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Condition monitoring and diagnostics of machines — Ultrasound

Part 2: Procedures and validation

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National foreword

This British Standard is the UK implementation of ISO 29821-2:2016.

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Part 2: Procedures and validation

Surveillance des conditions et diagnostic d'état des machines — Ultrasons —

Partie 2: Modes opératoires et validation

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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 machine systems*.

ISO 29821 consists of the following parts, under the general title *Condition monitoring and diagnostics of machines — Ultrasound*:

— *Part 1: General guidelines*

— *Part 2: Procedures and validation*

Introduction

This part of ISO 29821 provides specific guidance on the interpretation of ultrasonic readings and wave files or frequency and time domain printouts (sometimes called "sound images") as part of a programme for condition monitoring and diagnostics of machines. Airborne (AB) and structure-borne (SB) ultrasound can be used to detect abnormal performance or machine anomalies. The anomalies are detected as high frequency acoustic events caused by turbulent flow, ionization events and friction, which are caused, in turn, by incorrect machinery operation, leaks, improper lubrication, worn components, and/or electrical discharges.

Airborne and structure-borne ultrasound is based on measuring the high frequency sound that is generated by either turbulent flow, friction or by the ionization created from the anomalies. The inspector therefore requires an understanding of ultrasound and how it propagates through the atmosphere and through structures as a prerequisite to the creation of an airborne and structure-borne ultrasound programme. Ultrasonic energy is present with the operation of all machines. It can be in the form of friction, turbulent flow and/or ionization as a property of the process, or produced by the process itself. As a result, ultrasonic emissions are created and these are an ideal parameter for monitoring the performance of machines, the condition of machines, and for diagnosing machine anomalies. Ultrasound is an ideal technology to do this monitoring because it provides an efficient way to quickly and non-invasively determine the location of an anomaly with little setup and in a very short period of time.

Condition monitoring and diagnostics of machines — Ultrasound —

Part 2: Procedures and validation

1 Scope

This part of ISO 29821

— provides guidance on establishing severity assessment criteria for anomalies identified by airborne (AB) and structure borne (SB) ultrasound,

— outlines methods and requirements for carrying out ultrasonic examination of machines, including safety recommendations and sources of error, and

— provides information relative to data interpretation, assessment criteria and reporting.

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 29821-1:2011, *Condition monitoring and diagnostics of machines — Ultrasound — Part 1: General guidelines*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13372 and ISO 29821-1 apply.

4 Ultrasonic condition monitoring

4.1 Application of airborne and structure-borne ultrasound within condition monitoring programmes

Ultrasound is not normally used as a primary monitoring technique in typical condition monitoring programmes. The exceptions to this are when ultrasound is preferred as a non-invasive indicator of impending failure or performance deterioration or when rapid pressure or vacuum leak localization is necessary to lessen machine performance degradation.

Examples of such applications are:

— electrical transformers;

— enclosed electrical systems;

— gearboxes;

— motors;

— pumps;

— conveyor bearings;

— lubrication failure;

— compressors;

— turbine engines;

— condensers;

— heat exchangers;

— compressed gas systems.

4.2 Correlation with other technologies

Traditionally, airborne and structure-borne ultrasonic inspection is used in a condition-monitoring programme to detect characteristics of failure modes that have been previously identified by another technology. There are instances where airborne or structure-borne ultrasound is the first indicator of a failure mode, such as in the detection of faulty slow-speed bearings and/or insufficient lubrication in rolling element bearings. Airborne or structure-borne ultrasound can also be used to identify a potential safety hazard to an inspector using an alternate technology, for example in the inspection of enclosed electrical systems. Airborne and structure-borne ultrasound are used to determine if an arc flash hazard is present before opening the cabinet for an infrared thermographic inspection.

5 Equipment choice

5.1 Kinds of sensors

Airborne ultrasound is propagated through an atmosphere (air or gas) and detected with an ultrasonic microphone while structure-borne ultrasound is generated within and propagated through a structure and is usually detected with a contact module, although other sensors may be used. A guide for which sensor should be chosen can be found in ISO 29821-1:2011, Table 1.

5.2 Airborne sensor choice

An ultrasonic instrument with fixed sensors might have limitations with respect to field of reception and might not be suitable for all applications. For ultrasonic instruments with interchangeable sensors, there is normally a choice of two kinds of sensors: wide-angle and parabolic.

For machine condition monitoring, wide-angle airborne sensors are particularly useful for gaining an overall assessment of the machine condition utilizing the maximum machine area for comparison of ultrasonic signatures. This allows the comparison of multiple components in a single machine. This module type is also useful in confined-space areas where the access area can be very small.

Parabolic sensors are useful for remote component locations such as elevated conveyors, equipment, vessels and outdoor substations, where access is limited and the machine, system, or component of either, is a great distance away. The narrow field of reception is helpful especially for pinpointing leaks in piping or in determining which phase in a high voltage tower has an electrical discharge

5.3 Structure-borne sensor choice

Structure-borne sensors are used to non-invasively detect internal abnormal performance or machine anomalies. There is normally a choice of contact and magnetically coupled sensors.

The contact sensor (stethoscope) is most commonly used when a machine, system or component needs to be quickly scanned to determine where an anomaly or fault condition is located. It is also effectively used to get into tight spaces to gain access to a good monitoring point. For measurement points that are just out of reach, extension contact rods can be used. For measurement points that are in difficult to reach or in unsafe areas, permanent remote contact sensors can be used.

Magnetically-coupled contact sensors remove the measurement variation associated with hand-held contact sensors. They are therefore ideal in circumstances where a long sampling time is required or where there are multiple inspectors taking readings on the same sampling point. An example would be when monitoring an electrical transformer, as a slight movement of a contact sensor can sound very similar to a partial discharge inside the transformer, which would cause a false indication of an anomaly.

5.4 Instrument characteristics

5.4.1 General

When selecting an ultrasonic instrument, the sensitivity, frequency response and ability to record the heterodyned (demodulated) ultrasonic signal output should be carefully considered with respect to the intended applications. Some applications require monitoring at different frequencies for the best results. Other applications require a recording of the heterodyned (demodulated) sound signature for further analysis and for reporting.

5.4.2 Frequency response

If using an airborne or structure-borne ultrasonic instrument with heterodyned (demodulated) frequency tuning capability, the ultrasound inspector should be aware that there are certain monitoring frequencies that enhance the data that is acquired for specific applications. These monitoring frequencies are primarily due to the propagation of the ultrasonic wave through specific media, but can also be influenced by the resonance of the ultrasonic sensor. Examples of typical monitoring frequencies are shown in Table 1.

Table 1 — Typical monitoring frequencies

Acquisition method	**Application**	**Frequency** (kHz)
Airborne	Leaks, electrical	40
Structure-borne	Bearings, mechanical	30
	Valves, steam traps	25
	Electrical – sealed leaks-underground	20

6 Data collection guidelines

6.1 General

Several techniques are recognized and in use throughout industry to collect data. As indicated in ISO 29821-1:2011, Table 2, depending upon the fault type, the ultrasound inspector may record the test data as a decibel value, record sound samples, and analyse the data and/or the recorded sound samples using time and frequency domain techniques. This provides the capability to identify changes in the condition of monitored equipment and to determine if any further action needs to be taken.

The procedures are slightly different when using the airborne or structure borne techniques as shown in Figures 1 and 2.

Figure 1 — Example of airborne ultrasound monitoring

Figure 2 — Example of structure-borne ultrasound monitoring

Photographs should be taken that indicate the location, orientation, and subject content of the acquisition point with indication of what sensor was used. These will aid with the interpretation of the data and also help in identifying the acquisition point for subsequent readings.

6.2 Error sources, accuracy, and repeatability

Ultrasonic readings or recorded heterodyned (demodulated) sound files, or both, should be acquired from locations selected to minimize the errors caused by sounds from other sources such as reflections from these other sources. Care should also be taken to avoid taking readings during times when the operation of machines produces competing ultrasound. Subsequent readings for trending should be taken in accordance with ISO 29821-1.

Where decibel alarm or sound interpretation criteria are used, all instrument settings such as frequency should be correctly determined in accordance with 5.4.2 and ISO 29821-1. The machine under test should be operating under steady state conditions representative of normal operating conditions.

In some instances, environmental conditions, such as temperature or humidity, can influence the ultrasonic readings or severity determination, especially in electrical emissions. Data acquisition shall be carried out in accordance with ISO 29821-1 as well as established industry standards and practices and manufacturers' guidelines.

As required by ISO 29821-1:2011, Clause 9, an ultrasonic instrument shall be in calibration and a sensitivity validation procedure should be performed prior to an ultrasonic inspection. Annex A gives an example of a sensitivity validation procedure.

7 Assessment criteria

When the ultrasonic instrument detects deviations from the baseline, previous reading, or comparative differences, these deviations should be noted. The decibel value data or the heterodyned (demodulated) ultrasound anomalies, or both, should be recorded and analysed for severity and subsequent corrective action. The use of time and frequency domain analysis is very helpful, not only to provide a way to determine the severity of the anomaly, but also to provide a way to report the condition of the machine as a sound image.

When applying airborne and structure-borne ultrasound to the condition monitoring and diagnostics of machines and their related components, it is strongly suggested that assessment criteria be established. Measurements shall be carried out in accordance with ISO 29821-1. Examples of typical fault types and assessment criteria are shown in ISO 29821-1:2011, Table 2, as well as established industry standards and practices and manufacturers' guidelines.

8 Interpretation guidelines

For a given machine, interpretation of ultrasonic readings and sound images is a process of comparing these data against those that are representative of the ideal design, manufacture, installation, operation, and maintenance criteria. Once the comparison is complete and anomalies are identified, analysis normally takes the form of comparing readings and sound patterns with those consistent with known faults and failure modes.

When using ultrasound for machinery condition monitoring purposes, the operating and environmental conditions of the machine at the time of each survey shall be recorded in detail as these conditions can affect the severity assessment criteria. It is also essential to understand the design of a machine, such as in component loading, for anomaly location.

A typical fault identification process that may be used is as follows:

a) determine the expected decibel readings and sound patterns of the machine system when the system is operating in as-designed conditions for each typical operating state;

b) develop severity assessment criteria associated with the as-designed operating condition for each typical operating state;

c) determine if any anomalies exist and their severity;

d) for each anomaly, determine whether it is caused by the operating condition or the fault condition;

e) determine the rate of change or trend for each anomaly;

f) develop fault diagnosis and prognosis, if required;

g) apply confirmatory analysis using an alternative technology, if required;

h) determine corrective actions;

i) issue a report.

9 Diagnosing ultrasonic problems

9.1 Principles of diagnostics using ultrasound

Diagnosing machine systems using ultrasound is not generally rule based. Diagnostics, therefore, requires a principle based approach where analysts use thorough understanding of the principles of ultrasound generation to diagnose machine systems faults.

These are general principles that underpin such analysis:

— Sources of ultrasound within a machine system;

— Sources of energy loss from a machine system;

— Principles of sound generation that affect the sound propagation to and from a machine system.

Diagnosis of machine systems usually requires the application of all these principles to identify the source of anomalies and to diagnose causes.

9.2 Generation of ultrasound

9.2.1 Surface friction

Ultrasound may be generated by friction, which is the interaction of two surfaces moving in relative motion whilst in contact. Surface friction is influenced by relative velocity, surface roughness, relative surface hardness, lubricant condition, materials, and load.

9.2.2 Fluid flow

Ultrasound may be generated by the disturbance of a fluid flow over a surface. Such fluid flow disturbance can be influenced by fluid velocity, flow characteristic (laminar or turbulent), fluid density, thermal properties, surface roughness, and pressure.

9.2.3 Ionization

Ultrasound may be generated by ionization, which occurs when an electric charge builds up on, or in, a component resulting in a discharge between or on components. This discharge creates ionization.

10 Reporting

The ultrasound data can be reported in the form of a graph, chart, or sound image of the heterodyned (demodulated) ultrasonic sound sample displayed in a time or frequency domain (or both) sample of the anomaly. Only trained personnel should write reports.

Several report examples are shown in ISO 29821-1:2011, Annex B.

Annex A
(informative)

Example of a generic sensitivity validation procedure: Ultrasonic tone generator method

It is recommended to check the sensitivity of the ultrasonic instrument before proceeding with an ultrasonic inspection. To assure reliability, keep a record of all sensitivity validation tests. Keep the ultrasonic tone generator charged or check the battery voltage.

Procedure:

A. For the airborne sensor:

a) Select the test frequency, if the instrument has frequency tuning, and record it.

b) Plug in the headphones and adjust the earpieces so that they are opened up and place them on the test table.

c) Select an item such as a rod or the instrument case as a repeatable distance gauge that will be the same for every time the instrument is tested.

d) Place the tone generator so that the emitter is directly facing and directly in line with the airborne sensor of the ultrasonic instrument. Select an output level on the tone generator, if it is adjustable.

e) Note the level and record it for future validations.

f) Make certain that the airborne sensor is directly facing the tone generator emitter and that they are aligned with the centre area of the airborne sensor.

g) Adjust the sensitivity of the instrument under test until there is either a meter deflection to midscale or a stable decibel indication on the display.

h) Record either the sensitivity dial setting or the decibel reading on a chart for trending.

B. For the structure-borne sensor:

a) Select the test frequency, if the instrument has frequency tuning, and record it.

b) Plug in the headphones and adjust the earpieces so that they are opened up and place them on the test table.

c) Place the tone generator flat with the emitting transducer facing up.

d) Select an output level on the tone generator if it is adjustable.

e) Note the level and record it for future validations.

f) Locate a point on the tone generator that will give a repeatable reading to place the structure-borne sensor. The contact probe should be perpendicular to the emitting surface of the tone generator.

g) Adjust the sensitivity of the instrument under test until there is either a meter deflection to midscale or a stable decibel indication on the display.

h) Record either the sensitivity dial setting or the decibel reading on a chart for trending.

For all tests:

Whenever a sensitivity validation test is performed, review the recorded data and repeat the test using the same distance, module, frequency, and tone generator output setting.

A problem is indicated by a change in the meter reading of an analogue ultrasonic instrument that is greater than +/-20 % of full scale from the mid-scale reading. If a digital instrument is used, a change of greater than +/-3 dB indicates a problem. A variation greater than +/-20 % of full scale or +/-3 dB is greater than the expected operator error in performing the sensitivity validation and the ultrasonic instrument or the defective sensor should be repaired.

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BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK