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Condition monitoring and diagnostics of machines — Ultrasound —

Part 1:
General guidelines

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

Partie 1: Lignes directrices générales

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 29821-1 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machines*.

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

— *Part 1: General guidelines*

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The following part is planned:

— *Part 2: Procedures and validation*

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Introduction

This part of ISO 29821 provides guidance for the condition monitoring and diagnostics of machines using airborne and structure-borne ultrasound (A&SB ultrasound). A&SB ultrasound can be used to detect abnormal performance or machine anomalies. The anomalies which are detected are 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 or electrical discharges.

A&SB ultrasound is based on measuring the high-frequency sound that is generated by turbulent flow, by 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 A&SB ultrasound programme.

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Condition monitoring and diagnostics of machines — Ultrasound —

Part 1: General guidelines

1 Scope

This part of ISO 29821 outlines methods and requirements for carrying out condition monitoring and diagnostics of machines using airborne and structure-borne ultrasound. It provides measurement, data interpretation, and assessment criteria. This technique is typically carried out on operating machinery under a range of conditions and environments. This is a passive technique that detects acoustic anomalies produced by machines.

2 Normative references

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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.

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041 and the following apply.

3.1
airborne and structure-borne ultrasound
A&SB ultrasound
non-destructive test method used to inspect for airborne and structure-borne ultrasound above 20 kHz created from or through a medium

3.2
background noise
unwanted noise present in a signal which cannot be attributed to a specific cause

[ISO 13372:—[1], 5.2]

NOTE This ultrasonic noise can emanate from the area surrounding the inspection which can cause false indications.

3.3
scanning
moving a receiving transducer or an array of transducers around a suspected source of ultrasound to verify the location

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3.4
sonic reflection
airborne ultrasound reflected off a solid surface possibly indicating a false reading

3.5
stethoscope module
waveguide in the form of a rod that is coupled to a receiving transducer that receives ultrasounds by making physical contact with the subject and test equipment, for structure-borne ultrasounds

4 Principle of the airborne and structure-borne method

Airborne and structure-borne ultrasound is a physical wave that occurs within, or on the surface of, the test subject (material or machinery component) and is detected externally either close to or at a distance from the test subject. This technology is based on the detection of high-frequency sounds. Most ultrasonic instruments employed to monitor equipment detect frequencies above 20 kHz, which is above the range of human hearing (20 Hz to 20 kHz). The differences in the way low-frequency and high-frequency sounds travel helps to explain why this technology can be effective for condition monitoring. Low-frequency sounds maintain a high intensity of sound volume and travel further than high-frequency sounds. High-frequency sounds are more directional. As high-frequency sound waves propagate from the point of generation, their intensity level decreases rapidly with distance depending on the elasticity and density of the medium traversed, which helps to identify the origin of a sound source.

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 the structure, and is usually detected with a stethoscope (contact) module, although other sensors may be used. These stethoscope modules do not require any coupling agent, as the detection frequencies are low enough that, unlike traditional pulse-echo ultrasound, small air gaps between the contact probe and the structure under test do not significantly attenuate the received signal. If permanently mounted sensors are used, careful mounting techniques should be utilized to avoid signal attenuation or resonances, or both. The structure may be a machine or any component of a machine or a system.

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5 Applications of the ultrasound method

Airborne and structure-borne ultrasound can be applied to a wide range of applications of equipment or machinery. Any equipment or machinery that produces turbulent flow, ionization or friction produces ultrasound. Table 1 shows typical examples of ultrasound applications to machine condition monitoring.

6 Training requirements

When performing ultrasound inspections under less-than-ideal conditions with considerable background noise, the confidence in the information obtained is dependent upon the training and experience of the practitioner and the detection method applied. The skills and expertise of the practitioner performing the measurements and analysing the data are critical to the effective application of ultrasound[1)]. A skilled practitioner shall utilize the proper shielding techniques for minimizing the background ultrasound noise and incorporate methods and procedures that lead to reliable inspection results.

1) ISO 18436-8[5] will specify the requirements for qualification and assessment of personnel who perform machinery condition monitoring and diagnostics using ultrasound.

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Table 1 — Ultrasonic application examples

Machine description	Pressure or vacuum leak detection[a]	Mechanical[a]	Electrical[a]
Heat exchangers	AB	—	—
Boilers	AB	—	—
Condensers	AB	—	—
Control air systems	AB	—	—
Valves	SB	—	—
Steam traps	SB	—	—
Motors	—	SB	SB
Pumps	AB	SB	SB
Gears/gear boxes	—	SB	—
Fans	—	SB	—
Compressors	AB	SB	SB
Conveyors	—	SB	—
Switchgear	—	AB	AB
Transformers	—	SB	AB/SB
Insulators	—	—	AB
Junction boxes	—	—	SB
Circuit breaker	—	—	SB
Turbines	AB	SB	—
Generators (utility)	AB	SB	AB/SB
Lubrication	—	SB	—
High-speed bearings	—	SB	—
Low-speed bearings	—	SB	—

[a] AB: airborne; SB: structure borne.

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7 Ultrasound equipment

A&SB ultrasonic detection instrument systems are typically hand held, portable and battery operated for ease of use in the field. Online, non-portable systems are also utilized mainly for condition monitoring where an anomaly can occur and shall be addressed at the inception rather than when a route-based inspection is scheduled. Most online applications target a narrow range of applications where amplitude is the primary parameter that is monitored and false indications are less likely to occur. It is recommended that the system consist of an instrument, ultrasonic transducers, and headphones. It is highly recommended that the demodulated signal output be appraised through headphones to enable discrimination between competing sources. This allows the practitioner to recognize and prevent the acquisition of poor quality data. The system shall provide for the detection of acoustic energy that is either airborne or structure borne in the range above 20 kHz and shall translate (demodulate) this energy into an audible signal that can be seen on a signal strength indicator and heard through the headphones. The signal strength is usually displayed in decibels and commonly referred to as “decibel value”. The demodulated signal is representative of the amplitude and frequency characteristics of the original ultrasonic signal. The ultrasonic physical pressure wave or pressure variation which is received and measured by the ultrasound instrument is demodulated and converted to a corresponding level having the unit decibel (not standard definition); a sound pressure level, L_p, referenced to the threshold level of the A&SB ultrasound instrument where the mathematical expression is: L_p dB = 20 $\log_{10} r_a$, where r_a is the amplitude ratio.

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Currently, instrument sensitivity varies because each manufacturer establishes its own threshold level (0 dB) as there are no standards to uniformly define this threshold level. There are also different levels of sensitivity for different instruments produced by a single manufacturer. Most condition-monitoring applications of this technology are based on comparison or trending of signal strength readings over time, so care should be taken to use instruments that have the same sensitivity so that comparable data can be obtained.

The main housing contains ultrasonic transducers that receive the ultrasound signal and convert it to an amplified electrical signal. Next, this signal is fed into the main instrument where it is amplified again, then demodulated or heterodyned. The demodulation (heterodyne) principle is used to convert the ultrasonic frequencies down to the audible level suitable for humans to hear and for interfacing with recording and analysing devices. The same principle is used in AM radio broadcasting and reception. In the demodulation or heterodyne process, the audio signal is a direct translation of the original signal and this demodulated signal is used for further analysis (see Figure 1).

The demodulated signal allows the inspector to identify a relevant sound source and to determine the event or condition producing the ultrasound (e.g. air leaks in the same area as an electrical discharge can cause confusion to an unskilled inspector). The demodulated signal can also be used to determine the location of the irrelevant ultrasound that could lead to a false reading.

Therefore, the headphone output signal is not a “divided” signal where the audio frequency is multiplied by a number and ends up with the ultrasonic frequency. In the demodulation (heterodyne) process, the incoming ultrasonic signal is mixed with an internal oscillator signal and the difference is amplified and then sent to the headphone output and the meter circuit. A good analogy would be a piano key being struck once a second (1 Hz); the resultant sound would contain the resonant frequency of the string that the piano key is linked to, modulated by the 1 Hz of the key being struck. If the piano string signal (carrier frequency) were removed, what would be left is the 1 Hz signal (modulation frequency) of the key being depressed.

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The ultrasonic detection modules only detect high-frequency noise caused by friction or turbulent flow and do not respond to low-frequency acceleration, displacement or audible sounds. In the case of bearings, ultrasound is created by the motion of the rotating elements. As a bearing deteriorates, defects form on the rotating surfaces and when a rotating element interacts with the defect, it produces an acoustic event or fault indication. The actual fault frequencies of the affected bearing modulate the high-frequency components of the generated ultrasonic noise or signal. The signal after the demodulation would only leave the original modulation. For example, in a bearing, if the fault frequency is 48 Hz, the instrument detects the ultrasonic component that is modulated by the 48 Hz fault frequency. When that signal is demodulated, the audio signal at the headphones does not contain the ultrasonic signal, but contains the 48 Hz fault-frequency signal.

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In high-speed bearings, if one were to analyse the demodulated ultrasound signal with a spectral (FFT) analyser, and compare it to the signal from an accelerometer, the signals would be qualitatively similar. With low-speed bearings at speeds typically below 100 r/min, standard vibration accelerometers would have low signal strength due to the lack of enough energy to stimulate the piezoelectric sensing element with the calibration mass attached. For example, there are sensors currently used in mining operations to provide a signature from a 16,8 m diameter bearing operating at a speed less than 1 r/min for input from an ultrasonic detector into a portable FFT analyser for analysis and archival.

In addition to mechanical condition analysis, spectrum analysis of the heterodyned signals received from electrical discharges can help identify the severity of the condition, and can also help distinguish the difference between “loose” or 50 Hz to 60 Hz vibrating components such as a transformer winding and the actual electrical discharges.

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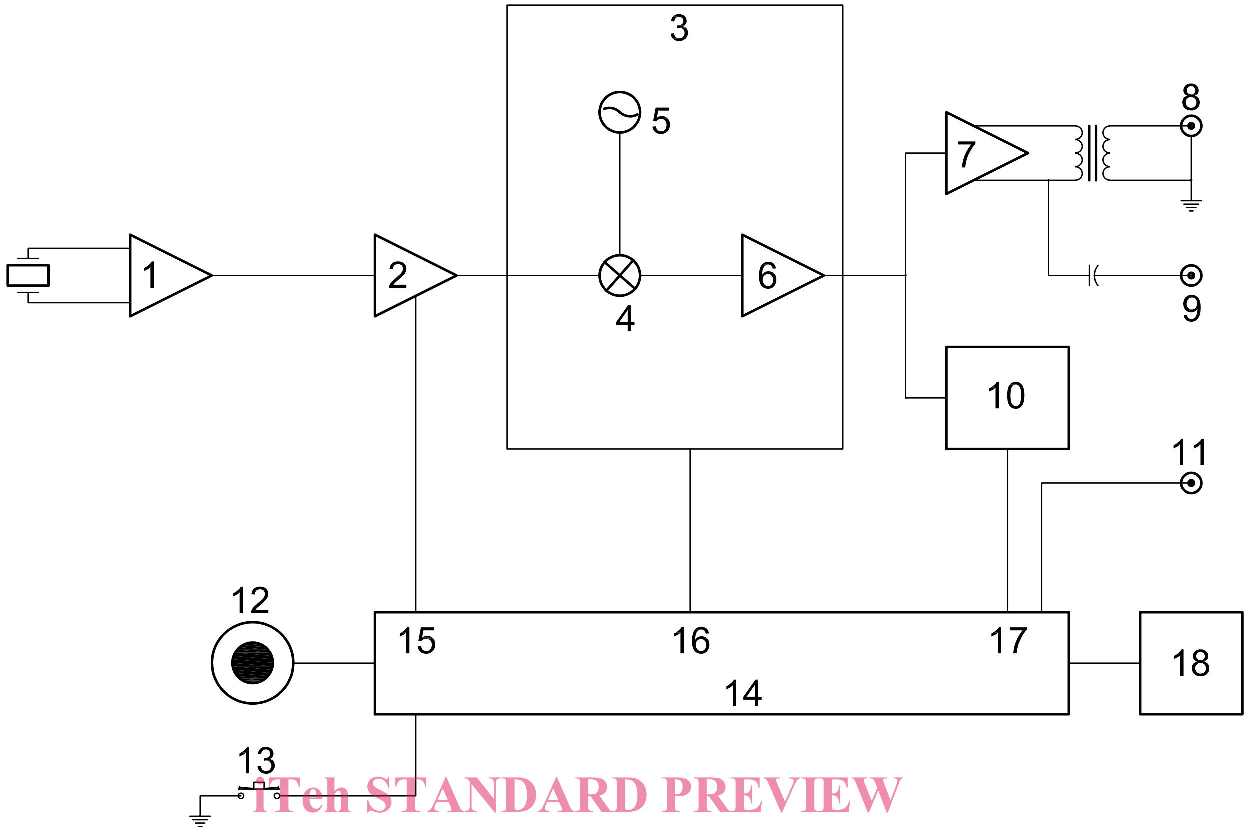

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Key

1 transducer preamp
2 variable gain amplifier
3 demodulation circuit
4 mixer
5 oscillator
6 low pass filter
7 audio amplifier
8 phone output
9 line output
10 RMS to DC converter
11 digital I/O
12 sensitivity/frequency adjustment knob
13 store button
14 CPU and digital controls
15 gain control
16 frequency control
17 converter input
18 display

Figure 1 — Block diagram example of an ultrasonic detector

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