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Condition monitoring and diagnostics of machines — Vibration condition monitoring —

Part 7: Diagnostic techniques for machine sets in hydraulic power generating and pump-storage plants

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Contents

Page

iTeh STANDARD PREVIEW
(standards.iteh.ai)
ISO 13373-7:2017
https://standards.iteh.ai/catalog/standards/sist/0ac96587-cb33-4426-98fd-e8f0db4a05ef/iso-13373-7-2017

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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*.

ISO 13373-7:2017
https://standards.iteh.ai/catalog/standards/sist/0ac96587-cb33-4426-98fd-e8f0db4a05ef/iso-13373-7-2017

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

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Introduction

This document is a guideline for procedures to be considered when carrying out vibration diagnostics of machine sets in hydraulic power generating and pump-storage plants, shortly named hydropower units. It is intended to be used by vibration practitioners, engineers and technicians, and it provides them with diagnostic tools. These tools include the use of diagnostic process tables and fault tables. The material contained herein presents the most basic, logical and intelligent steps that should be taken when diagnosing problems associated with these particular types of machines.

Acceptable vibration values for hydropower units, however, are contained in ISO 10816-5 (vibration of non-rotating parts) and ISO 7919-5 (vibration of rotating shafts), which are at present under revision and amalgamation to be published as ISO 20816-5.

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

ISO 13373-2 leads to the diagnostics of machines. It 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, tools 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

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

— executed synchronously with monitoring from the beginning.

This document considers only the first case in which diagnostics is performed after an anomaly has been detected. Moreover, it focuses mainly on the use of 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.

When approaching a machinery problem that manifests itself as a high or erratic vibration signal, the diagnosis of the problem should be carried out in a well-thought-out systematic manner. ISO 13373-3 and this document 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 recommended step-by-step procedures for the diagnosis of problems associated with various types of machine sets in hydraulic power generating and pump-storage plants.

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

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

For some cases, it can be dangerous to start the machine again after a serious anomaly caused a trip. Then, the diagnosis to be performed may differ from the methods described in this document.

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ISO 13373-7:2017
https://standards.iteh.ai/catalog/standards/sist/0ac96587-cb33-4426-98fd-e8f0db4a05ef/iso-13373-7-2017

Condition monitoring and diagnostics of machines — Vibration condition monitoring —

Part 7:
Diagnostic techniques for machine sets in hydraulic power generating and pump-storage plants

1 Scope

This document gives guidelines for specific procedures to be considered when carrying out vibration diagnostics of various types of machine sets in hydraulic power generating and pump-storage plants (hydropower units). It 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 includes a number of examples for a range of machine and component types and their associated fault symptoms.

2 Normative references

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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 13373-7:2017
https://standards.iteh.ai/catalog/standards/sist/0ac96587-cb35-4426-98fd-e8f0db4a05ef/iso-13373-7-2017

ISO 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

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

ISO 13373-1, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 1: General procedures*

ISO 13373-2, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 2: Processing, analysis and presentation of vibration data*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041, ISO 13372 and ISO 21940-2 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

4 Hydropower vibration

Vibration measurements mainly consist of quantifying the oscillation of the rotating shaft at the guide bearings relative to the bearing housing (shaft relative vibration) and the absolute vibration of the bearing housing itself (bearing housing vibration), which is representative for non-rotating parts.

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Unlike other heavy rotating equipment, such as gas turbines, compressors and pumps, hydropower units are rigid without flexible couplings between the components and normally operate below the first resonance speed. A hydropower unit shall therefore be analysed as one dynamic unit, which means that all vibration quantities should be measured simultaneously at all bearing planes.

Hydropower units are influenced by

— mechanical unbalance,

— hydraulically excited forces acting on the turbine runner,

— magnetically interacting forces between the stator and rotor,

— mechanical forces in the bearings (bearing faults),

— fluid-film instability, and

— contact between rotating and non-rotating parts.

Any of these forces can cause mechanical vibration and deflections. The magnitude and behaviour of the vibration varies dependent on the type of hydropower unit, general layout, bearing design, foundation, rotational speed, etc. As the forces can seldom be measured directly, or as measuring the forces is much more complex, vibration is used as an indirect indicator. Vibration analyses are based on the detection and estimation of mechanical forces by observing the resulting vibrations.

5 Measurements

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5.1 Vibration measurements in general

ISO 13373-7:2017
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Hydropower units normally have a long lifespan with a stable and solid behaviour. Possible faults in hydro plants usually develop slowly. Occasional monitoring is suitable to detect slowly developing faults. Therefore, temporarily installed measurement systems for periodic, random or seldom monitoring might be sufficient for an initial analysis as described in ISO 13373-3. But those systems might not be sufficient for detailed diagnosis of faults that develop slowly as described in ISO 13373-2.

Trending of parameters should be performed regularly to detect changes of the vibration state over longer periods of time. For such trend analyses, continuous long-term monitoring by a permanent monitoring system is preferred. A permanent monitoring system will also give protection against failures (e.g. bearing breakdowns). Periodic measurements with additional transducers give valuable information for the condition evaluation and useful information to enable planning of maintenance work.

Condition-based monitoring may be considered and applied as described in ISO 17359. This can lead to additional effort, including

— installation of additional transducers,

— monitoring of machine operating parameters influencing the vibration behaviour,

— more detailed analysis, and

— continuous online measurement with appropriate data storage and acquisition system.

More information relevant for vibration measurements on hydropower units is given in the documents listed in the Bibliography.

5.2 Instrumentation

Two principal kinds of vibration measurement are common, which provide complementary information.

— **Shaft relative vibration,** measured with non-contacting proximity probes that are mounted at or near the bearings, e.g. inductive, capacitive and eddy current probes.

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— **Bearing housing vibration,** measured with seismic transducers, e.g. accelerometers or velocity transducers, that are mounted on non-rotating parts of the bearing housing.

In addition to vibration measurements, transducers may also be installed to measure dynamic pressure, air gap and, by means of strain gauges, even stress. These parameters can be used to correlate the cause and effect of an event.

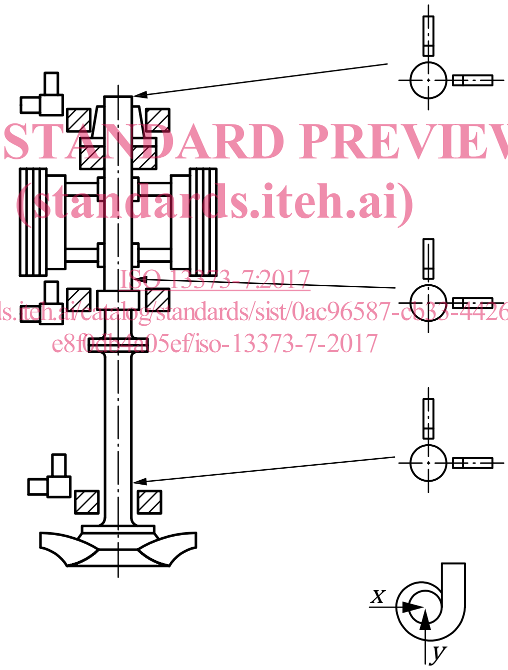
Large hydropower installations normally include proximity probes at each bearing as standard. However, if this is not the case, it is advisable to install two temporary proximity probes at each bearing position. The orientation is in the radial plane orthogonal to each other, see Figure 1.

When using temporarily installed proximeter probes, the following should be noted.

Relative vibration transducers can be susceptible to electrical and mechanical runout which can differ based upon probe axial location related to shaft. Axial locations should be chosen to allow repeatable installations for monitoring and to reduce the effects of this measurement error.

The residual total electrical and mechanical runout should be documented and used to correct turning speed vibration components when an appropriate phase reference signal is available.

Temporary vibration transducer radial locations should be consistent between measurement events.



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ISO 13373-7:2017
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Figure 1 — Example of measurement locations and directions on a vertical hydropower unit

For full information about bearing housing vibration, an installation should contain two radial seismic transducers in orthogonal directions on each bearing housing and one seismic transducer in axial direction for thrust bearing or a bearing braced against a vibrating structure like the turbine head cover. The commonly used signal output is vibration velocity, measured directly with velocity transducers or measured with accelerometers and signal integration.

Some acceleration and velocity measuring systems are only able to measure vibration at frequencies down to 10 Hz, which is not suitable in hydropower units where the rotational speed is normally below 600 r/min. Recommended minimum frequency is 0,1 times rotational frequency for reaction turbines and pumps and 0,4 times rotational frequency for impulse turbines.

All signals should be measured simultaneously with measurement duration sufficient to characterize such low frequencies.

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Adding a phase mark transducer for a trigger will provide a method to synchronize the measurements and to give phase reference at each measurement point.

International Standards are available to help assessing the vibration severity for the described types of measurement, in particular ISO 20816-1.

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 transducer and measurement system selection.

5.3 Measurement of machine operational parameters

Hydropower machine operational parameters, e.g. rotational speed, load, head, tail water level, opening of main regulation device (e.g. wicket gate opening) and bearing oil temperature, can have an influence on the machine vibration characteristics. For a reliable diagnosis, it is important to measure and to store these data simultaneously to correlate vibration and the operational state because of very different hydraulic and other forces.

A hydraulic operational point needs to be defined by at least two operational parameters, e.g. head and discharge and operation mode (generating, pumping, transient, etc.). For variable speed machines, the actual rotational speed shall be known.

The direction of rotation is also an important parameter, which is required to interpret the phase of synchronous vibrations correctly.

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ISO 13373-7:2017
https://standards.iteh.ai/catalog/standards/sist/0ac96587-cb33-4426-98fd-e8f0db4a05ef/iso-13373-7-2017

6 Initial analysis

The first step should be to collect the design configuration of the machine and the history of any anomalies. This initial analysis can be performed using the guidelines given in ISO 13373-3:2015, Annex A, which indicates that this analysis should identify safety concerns, the presence of high vibration and its vibration severity, the history, effects of operating parameters and the consequences of failing to take corrective actions. All this is used as a basis to judge the risk of operating the machine.

When changes in the dynamic behaviour are detected, special investigations and tests should be performed to find the reason for the changes.

7 Specific analysis of hydropower units

Hydropower units are often individual prototypes, which makes it difficult to compare one machine to another. The assessment of the vibration state therefore needs to take into account actual boundary conditions and design configuration. Long-term trend recording is of significant help.

The vibration magnitude is a reaction to the exciting forces. On the hydraulic side, e.g. flow condition in the runner or pressure pulsation on stationary parts, there is a strong dependency on the hydraulic operation point, which has to be defined by two operation parameters, e.g. head and discharge or gate opening (see 5.3).

NOTE 1 The vibration magnitude alone does not necessarily indicate the stress level in the affected components. A strain gauge measurement and/or a suitable calculation model is needed to derive the fatigue impact.

The generator or motor part is normally directly coupled to the hydraulic part, therefore the combined system shall be analysed. A diagnosis of either the hydraulic components or the electrical side alone is not advisable and will most probably not be successful. Exceptions are units with gearbox between turbine and generator, or units with clutch between pump und turbine or pump and motor.

NOTE 2 Identical power units at the same apparent operating points can have different vibration behaviour. If this cannot be related to different boundary conditions, such as temperature, the operation of adjacent machines can provide an indication of an anomaly of the machine state and possibly to a fault.

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The fault table presented in Annex A gives a list of the most common faults in machinery and their manifestations in the vibration data. It shall be followed in the vibration analysis of hydropower units.

The diagnostic process table in Annex B gives a guideline for a methodical approach to diagnosis for a person in the field to diagnose a fault and find its cause.

Annex C gives examples of vibration problems in hydropower units and physical explanations for the related vibration pattern.

8 Additional diagnostics

This document focuses on the vibration based condition monitoring. While vibration values and changes in vibration value are quite helpful, other values give additional information about condition of the unit. Monitoring of steady-state operational parameters such as flow, head and guide vane opening together with generator power output will show loss of efficiency, but very precise measurements are necessary to detect common faults not showing up in vibration value.

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ISO 13373-7:2017
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