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Condition monitoring and diagnostics of machines — Ultrasound — General guidelines, procedures and validation

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

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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 5, *Condition monitoring and diagnostics of machine systems*.

This first edition of ISO 29821 cancels and replaces ISO 29821-1:2011 and ISO 29821-2:2016, which has been technically revised.

Introduction

This document provides specific guidance on the interpretation of ultrasonic readings and wave files or frequency and time domain printouts (sometimes called “sound characteristics”) 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, impacts 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, impacts 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, impacts 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 — General guidelines, procedures and validation

1 Scope

This document

— gives guidelines for establishing severity assessment criteria for anomalies identified by airborne (AB) and structure-borne (SB) ultrasound,

— specifies 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 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 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 13381-1, *Condition monitoring and diagnostics of machines — Prognostics — 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 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 https://www.iso.org/obp

3.1
airborne and structure-borne ultrasound
AB&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

Note 1 to entry: 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

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

3.5
contact 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

4.1 General

Airborne and structure-borne ultrasound is a physical wave that occurs within the test subject (material or machinery component) or in the atmosphere 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 help 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 contact module, although other sensors may be used. These contact 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 can be a machine or any component of a machine or a system.

4.2 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. Table 1 shows typical examples of ultrasound applications to machine condition monitoring.

4.3 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.

Acoustic emission is the phenomenon of radiation of acoustic (elastic) waves in solids that occurs when a material undergoes irreversible changes in its internal structure. Acoustic emission is traditionally utilized to monitor items that are under stress for the formation and location of cracks. These include pressure vessels, pipelines. Many of the acoustic emission applications are similar to the structure-borne ones described in this document. Further information on acoustic emission can be located in ISO 22096.

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 and AB	SB
Switchgear	—	AB and SB	AB and SB
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 and AB	—
Low-speed bearings	—	SB and AB	—

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

5 Ultrasound equipment

5.1 General

AB&SB ultrasonic instruments 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 or heterodyne) 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 or heterodyned 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 ultrasonic instrument is demodulated and converted to a corresponding level having the unit decibel (not standard definition); a sound pressure level, L_p, is referenced to the threshold level of the AB&SB ultrasonic instrument, where the mathematical expression is L_p dB = 20 $\log_{10} r_\mathrm{a}$, where r_a is the amplitude ratio.

Currently, instrument sensitivity can vary between different manufacturers. Each manufacturer establishes its own threshold level (0 dB) as there are no standards to uniformly define this threshold level. There can even be different levels of sensitivity for different instruments produced by a single manufacturer. If a condition monitoring application requires a comparison or trending of signal strength readings over time, care should be taken to use instruments that have the same sensitivity so that comparable data can be obtained. When making comparisons between instrument readings, the dB readings shall be of the same type.

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 or heterodyne principle is used to convert the non-audible 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).

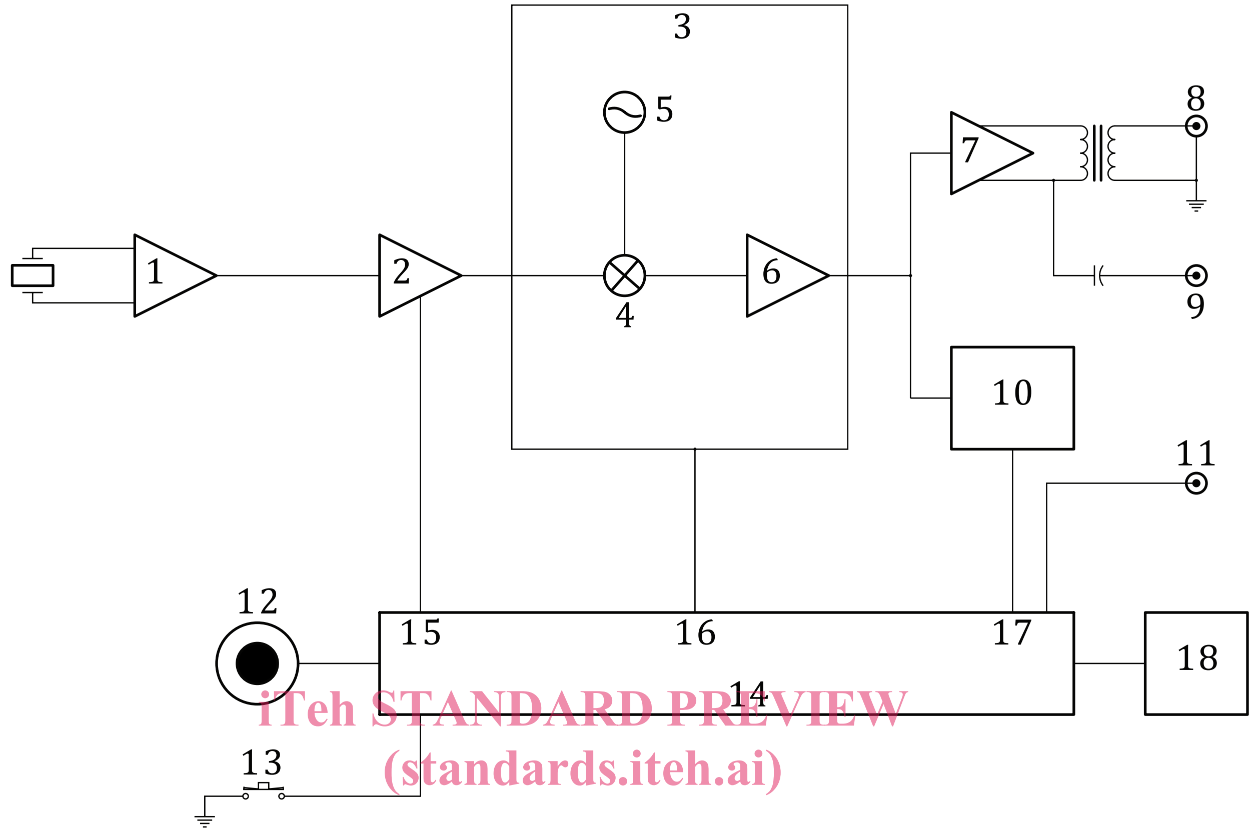
The demodulated or heterodyned signal allows the inspector to identify a relevant sound source and to determine the event or condition producing the ultrasound (e.g. air leaks in the same area as an electrical discharge can cause confusion to an unskilled inspector). The demodulated signal can also be 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.

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 or heterodyning 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 or heterodyned, the audio signal at the headphones does not contain the ultrasonic signal, but contains the 48 Hz fault frequency signal.

In high-speed bearings, if one were to analyse the demodulated or heterodyned 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 10 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 ultrasonic 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, signal 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.



Key

1 transducer pre-amp
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

5.2 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 Table 1.

5.3 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 overhead piping or in determining which phase in a high-voltage electrical tower has an electrical discharge.

5.4 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 hand-held contact, magnetically coupled or permanently installed (threaded) 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 inspection 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.

5.5 Instrument characteristics

5.5.1 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 manufacturers recommend that 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.

5.5.2 Frequency response

If using an airborne or structure-borne ultrasonic instrument with heterodyned (demodulated) frequency tuning capability, the inspector should be aware that there are certain monitoring frequencies that enhance the data that are 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 2.

Table 2 — 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

