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Condition monitoring and diagnostics of machines — Approaches for performance diagnosis

Surveillance et diagnostic d'état des machines — Démarches pour le diagnostic de performance

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machines*.

Introduction

Challenged with high energy costs, emission reduction demands, and increasing flexibility demands, ensuring and verifying maximum efficiency of machines and systems has become a constant struggle for owners and operators.

Machines, groups of machines or industrial installations (equipment) fulfil their tasks by employing energy conversion or energy transportation processes. The efficiency of these energy conversion and energy transportation processes is the performance of the equipment or related processes. Good performance means high efficiency and low losses. If the energy conversion process includes a thermodynamic process, especially a thermodynamic cycle process, performance monitoring can become very complex.

Performance monitoring and diagnostics systems are increasingly implemented for this purpose. These are modern information systems that monitor the processes of machines, groups of machines, or complete industrial installation in order to detect and localize opportunities to improve their efficiency respective performance.

The benefits of performance monitoring and diagnostics lie in the provision of information (e.g. measured descriptors and expected descriptors) regarding the current performance status of the equipment. This information is the basis to avoid non-optimal operating states, degradation processes, and to ensure early detection and quantification of deterioration processes (e.g. erosion, corrosion).

Performance monitoring is often used in addition to condition monitoring.

Targets of performance monitoring and diagnostics are

— enhanced quality of energy conversion by achieving optimized operation,

— emission reduction,

— quantifying deterioration,

— recognizing faulty instrumentation,

— detecting defective equipment,

— enhanced availability of machines,

— increasing efficiency, thereby reducing energy costs and costs for emissions, and

— improvement in internal reporting and communication by increased transparency and calculation of well-defined descriptors.

Results of performance monitoring and diagnostics are addressed to

— operators to change the operating regime in case of identified not optimal operation, and

— maintenance staff to repair or modify the machine or equipment in order to eliminate identified faults/deterioration.

Condition monitoring and diagnostics of machines — Approaches for performance diagnosis

1 Scope

This International Standard provides an introduction on how to apply performance monitoring and diagnostics for machines, groups of machines, up to complete industrial installation (equipment) typically covering the whole lifetime of the machines.

This International Standard is intended to

— introduce the terminology specifically related to performance monitoring and diagnostics of machines,

— describe the types of performance monitoring and diagnostics procedures and their merits,

— provide guidance on installation of performance monitoring and diagnostics systems,

— outline methods and requirements for carrying out performance monitoring and diagnostics of machines, and

— provide information on data interpretation, and assessment criteria and reporting requirements.

This International Standard includes testing procedures for determining the accuracy of performance monitoring and diagnostics systems and procedures (including providing inputs for benchmarking the performance of equipment).

2 Normative references

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

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*

ISO 17359, *Condition monitoring and diagnostics of machines — General guidelines*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13372, ISO 13379-1, ISO 17359, and the following apply.

3.1
performance
behaviour, characteristics and efficiency of a technological process, running in a machine derived by measurement and calculation of one or more parameters, for example, power, flow, efficiency or speed, which singly or together provide the necessary information

[SOURCE: ISO 13372:2012, 2.3]

Note 1 to entry: Performance is used to qualify energy conversion processes with mostly thermodynamic process parts included.

Note 2 to entry: According to ISO 13372 machines, group of machines and complete industrial installations are referred to as equipment.

3.2
thermodynamic process
energy conversion process where thermal energy is involved as a major energy form

3.3
steady state
operating condition whereby the value of the described signal does not vary significantly with time

Note 1 to entry: A process is regarded as steady-state when characteristic parameters are steady-state.

3.4
descriptor
feature
data item derived from raw or processed parameters or external observation

[SOURCE: ISO 13372:2012, 6.2]

3.5
measured descriptor
signal obtained directly from the monitored equipment as measured value or processed directly from measured values, which is relevant for performance

3.6
expected descriptor
corresponding value to a measured descriptor that is obtained from a model, where the model describes the expected performance of the equipment

3.7
performance factor
ratio between actual value and expected value of efficiency

Note 1 to entry: A performance factor greater than 100 % means “better than target”, less than 100 % is deterioration.

Note 2 to entry: It is expressed as a percentage (%).

4 Types of performance monitoring and diagnostics

4.1 Basic concepts

Performance monitoring typically includes a comparison between measured descriptors (describing the performance of a machine, for example, power, flow, efficiency) against the expected descriptors.

The assessment of the performance by comparison requires identical operating conditions, such as speed, load, or temperature. Therefore, reference operating conditions are needed. With respect to the objective of the performance monitoring, different concepts are applicable:

a) Performance monitoring at actual measurement conditions – the operating conditions during measurement are used as reference and the expected descriptors are converted into values at these conditions. This concept is preferred, if for example, information about actual losses due to degradation under the present operating conditions is demanded.

b) Defined operating conditions are used as reference for performance monitoring. The measured descriptors gained at present operating conditions are converted into values at reference conditions. This method is preferred for trending purposes to eliminate the operating conditions influence.

NOTE Where correction to reference conditions 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 to ISO 17359.

4.2 Online performance monitoring

The basis of online performance monitoring is a model of the process running in a machine (e.g. thermodynamic process like Clausius-Rankine-Cycle or Joule Cycle).

Calculation results of the model are referred to as "expected" descriptors as they represent the theoretical or healthy status of the equipment for given operating conditions, i.e. without consideration of degradation, fouling, and faults. Here, the operating conditions are characterized by a small number of input parameters which are taken from measured values (in general, ambient conditions, fuel properties, speed, load, etc.).

The comparison of measured descriptors with expected descriptors allows monitoring of component performance, identification of abnormal performance situations, and analysis of component performance and abnormal operating conditions.

The monitoring of abnormal situations is followed by an analysis. This analysis is supported by the computation of key performance parameters (e.g. efficiencies and losses). Such parameters are derived from both corresponding measured descriptors and expected descriptors obtained with the model.

4.3 Offline performance analysis

Offline performance analysis is based on the same or a similar sophisticated model as online performance monitoring.

However, offline performance analysis allows controlled variation of the input parameters or the model characteristics.

This provides the basis for "what-happens-if" calculations, which are helpful for diagnostics of deviations between measured and expected descriptors from online performance monitoring.

4.4 Online performance monitoring with validation

In order to enhance data quality and to detect corrupt measurements, data validation according to VDI 2048-1 is recommended.

Using this method of data reconciliation, validated results provide a consistent set of measurements and the accuracy is enhanced overall. This allows better comparison of measured descriptors with expected descriptors.

The calculation process is strongly dependent on the availability of redundant or physically related measurements and the accuracy of the measured descriptors.

By building closed energy and mass balances, additional (not measured or not measurable) parameters can be calculated like heating surface properties that are not available without data reconciliation.

NOTE An inconsistent set of measurements can be detected by the validation process. Therefore, online performance monitoring with validation is helpful to enhance data quality and to detect suspect measurements.

5 Guidance on installation of performance monitoring and diagnostics systems

5.1 Preconditions

A general precondition of performance monitoring and diagnostics system is that the operating characteristics of the equipment to be monitored match the required function.

NOTE Errors arising from inadequate system design cannot be corrected by means of performance monitoring.

The following prerequisites are recommended for analysis of suitability:

— All machines of the equipment under consideration should run at manufacturer specified nominal conditions (characterized by, for example, flow, pressure, temperature, power).

— If a machine is operated in partial load or overload regions, at least these regions should belong to the allowable operating region specified by the manufacturer.

NOTE High efficiency of a machine is not identical with high efficiency of the equipment to which the machine belongs if, for example, the machine always runs in partial load.

5.2 Planning

Before performance monitoring and diagnostics are started, the following steps should be carried out:

— analyse operation of the machines and define output performance parameters (pairs of actual measured and expected descriptors);

— select input parameters to be used (see Annex A);

— define operation states foreseen for performance monitoring, including defining the steady-state condition for the monitored equipment;

— adjust the model for the monitored equipment;

— test the performance monitoring.

5.3 Operation analysis of equipment and definition of output performance parameters

The objective of the operation analysis of the equipment is the selection of descriptors describing the performance of the equipment and its components. The following items should be taken into account:

— determination of the required function of the equipment;

— evaluation of the required function of the equipment concerning behaviour, characteristics, and efficiency to be essential and representative for performance;

— comparison of equipment's design with the required function in order to analyse the capability to meet the required function;

— evaluation of the nominal operation parameters;

— analysis of procedures and constraints influencing the operational behaviour of the equipment;

— determination of descriptors describing the performance of the equipment (see Annex B);

— equipment break down into main components representing the main functions of the equipment;

— analysis of the interaction of the components.

The result of the analysis should be a set of descriptors (output performance parameters), which can be measured directly or derived from measured values.

5.4 Definition of operation states

5.4.1 General

It is recommended that performance monitoring and diagnostics be carried out for standard operation states of the equipment, which are defined as follows:

— steady-state operation;

— equipment is in operation with load or power above a specified minimum load or power;

— main operation characteristics (e.g. speed, valve positions, bypasses) are within specified ranges.

The result of this operation analysis is a list of operation states with their specification.

NOTE The performance monitoring can be limited to some specified operation states. Other operation states are defined as non-standard operation states and will not be considered.

5.4.2 Steady state

Models used for performance monitoring are based on assumptions concerning the operation states of the machines. Usually, steady state is required. This implies stabilization of characteristic performance parameters (descriptors).

The following method is an example for a robust estimation of steady state (see Figure 1).

The steady-state conditions are defined by

— selecting descriptors of the machine, suitable to describe operation states and available as measured signals,

— defining the allowable fluctuation range $2d$ for each descriptor (e.g. peak-peak-value of the descriptor), and

— specifying the length of a moving time window t_b:

— calculating the mean value $\bar{x}$ over the time $t - t_b$ to t, counting back from the current time t, the result is the arithmetic average over the length of the moving time window;

— checking whether the signal $\boldsymbol{x}$ during time $t - t_b$ to t is within the fluctuation range between $\bar{x} - d$ and $\bar{x} + d$ interval, if it is inside, then it is “steady state”.