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Condition monitoring and diagnostics of machines — Ultrasound — General guidelines, procedures and 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 voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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 $\log_{10} r_a$, 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).

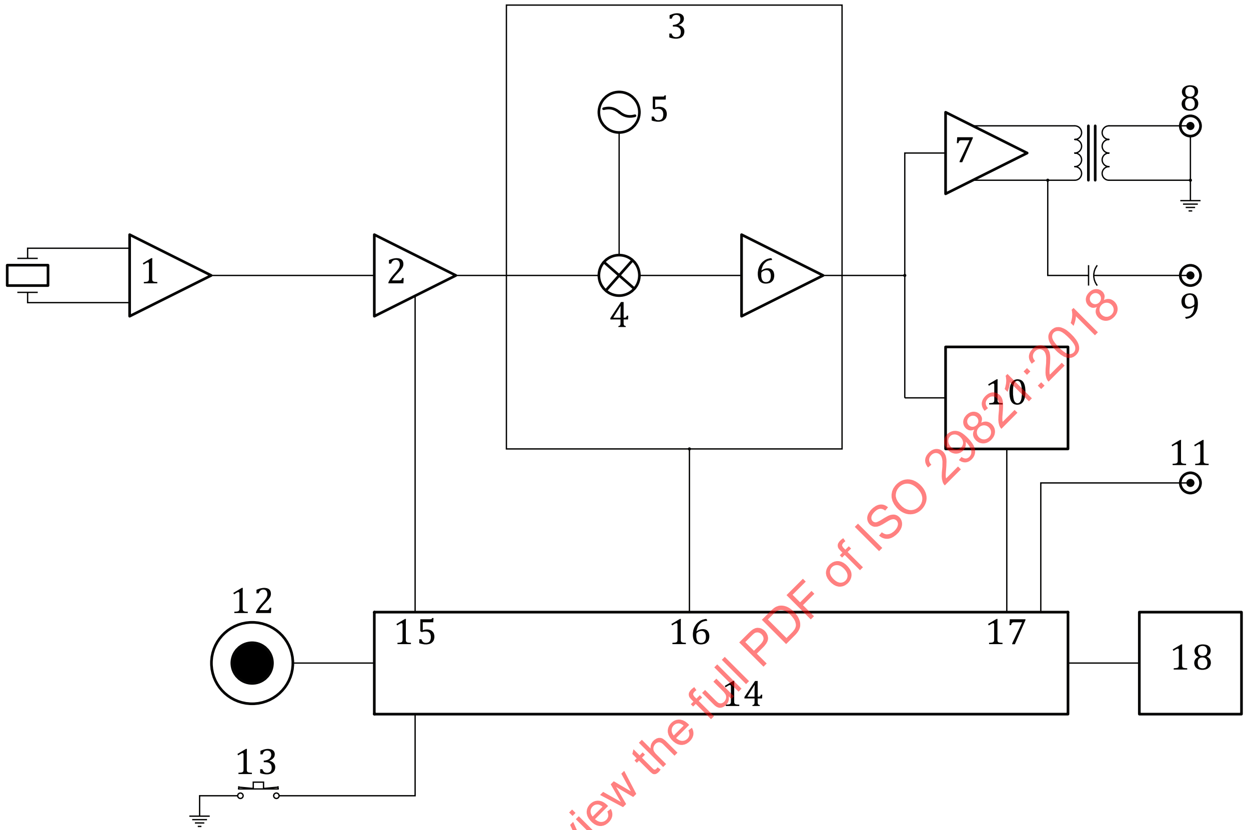
The demodulated or heterodyned signal allows the inspector to identify a relevant sound source and to determine the event or condition producing the ultrasound (e.g. air leaks in the same area as an electrical discharge can cause confusion to an unskilled inspector). The demodulated signal can also be 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	10	RMS-to-DC converter
2	variable gain amplifier	11	digital I/O
3	demodulation circuit	12	sensitivity/frequency adjustment knob
4	mixer	13	store button
5	oscillator	14	CPU and digital controls
6	low-pass filter	15	gain control
7	audio amplifier	16	frequency control
8	phone output	17	converter input
9	line output	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

6 Data collection guidelines

6.1 General

Several techniques are recognized and in use throughout the industry to collect data. With the most recent advances, ultrasonic detectors have become much more sophisticated and have evolved from subjective listening devices with hand-written data to systems that can store test data, record sound samples, and analyse the data through data management software and the recorded sound samples with signal analysis software. These new instruments provide the capability to identify changes in condition of monitored equipment and to determine any further action to be taken.

It is necessary that each of these ultrasound techniques be used as part of a condition-monitoring process when such a process is implemented in accordance with ISO 17359. Ultrasound shall also be used as a primary or secondary technique for diagnosis and prognosis when these processes are carried out in accordance with ISO 13379-1 and ISO 13381-1, respectively.

6.2 Comparative ultrasound

When starting an inspection route for the first time, it is important to be able to identify anomalies, especially those that can be in a failure state. The most common technique is to use the comparative method. It is the best method to use when there are no established baselines set and a series of points on a machine needs to be assessed with no previous assessment criteria. As with all technologies, the confidence level of the information obtained is dependent on the detection method applied, equipment used, and training and experience of the inspector.

Comparative ultrasound can be either *quantitative* or *qualitative*. The quantitative method is the most often used method for many ultrasound applications. This method uses the strength of the signal, expressed in decibels (commonly called "decibel value"), to determine the severity of a component's condition. As indicated in Table 3, depending upon the fault type, the 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. The resultant decibel value is compared to that of a similar component or the baseline of the original component.

Many applications do not require quantitative data to monitor the condition of components of a machine. In the case of compressed air leaks and electrical discharges, qualitative techniques are usually the preferred methods, as these conditions do not produce ultrasound if they do not exist.

A typical example of the qualitative technique is where there are multiple electrical components operating at the same voltage under the same load and where one component is discharging, producing an ultrasonic signal. This is usually an indication of a deteriorating condition. In this instance, an evaluation of the demodulated or heterodyned sound pattern would be a better indicator of severity than change in signal level (decibel value). The sound analysis provides information that identifies the type and severity of the condition. This is where qualitative measurements can help locate the source of the ultrasound emission by the increase in the signal level and the sound characteristic indicates the degree of severity. The severity criteria can be learned in formal training as per ISO 18436-8.

Each application requires an organization or a qualified practitioner to establish their own set of criteria for degradation levels. As an example, a compressed air leak from a supply line that has an extremely low decibel value might not require repair, while a larger leak with a high decibel value would require repair. A detectable air leak at 1×10^{-2} cm^3/s might not justify repair, while a leak at 100 cm^3/s would. In pneumatic control applications, no detectible leak is acceptable.

6.3 Baseline method — Quantitative ultrasound

The most common structure-borne ultrasound method in use for condition monitoring is the baseline or quantitative method. This is important when critical plant components are monitored on a routine basis for diagnostic reference. When subsequent inspections or surveys indicate an increase in the decibel value or a change in sound characteristics, these baselines can be used for a comparison. This is useful to identify deteriorating conditions before they require any major maintenance or become catastrophic. The baseline method can include decibel value and baseline sound samples. The advantage of a baseline sound sample is the ability to review and analyse any changes in the subject equipment based on spectral and or time series views that might not be apparent with just a decibel value. The selection of a measurement as a baseline should only be conducted by a qualified person.

Several techniques are recognized and in use throughout the industry to collect data. As indicated in Table 3, 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 analysing 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 2 and 3.

Figure 2 — Example of airborne ultrasound monitoring

Figure 3 — Example of structure-borne ultrasound monitoring

7 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.

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

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.

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.

8 Assessment criteria

8.1 General

The most common form of severity criterion is the use of a signal level differential (delta dB).

To apply ultrasound inspection to the condition monitoring of machines and their components, severity criteria should be established by a competent practitioner, their company, client, or a third party. It is common practice that these criteria are established through experience and the accumulation of data on specific machines or components. Since there are many applications of ultrasound that differ in the way data are evaluated, there are currently no universally accepted severity criteria in the industry.

Therefore, each category of equipment and its application should have severity criteria established based on its design, operating conditions, baseline condition, maintenance and criticality.

These severity criteria are usually based on historical data showing an increase in decibel value (quantitative baseline method) or another post-process parameter. This can help establish a rate of deterioration and help establish when corrective action is taken to prolong component life. This can apply to applications that would use an increase of the decibel value as a criterion, such as on bearing lubrication levels where the corrective action would be to lubricate the bearing to reduce the ultrasonic decibel value. Other examples of severity criteria are:

— elevated ultrasonic signals along with information from signal analysis of electrical components, which could cause machinery shutdown;

— decibel value increases in compressed air system leaks, which could cause machine performance degradation or high energy costs.

As multiple measurements are taken over time on the same piece of equipment under the same operating conditions, the recorded data can be used to set parameters for trending and aid in the prediction of the failure of this component.

An example of severity criteria based on increased decibel value above an established reference or baseline for high speed bearings of rotating equipment is as follows.

— *Pre-failure stage — 8 dB*: This is the earliest stage of failure. The bearings might have developed hairline cracks or microscopic spots that are not visible to the human eye. This might also signal a need to lubricate the bearing.

— *Failure stage — 16 dB*: At this stage, visible flaws develop along with a marked rise in acoustic energy. It is at this stage that the bearings should be replaced or more frequent monitoring should occur.

— *Catastrophic stage — catastrophic failure — 35 dB to 50 dB*: Here, rapid failure is imminent. The acoustic sound level is so intense as to be audible and the temperature of the bearings might rise enough to be measurable. This is a highly dangerous stage since changes in the bearing clearances and tolerances can cause additional friction and rubbing within the machine, potentially damaging other components.

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. Examples of typical fault types and assessment criteria are shown in Table 3, as well as established industry standards and practices and manufacturers' guidelines.

Table 3 — Typical fault types and assessment criteria

Machine description	Fault type	Assessment criteria	
		Change in signal strength (decibel value)	Signal analysis
Heat exchangers	Leak	Yes	No
Boilers	Leak	Yes	No
Condensers	Leak	Yes	No
Control air systems	Leak	Yes	No
Pressurized gas systems	Leak	Yes	No

Table 3 *(continued)*

Machine description	Fault type	Assessment criteria	
		Change in signal strength (decibel value)	Signal analysis
Valves	Leak, blocked, cavitation, flashing	Yes	Yes
Steam traps	Leak, blocked, cavitation, flashing	Yes	Yes
Motors	Mechanical or electrical failure, or both	Yes	Yes
Pumps	Mechanical failure leaks, cavitation	Yes	Yes
Gears/gear boxes	Mechanical failure	Yes	Yes
Fans	Mechanical failure	Yes	Yes
Compressors	Mechanical failure	Yes	Yes
Conveyors	Mechanical failure	Yes	Yes
Switchgear	Electrical discharge, mechanical failure	Yes	Yes
Transformers	Electrical discharge, mechanical failure, leaks	Yes	Yes
Insulators	Electrical discharge	Yes	Yes
Junction boxes	Electrical discharge	Yes	Yes
Circuit breaker	Electrical discharge, leaks	Yes	Yes
Turbines	Mechanical failure, leaks	No	Yes
Generators (utility)	Mechanical failure, electrical discharge, leaks	Yes	Yes
Lubrication	Mechanical failure	Yes	Yes
High-speed bearings	Mechanical failure	Yes	Yes
Low-speed bearings	Mechanical failure	Yes	Yes

8.2 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 ultrasound from other sources such as sonic 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.

Where decibel alarm or sound interpretation criteria are used, all instrument settings should be correctly determined in accordance with 5.5.2 if that type of instrument is used. 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 this document as well as established industry standards and practices and manufacturers' guidelines.

As required, 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.

9 Interpretation guidelines

For a given machine, interpretation of ultrasonic readings and sound characteristics is a process of comparing these data against those that are representative of the ideal design and manufacture, installation, operation and maintenance criteria if available. 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 inspection 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 can 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.

10 Diagnosing ultrasonic problems

10.1 Principles of diagnostics using ultrasound

Diagnosing machine systems using ultrasound is not generally rule-based. Diagnostics, therefore, require a principle-based approach where analysts use a 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.

10.2 Generation of ultrasound

10.2.1 Surface friction

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

10.2.2 Fluid flow

Ultrasound can 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.

10.2.3 Ionization

Ultrasound can 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 in the surrounding gas generating ultrasound.

10.2.4 Impacting

Ultrasound can be generated when, for example, two objects come in contact with each other or a rotating object comes in contact with a fault or void in a surface.

11 Sensitivity validation guidelines

Ultrasound inspectors shall verify the sensitivity of their instruments on a regular basis and shall have them calibrated to the manufacturer's specifications. One common sensitivity validation method is described in ASTM E1002[3] where a calibrated reference ultrasonic source is used. It is recommended that a sensitivity validation procedure be performed prior to each inspection or survey. A quick sensitivity check can be made by using the detection of a human eye blink as a low level signal for airborne sensors and the detection of the signal from a quartz watch crystal in a wristwatch for structure-borne sensors. An example of another sensitivity validation is presented in Annex C.

12 Monitoring interval

Monitoring intervals can be established based on severity criteria, such as the expected rise in decibel value over time that is representative of a fault condition or an ultrasonic pattern anomaly. Examples of monitoring interval schedules are as follows.

— *Monthly* — if the loss of a component or system would shut down an operation.

— *Every other month* — if there is a back-up component or system in case one component or system fails.

— *Quarterly* — if the operation could continue to operate without the component or system if it were to fail.

13 Data interpretations

When the ultrasonic instrument detects deviations from baseline or previous readings, these variations shall be noted; the decibel value data and demodulated or heterodyned ultrasound anomalies should be recorded and analysed for severity and subsequent corrective actions. The use of spectrum and time characteristics analysis is very helpful not only to determine the severity of the anomaly, but also to provide a way of reporting the condition of the item under evaluation as a “sound characteristic”. Examples of typical fault types and assessment criteria are shown in Table 3.

If the initial evaluation of the anomaly is not conclusive, further action is required, such as the evaluation of the anomaly with alternate methods suitable for the diagnosis and subsequent corrective action. These technologies could be acoustic emission, infrared imaging, vibration analysis, motor current analysis and oil analysis.

14 Reporting

Reporting of the ultrasound data can be in the form of either a graph or chart to show the trend of the decibel value increase over time for those applications where trending is appropriate. Those applications that are qualitative, and where a change in decibel value is not indicative of a failure, can be reported as an image of the spectrum or time waveform, or both, of a recorded audio file of the anomaly. Only trained personnel should write reports. Typical examples of ultrasonic test reports are shown in Annex B.

Annex A
(informative)

Example of a compressed air leak survey

A.1 Compressed air procedure

In order to create a successful compressed air leak survey, there should be a planned, organized approach. The first thing to consider is what is to be accomplished with the survey. Is it going to be a one-time investment or a part of an on-going programme? Is the goal of the survey to reduce energy costs or improve production or both?

If the goal is to introduce an on-going programme, it is necessary to set up a workable schedule. This can vary from once a month to once a year. Often, an audit or compressed air review is used to determine whether there is a need for additional compressed air equipment. The audit can help to determine whether the use of compressed air has increased due to expanded production or equipment requirements, or if it has increased because of air loss.

Other considerations are: what alternative utilities are available to perform the task (e.g. when electric controllers can be used in place of compressed air), what types of compressors are being used, and do the compressors have variable speed drives? Also, are there alternative compressor types that can be more economical?

Of considerable importance is to consider what is to be done to educate employees about the effective use of compressed air. They need to know that wasted air is not free; it affects everybody. When waste hits the bottom line, it has an impact on the profitability of a company.

Before beginning the survey, create a plan. Here are some suggestions.

a) Limit the leak test area to a manageable size. Do not be overly ambitious. Walk the plant section by section to determine the strategy to consider where the survey starts and plan the route. It is recommended the survey be started at the compressor area and move out from there.

b) Walk through the plant section by section.

    1) Pay attention to and note air-waste practices.

    2) Note the location of obvious leaks.

    3) Note potential safety hazards.

    4) Determine what equipment is needed such as flashlights, ladders, etc.

c) Select the inspection equipment. Are specialized modules needed, e.g. a parabolic microphone for high or hard-to-reach areas, or is the standard scanner sufficient?

d) Set up a leak identification or tag system. Use tags and hangers that can be placed on leaks. The tags should have numbers or codes that are used in the record keeping.

e) Consider how to report the results. Take a digital photograph of the leaks with the tags attached. If it is required to report cost savings, perform a cost analysis using software that produces the cost justification for repairs.

f) Be sure to install a system of leak reporting and follow-up to be sure the leaks are repaired. When the survey is completed and the repairs are finished, retest to be sure the leaks have been repaired properly and that no new leaks were created during the repair.

g) If leaks have been present for a long time before the survey, it is likely that the pressure in various parts of the plant has been increased over time. Recheck those areas and bring the pressure down to the appropriate level.

A.2 Instrument set-up

a) Analogue:

1) plug in headphone;

2) check batteries and replace, if necessary;

3) perform sensitivity validation;

4) set instrument to peak frequency response if that type of ultrasonic instrument is used.

b) Digital:

1) be sure the memory is cleared and is sufficient for the survey;

2) perform sensitivity validation;

3) set frequency to the peak response if that type of ultrasonic instrument is used;

4) check battery level.

A.3 Test equipment

a) Suggested equipment to bring:

1) writing pad and pen/clipboard;

2) flashlight;

3) wipe rag;

4) tags and hangers;

5) marker pen;

6) digital camera.

b) Suggested accessories:

1) parabolic microphone;

2) rubber focusing probe.

A.4 Inspection

a) Safety:

1) be aware of and observe all safety procedures;

2) wear appropriate clothing and other protective gear, as required;

3) follow all confined space procedures when entering such conditions.

b) Pre-inspection:

1) walk the test area, use piping diagram or take digital photos of piping and components — if using a digital camera, take long-range and close-up photos;

2) during walk-through:

i) plan the scan strategies;

ii) note air wasting activities such as abuse, open valves, etc.;

iii) note and tag obvious leaks;

iv) take a note of any additional items that might be needed for an efficient test such as a hi-low or ladder, keys to open locked cabinets (observe lockout-tag out procedures, if called for).

c) Test procedure:

1) test one area at a time in the planned route;

2) use shielding methods when confronted with competing ultrasound;

3) confirm the leak location by:

i) scanning around the suspect leak area in all directions (360°);

ii) sealing the rubber focusing probe against the leak area.

d) Tag the leak.

e) Take digital photos of the leak with a tag.

f) Perform compressed air loss analysis.

g) Enter data into an electronic report.

h) Create work order and attach photo (close-up of leak site) to work order.

A.5 Post-inspection

a) Verify that the repairs have been completed.

b) Retest repaired leaks.

c) Update report with repaired leaks entered.

d) Issue report showing

1) number of leaks found, and

2) number of leaks repaired.

e) Assess compressed air lost or compressed air saved.

f) Issue survey to assess the economic savings potential — if a before and after log of compressor run time is taken, a good assessment of economic gains can be obtained from the survey.

g) Provide recommendations.

h) Schedule future surveys.

Annex B
(informative)

Typical examples of ultrasound test reports

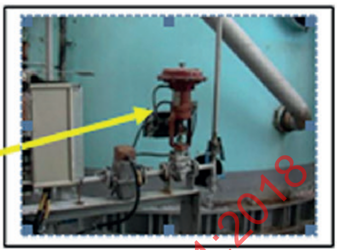
An example of an analogue instrument report is given in Figure B.1.

Test Room Report

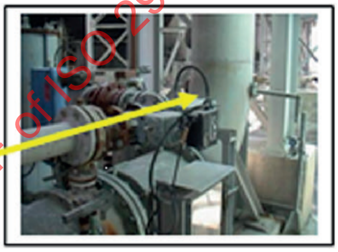
Fault Report – Description and Photo

Return this report with Fault Repaired tear-off tag to Ultrasonic Department for re-testing

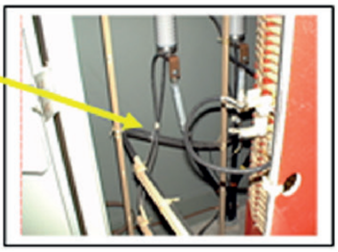
Report No: 1	Photo No:	1dB: 40	Freq: 40	LI: 2
Function Location: 785-FCV-1026				
Plant Location: Ground floor adj to d1 tower				
Equipment: Air controlled Valve				
Fault Description: Air leak at positioner				
Comments: Another positioner leaking a lot of air				



Report No: 2	Photo No: 2	dB: 37	Freq: 40	LI: 1
Function Location: 785-FCV-0032				
Plant Location: Ground floor adj to Motor 785-1096				
Equipment: Air controlled valve				
Fault Description: Air leak at positioner				
Comments:				



Report No: 3	Photo No: 65	dB: 48	Freq: 40	LE: 3
Function Location: 495-OC-2345				
Plant Location: Office Complex Ground Floor				
Equipment: 13.6 Switchgear				
Fault Description: Arcing Phase to Phase				
Comments: REPAIRED IMMEDIATELY BY PLANT ELECTRICIAN				



Report No: 4	Photo No: 37	dB: NA	Freq: 20	LI:
Function Location: 785-fCV-2556				
Plant Location: Ground Floor adj to T1 Autoclave				
Equipment: Steam Trap				
Fault Description: Blowing Live Steam				
Comments: REPLACE				

Ultrasonics – for Air, Gas Steam & Electrical Problems

Document1

Figure B.1 — Analogue instrument report example

Reporting of the ultrasound data is typically in the form of a graph or chart to show the trend of the signal level increase, in decibels, over time for those applications where trending is appropriate. Those applications that are qualitative, and where signal level value change is not indicative of a failure, can be reported as an image of the FFT spectrum or time series or both of a recorded audio file of the anomaly.

Figure B.1 shows what a typical analogue instrument report would look like when there is an anomaly found and the only way to document the finding is an image with a description of the anomaly.