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Sound Intensity Fundamentals

Introduction

This little introduction to the noble art of sound intensity measurements describes a modus operandi applicable to all types of stationary machinery and radiating surfaces. The procedures described may be used in any environment in which sound intensity can be accurately measured.

No restrictions exist on source size. The radiated sound may be pure tone, narrow band or broad band. The description applies to steady as well as quasi-steady impulsive noise.

Sound Power Measurements, a Little Theory

Sound intensity is the rate of flow of acoustic energy per unit area in a given direction. Total sound power can be computed by adding the net power contribution from each portion of the measurement surface, assuming that the measurement surface surrounds the noise source.

Intensity is actually composed of two components: active and reactive intensity. Active intensity represents the net flow of energy. Reactive intensity, on the other hand, is the acoustic energy stored in an acoustic medium, yet causing no energy to flow. Such an environment exists in a reverberant room or a wave tube. Because of the hard walls and high reflection coefficients, the sound pressure can be quite high, as very little acoustic energy is absorbed by the walls or transmitted from the room.

Sound Pressure vs. Sound Power

The sound pressure measured by a microphone depends on the sound power of the source, its radiation pattern, the distance from the source as well as the acoustical effects of the surrounding objects and area surfaces. Given the sound pressure at one location, it is not a simple matter to calculate the levels in other locations.

The sound power level, however, is an inherent property of the source and mostly independent of external factors, so once the sound power has been established the resultant sound pressure level when installed in different locations can be calculated.

The Intensity Advantage

Traditionally the measurement of sound power involved expensive anechoic or fully reverberant test rooms. The sound intensity probe - together with suitable instrumentation - allows you to measure the sound power as derived from the measurement of sound intensity on a surface enclosing the source. It is then assumed that the source absorbs no acoustic energy from the sound field. This is fulfilled in most cases where the materials the source is composed of are highly acoustically reflective. It can be shown that the influence from sources outside the measurement surface then can be excluded.

Sound power, W, has units of watt (W), but it is usually expressed in the decibel domain, as the sound power level, L_W, using a reference of 1 pW (10^{-12} W).

$$\mathbf{L_w = 10Log10\ (W/W_0)}$$

where $W_0 = 10^{-12}$ watt and W = total acoustic power.

ISO 9296 requires documentation of acoustic power rating in units of bel (B) rather than decibel (dB) to distinguish sound power levels from sound pressure levels. One bel is equal to ten decibel. The reference is still 1 pW.

$$\mathbf{L_{WBel} = log10(W/W_0)}$$

The unit of sound intensity is W/m^2, so the power W_k through an area A_k can be calculated as the product of the area and the mean sound intensity for the area (the intensity perpendicular to the surface).

$$\mathbf{W_k = A_k \cdot I_k}$$

The total sound power from a source can then be found by summation:

$$\mathbf{W_{Sum} = Sum_k\ (A_k \cdot I_k)}$$

Determining the Sound Intensity

The sound intensity can be determined from the sound intensity level by using the equation:

$$\mathbf{I = \pm I_0 \cdot 10^{(L_I/10)}}$$

in which I_0 = the sound intensity, weighted or in a specified fre-quency band
L_I = the sound intensity level in decibels (re: 1pW/m^2)
I_0 = 1pW/m^2

Intensity in the direction from the source is regarded as positive intensity and towards the source as negative.

Reproducibility Test

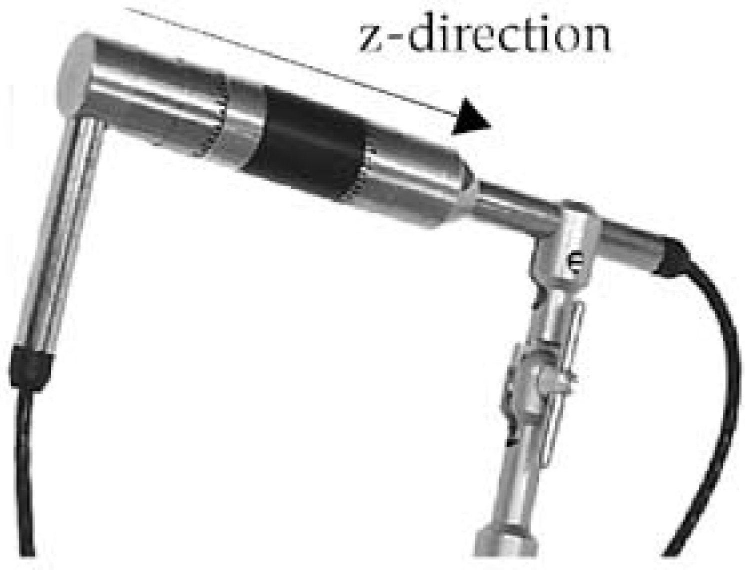
The following measurement procedure is recommended. Further details can be found in ISO 9614-1, which we recommend that you read through before you start making sound intensity measurements.

1. Select a facility that matches the requirements of the test
2. Place the device on an acoustically rigid stand
3. Define a measurement surface, usually a hemispherically or box-shaped surface, surrounding the device and terminated by a reflecting plane (floor). Choose your measurement positions
4. Calibrate microphones and do a field check to confirm the acceptability of the measurement environment
5. Measure pressure and intensity at each position
6. Verify that the number of measurement positions is sufficient
7. Compute total sound power
8. Document results.

The software package Nor-9614 together with the Real Time Analyser Nor-840 and the Sound Intensity Probe Nor-240 constitute a powerful set of tools for this application. The program guides you through the measurements from defining the measurement surface through calibration and measurement to the documentation as required by the ISO 9614-1.

The Instrumentation

The reference point of a sound intensity probe is at the centre between the two microphone diaphragms on the centre line between the microphones (z-axis). The reference direction is along the z-axis, and from channel 1 to 2.



The inherent noise of the Norsonic intensity microphones is below 21dBA. The maximum SPL peak is approximately 150dB. The probe is designed to measure SPL from 27dBA (7dB signal-to-noise) to 154dB and sound intensity over the same range. The IEC 61043 define the requirements to a sound intensity measurement system.

Test Environment

Even though anechoic chambers are not required for sound intensity measurements, care should be taken to avoid test environments violating the assumptions of sound power calculated from intensity. For example, some noise external to the device under test is acceptable unless it is intermittent. Also, if intensity is being measured in a reactive environment such as a shop floor with hard walls and ceiling, the dynamic capability of the instrumentation must be compared to the measured pressure-intensity index using the following procedure:

1. Determine L_{RPI}, the residual pressure-intensity index for the probe and analyser measurement system, by calibrating the sound intensity system using a Nor-1254 sound intensity calibrator.
2. Measure pressure-intensity index L_{PI} averaged over the measurement surface with the device turned on
3. Check that the difference between L_{PI} and L_{RPI} is at least 7 dB for all frequencies of interest for this test environment. Outdoor measurements of intensity often yields better results due to the less reactive environments. However, other acoustics problems must be taken into account, such as intermittent noise problems like aircraft flyovers and local traffic. These can cause obvious errors. Outdoor measurements can also be affected by wind noise. Generally, windscreens should be used only if necessary (note that ventilation airflow may bias your measured low frequency values). A correction of +0.5 dB should be added to the measured sound power level, when windscreen is used or the calibration should be shifted accordingly.

Physical Site

Any physical site at which the ambient conditions permit accurate measurement of sound intensity may be used. However, the following should be observed:

- A major advantage gained in using sound intensity measurements to determine sound power is the ability to test the equipment being measured on site, i.e. in its own physical operating environment. It is not necessary to isolate the equipment on a specially controlled site such as a reverberation chamber, anechoic chamber, etc.
- The tester should be aware that the actual sound power output of certain kinds of noise sources may depend on the acoustical properties of the physical site. For this reason, in situ testing is encouraged.

Ambient Conditions

Ambient conditions that affect the sound generation and radiation characteristics of the source, the propagation of noise between the source and receiver, or the measurement accuracy shall be measured and controlled within appropriate limits. Significant factors may include:

- Background noise and variation in background noise including the noise equipment required to support the operation of the source under test
- Wind speed and wind gradients
- Temperature and temperature gradients
- Relative humidity
- Barometric pressure.

In connection with this the following should be observed:

- A significant advantage of using sound intensity to determine sound power is that this approach is two orders of magnitude less sensitive to contamination by ambient noise than methods based on sound pressure measurements.
- The effects of ambient conditions on sound propagation can be minimised by making the required sound intensity measurements in the near field of the source.

Measuring Power in the Presence of Noise

An advantage of using intensity instead of pressure to measure total sound power is that steady external noise sources do not contaminate the intensity measurement. This is because intensity is a vector quantity. When the contribution to an external noise source is positive on one surface, it will be negative on the opposite side. This results in a net power of zero from the surface.

The external noise source must be steady, otherwise errors will occur when the net power is summed. This is because the intensity due to noise into one side of the measurement surface might not be equal to the intensity out of the other side - if measurements are done at different times, and the external noise source is intermittent or different between the two measurements.

Measurement and Data Reduction

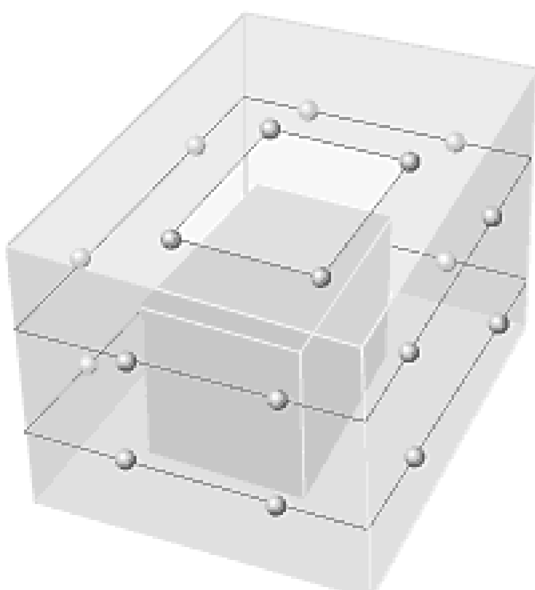
Subject to the following, any surface that completely encloses the noise source under test can be used as the measurement surface:

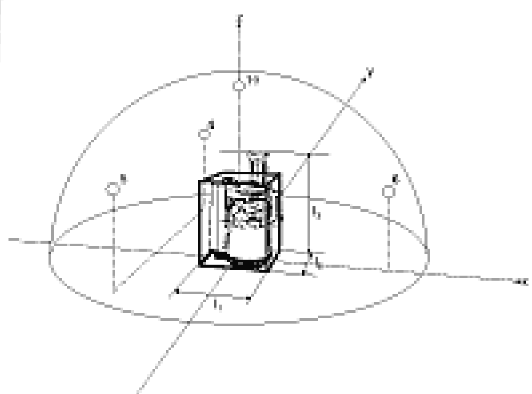
- The selected surface must have a well-defined area that can be measured accurately. The intensity shall always be measured perpendicular to the area element.
- There must be no extraneous acoustic absorption anywhere within the measurement surface.

Note: There is no explicit limit on the maximum size of the measurement surface, but the surface must not become so large that sound absorbed by the acoustic medium is significant.

Depending on the complexity of the source and the location, an imaginary hemisphere or a number of plane areas may be used as measurement surfaces. Whenever possible, the hemisphere is recommended because of simplicity and accuracy. In general, one should choose a radius equal to the largest dimension of the measurement object.

The use of a box type surface may be valuable. Attention should always be paid to the spacing between the measurement point used and the acoustic centre of the stronger power sources of the sound source under measurement.





The distance to the nearest background noise source outside the measurement area should also be taken into account. Any errors - in % of distance - in positioning the centre of the intensity probe relation to the sources will typically give the double errors, in %, of the measured intensity. Therefore, in order to obtain results within ±1dB, the most critical distances should be controlled to within ±10%.

For this reason, point measurements are often recommended instead of scanning where proper control of probe positioning is difficult to maintain. In order to control that a sufficient number of points are used, we recommend that you repeat a given measurement, using twice as many points.

When the reproducibility is better than 0.3 dB, the lower number of points in the two reproducible measurements may be chosen for repeated measurements on the same type of sources in the same environment.

The use of points is an advantage for time averaging. The space averaging may be evaluated afterwards. Scanning may yield better space averaging, but cause problems due to time varying signals and lack of documentation for the effect of the time variance. The reproducibility test should be reported, when carried out.

Test Report

The test report should be documented as required in the ISO 9614 and shall not be repeated here. We strongly recommend that you get yourself a copy of the Standard!

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