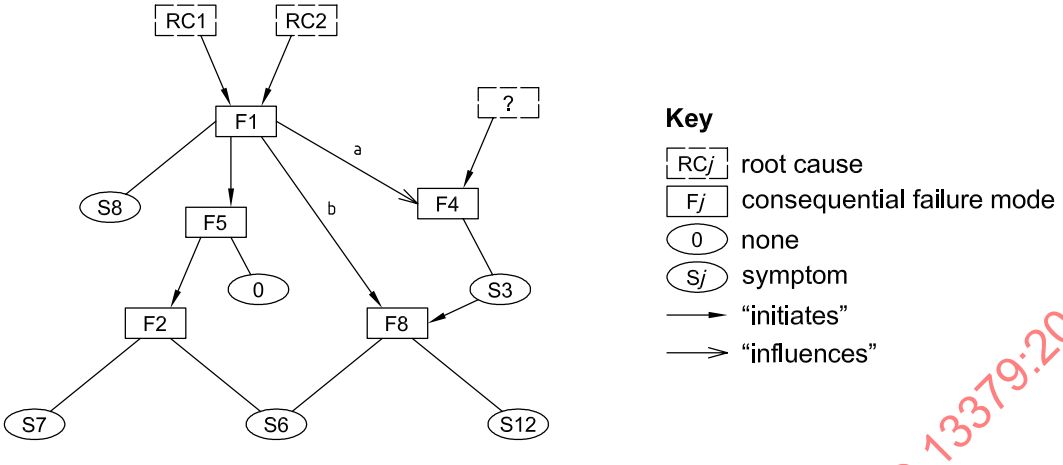
A causal tree models the knowledge as follows:

— in the past, the root cause has “initiated” one or more failure modes;

— the relationship between failure modes can be described by “influence factors” or “initiation criteria”;

— failure mode symptoms can “initiate”, “influence other failure modes”, or “have no effect”.

Figure 3 shows an example of a causal tree structure for diagnostics.



a $p = 0{,}75$ is the probability.

b The delay is 3 days.

Figure 3 — Example of causal tree modelling used for diagnostics

The links can be characterized by

— a delay value representing the time lag between the causes and the effects, and

— a probability value representing the probability that this cause has this effect ("initiates" and "induces" only).

A causal tree model is rarely complete, since

— each fault does not systematically have a symptom, and

— the root cause of failure modes is not always known.

An example of causal tree modelling is given in Annex E.

Annex A
(informative)

Failure Mode and Symptoms Analysis (FMSA)

Table A.1 — Analysis sheet

Part or Assembly Name _____ Suppliers _____ FMSA Number _____

Part or Assembly Number _____ Sheet _____ of _____

Drawing Issue _____

Amendments	1	2	3	4	5	6	7	8	9	10
Date										

FMSA Committee _____

FMSA Approved _____ Date _____

Name _____ Signature _____

Item	Part No. name, issue	Function or process	Failure mode	Effect of failure	Cause of failure	Failure symptoms	Primary technique	Frequency of monitoring	Primary MPN					Correlation techniques	Frequency of monitoring	Correlation MPN				
									DET	SEV	DGN	PGN	MPN			DET	SEV	DGN	PGN	MPN

Table A.1 (*continued*)

FMSA Number_____

Sheet _____ of _____

Item	Part No. name, issue	Function or process	Failure mode	Effect of failure	Cause of failure	Failure symptoms	Primary technique	Frequency of monitoring	Primary MPN					Correlation techniques	Frequency of monitoring	Correlation MPN				
									DET	SEV	DGN	PGN	MPN			DET	SEV	DGN	PGN	MPN
NOTE DET = detection; SEV = severity; DGN = diagnosis; PGN = prognosis; MPN = Monitoring Priority Number.																				

Annex B
(informative)

Effectiveness of the diagnostics system

Each fault can be diagnosed if its symptoms (and thus the descriptors used to evaluate these symptoms) are available. See Figure B.1.

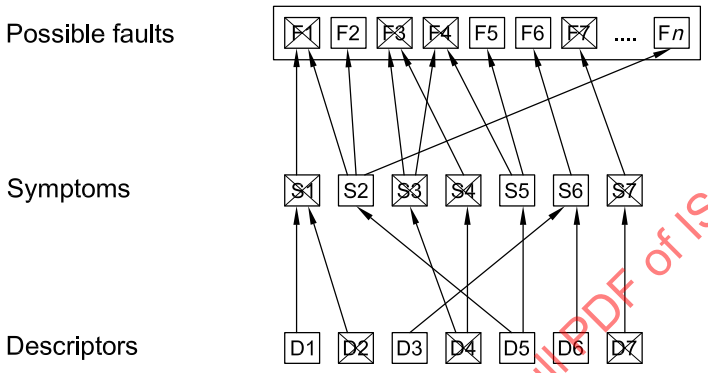


Figure B.1 — Example of faults/symptoms/descriptors relationship

Assuming fault F_i has the probability of occurrence p_i and severity S_i, it is possible to express a performance criterion for the overall diagnosis process, the diagnostics system effectiveness (DSE) as

$$\mathrm{DSE} = \frac{\sum_{D_F} S_i \cdot p_i}{\sum_{F} S_i \cdot p_i}$$

where

F is the possible faults set obtained by the FMEA or FMECA analysis;

D_F is the diagnosable faults set, a subset of F.

The severity S_i may be obtained by

$$S_i = \mathrm{FR} \times \mathrm{CF} \times \mathrm{SF} \times \mathrm{SDF}$$

where

FR is the failure rate (i.e. number of failures per hour);

CF is the cost factor, including maintenance and unavailability costs, ranked from 1 to 3 (low, medium, high);

SF is the safety factor, ranked from 1 to 3 (low, medium, high);

SDF is the secondary damage factor, ranked from 1 to 3 (low, medium, high).

Annex C
(informative)

Example of diagnosis report

DIAGNOSIS REPORT (sheet 1 of 3)	
DIAGNOSIS MADE BY	DATE
IDENTIFICATION OF THE MACHINE	
ANOMALY THAT TRIGGERED THE DIAGNOSIS	
GLOBAL SYMPTOMS VALIDATED 1 ..... 2 ..... 3 ..... 4	
FAULT No. 1 (most plausible)	
Component	Fault, failure mode name .....
VALIDATED NECESSARY SYMPTOMS 1 ..... 2 ..... 3	
VALIDATED REINFORCE SYMPTOMS 1. ..... 2. ..... 3.	