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Condition monitoring and diagnostics of machines — Vibration condition monitoring —

Part 9:
Diagnostic techniques for electric motors

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Surveillance et diagnostic d'état des machines — Surveillance des vibrations —

Partie 9: Techniques de diagnostic pour moteurs électriques

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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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This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

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A list of all parts in the ISO 13373 series can be found on the ISO website.

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Introduction

This document has been developed as guideline for the procedures to be considered when carrying out vibration diagnostics of electric motors. It is intended to be used by vibration practitioners, engineers and technicians and it provides them with useful diagnostic tools. These tools include the use of diagnostic flowcharts and process tables and fault tables. The material contained in this document presents the most basic, logical, and intelligent steps that should be taken when diagnosing problems associated with these particular types of machines.

The ISO 7919 (rotating shafts), ISO 10816 (non-rotating parts) and ISO 20816 (both rotating shafts and non-rotating parts) series of International Standards contain acceptable vibration and zones for various types and sizes of machines, ranging from new and well-running machines to machines that are in danger of failing.

ISO 13373-1 presents the basic procedures for vibration narrow-band signal analysis. It includes the types of transducers used, their ranges, and their recommended locations on various types of machines; online and periodic vibration monitoring systems; and, potential machinery problems.

ISO 13373-2 includes descriptions of the signal conditioning equipment that is required, time and frequency domain techniques, and the waveforms and signatures that represent the most common machinery operating phenomena or machinery faults that are encountered when performing vibration signature analysis.

ISO 13373-3 provides some procedures to determine the causes of vibration problems common to all types of rotating machines. It includes systematic approaches to characterize vibration effects, the diagnostic tools available, which tools are needed for particular applications, and recommendations on how the tools are to be applied to different machine types and components. However, this does not preclude the use of other diagnostic techniques.

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It should be noted that ISO 17359 indicates that diagnostics

— can be started as a succeeding activity after detection of an anomaly during monitoring, or

— can be executed synchronous with monitoring from the beginning.

The present document considers only the former in which diagnostics is performed after an anomaly has been detected. Moreover, this document focuses mainly on the use of flowcharts and process tables as diagnostic tools, as well as fault tables, since it is felt that these are the tools that are most appropriate for use by practitioners, engineers and technicians in the field.

The flowchart and diagnostic process table methodology presents a structured procedure for a person in the field to diagnose a fault and find its cause. This step-by-step procedure should be able to guide the practitioner in the vibration diagnostics of the machine anomaly in order to reach the probable root cause of this anomaly.

The fault tables present a list of the most common faults in machinery, as well as their manifestations in the vibration data. When used with the flowcharts, the tables assist with the identification of machinery faults.

When approaching a machinery problem that manifests itself as a high or erratic vibration signal, the diagnosis of the problem should be done in a well-thought out systematic manner. This document together with ISO 13373-3 achieve that purpose by providing to the analyst guidance on the selection of the proper measuring tools, the analysis tools and their use, and the step-by-step recommended procedures for the diagnosis of problems associated with various types of electric motors.

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Condition monitoring and diagnostics of machines — Vibration condition monitoring —

Part 9: Diagnostic techniques for electric motors

1 Scope

This document specifies procedures to be considered when carrying out vibration diagnostics of various types of electric motors. The four motor types covered by this document are squirrel-cage induction, wound-rotor induction, salient-pole and DC motors.

NOTE The first two types are defined in ISO 20958.

This document is mostly applicable to motors with power above 15 kW.

This document is intended to be used by condition monitoring practitioners, engineers and technicians and provides a practical step-by-step vibration-based approach to fault diagnosis. In addition, it gives a number of examples for a range of machine and component types and their associated fault symptoms.

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The procedures presented in this document can, in some cases, be applied to other types of electrical machines, such as generators, but there can be other specific techniques associated with such machines that are not included in this document.

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The use of non-vibration quantities, such as voltage and current, to identify and analyse vibration-related faults in electric motors is outside the scope of this document.

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 20958, *Condition monitoring and diagnostics of machine systems — Electrical signature analysis of three-phase induction motors*

ISO 21940-2, *Mechanical vibration — Rotor balancing — Part 2: Vocabulary*

IEC 60050, *International Electrotechnical Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041, ISO 13372, ISO 20958, ISO 21940-2, IEC 60050 and the following apply.

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

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

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

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3.1
DC armature
shaft with laminated, slotted core into which a two-layer winding is installed and connected to a commutator which is supplied with DC power via brushes

3.2
salient-pole rotor
shaft with solid or laminated poles having a winding on each pole

Note 1 to entry: The pole windings are connected together and to sliprings or a brushless exciter from which the required DC power supply is applied.

3.3
supply frequency
frequency of the power supply connected to AC motors

Note 1 to entry: The supply frequency is also called line frequency.

3.4
slip frequency
<induction motors> difference between the synchronous rotational speed and rotor rotational speed frequencies

3.5
number of stator poles
integer which is defined by the following formula:

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$$\frac{2\ n_{syn}}{60\ f_{supp}}$$

where

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n_{syn} is the synchronous rotational speed, in r/min;

f_{supp} is the supply frequency, in Hz.

Note 1 to entry: The number of pole pairs is the number of poles divided by 2.

3.6
pole passing frequency
<induction motors> rotor slip frequency times the number of poles

3.7
stator slot passing frequency
number of stator slots times the rotor rotational speed

3.8
rotor slot passing frequency
number of rotor slots times the rotor rotational speed

3.9
rotor bar passing frequency
number of bars in a squirrel-cage rotor times the rotor rotational speed

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4 Measurements

4.1 Vibration measurements

Vibration measurements may be obtained using two main categories of transducers:

— non-contacting, e.g. inductive, capacitive and eddy current probes used on rotating shafts;

— seismic transducers, e.g. accelerometers or velocity transducers used on non-rotating parts, such as bearing housings.

International Standards are available to help assess the vibration severity for the described types of measurement, in particular, ISO 7919, ISO 10816 and ISO 20816.

It is important to recognize that the appropriate transducer, signal conditioning, measurement and analysis system should be used for the diagnosis of faults considering specific situations in electric motors. For example, to detect rotor bar problems, high resolution in the spectrum is required to detect the slip frequency. In many cases, it is required to consider the grounding and electrical field of the machine before taking any measurement.

The description of transducer and measurement systems, as well as specification of techniques, are given in ISO 13373-1 and ISO 13373-2, which shall be considered for appropriate selection.

4.2 Machine operational parameter measurements

These are operational parameters, e.g. rotational speed, load, motor orientation (vertical or horizontal), mounting configuration (solid or flexible support arrangement) and temperatures, that can have an influence on the machine vibration characteristics and are therefore important to acquire in order to arrive at an appropriate diagnosis. For a given machine, these parameters can be associated with a range of steady-state and transient operating conditions.

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5 Initial analysis

An initial analysis should be performed using the guidelines given in ISO 13373-3:2015, Annex A. This analysis should identify safety concerns, the presence of high vibration, and if so, its vibration severity, past history, effects of operating parameters, consequences of not taking corrective actions and the need for a motor shutdown. Also, other factors such as motor mounting configuration, vibration from driven machinery, position relative to other rotating machines, building structure, environment, etc. should be considered during an initial analysis. See also ISO 13373-3:2015, Annexes B to D, for common faults such as from installation and bearing defects.

6 Motor specific analysis

Electric motors are used as drivers in many industrial applications such as pumps, fans and compressors. This document covers vibration diagnosis information for the most common types of electric motors. Symptoms of the most prevalent motor defects that cause excessive vibration magnitudes are given in Annex A which shall be considered. However, Annex A does not cover motor vibration from inadequate motor mounting, hydrodynamic bearing problems, or rolling element bearing problems which are addressed in ISO 13373-3:2015, Annexes B, C and D, respectively.

The methodology for vibration diagnosis of electric motors is given in Annex B, while case studies illustrating the methodology are provided in Annex C. The techniques used in vibration diagnosis of electric motors include visual inspections, vibration magnitudes, spectral analysis, time waveform analysis, phase analysis and operational deflection shape (ODS) analysis. The use of these techniques is described in B.2.

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Annex A
(normative)

Systematic approach to vibration analysis of electric motors

The systematic approach to vibration analysis of electric motors is given by the fault table in Table A.1.

NOTE Most of the theory as to why specific defects can be identified by certain vibration frequencies and other characteristics can be found in References [15] and [16].

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Table A.1 — Fault table for vibration analysis of electric motors

Defect	Measurement conditions under which vibration change occurs	Initial rate of change of vibration amplitude	Major frequency component of changed vibration amplitude and phase angles	Subsequent behaviour of vibration with time	Effect on resonance speed	Effect of cutting power	Repeatability	Comments
Loose stator coils (synchronous motors)	Usually gradually develops with time	Slow rate of change	(Number of stator coils) times (1× rotational speed) with 1× rotational speed sidebands	Magnitudes increase with time	None	Immediate drop in vibration magnitudes	Yes	Unlikely to occur if stator winding is global vacuum pressure impregnated
Bent shaft extension	Usually after failure of driven equipment, or if high radial load is imposed	Fast rate of change	Mainly 1× rotational speed, but exhibit 2× supply frequency and modulation of this at 2× slip frequency in 2-pole squirrel-cage motors if bent shaft leads to non-uniform air gap	If due to high radial load on shaft extensions can increase with time and vary with load	None	Some initial drop in the 2× supply frequency component, but then slowly increases with time	Magnitudes can change with load and temperature	Can be confirmed by total indicated runout measurement on shaft extension
Rotor running off magnetic centre	After motor installation, or axial realignment with driven equipment	Depends on how far rotor is off its axial magnetic centre	High axial 1×, 2× or 3× rotational speed frequency with much lower radial vibration	Can change with load	None	Immediate drop in vibration magnitudes	Magnitudes can change with load and temperature	Higher magnitudes on motors with radial cooling ducts on stator and rotor

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Table A.1 *(continued)*

Defect	Measurement conditions under which vibration change occurs	Initial rate of change of vibration amplitude	Major frequency component of changed vibration amplitude and phase angles	Subsequent behaviour of vibration with time	Effect on resonance speed	Effect of cutting power	Repeatability	Comments
Cracked or broken rotor bars	After motor starting, unless due to voids in diecast rotor bars	Slow if fabricated rotor bars	High 1× rotational speed frequency with sidebands at ± slip frequency times number of poles. Also harmonics of these frequencies. Vibration amplitude can vary at slip frequency times number of poles and increase with load. Can also be a high 4× rotational speed axial vibration	Vibration will increase if more rotor bars break. Also unbalance and vibration due to thermal bow will develop	Will change response	Immediate drop in vibration magnitudes	Magnitudes will change if more rotor bars break	Motor will become noisy during starting and start time will increase due to reduction in motor torque. Can usually be confirmed by current signature analysis and 2× slip frequency sidebands around supply frequency

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