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Determination of Sound Power Levels of Air Terminal Units Using Sound Intensity

Nordtest Project 1024-91

Abstract

Determination of sound power levels of air terminal units using sound intensity

The sound intensity technique has been tested on sound power measurements on air terminal units under laboratory conditions. It is shown that the agreement with traditional measurements based on sound pressure is excellent. The sound power levels, determined by the intensity technique, fall within the frame of the uncertainty values given in ISO 5135.

A Nordtest method is proposed. In this method the sound intensity is determined by scanning or by averaging over a number of discrete positions over a closed measurement surface about 0,5 m from the test object. The preferred measurement surface for small units is a hemisphere. For large units it is a box shaped surface.

The method has been tested by three laboratories, each carrying out measurements on two test objects, one air terminal unit and one damper, both with the diameter 250 mm, by both the intensity technique and the traditional sound pressure technique.

Key words: sound power, sound intensity, measurement, air terminal

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Preface

This project has been financed by Nordtest, project 1024-92. The project has been carried through by a project group consisting of

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The project group has had two meetings.

Thank you for all your help!

Hans Jonasson

1 Introduction

1.1 Background

Sound power measurements on air terminal devices and similar equipment are carried out in reverberation rooms according to ISO 5135, [1]. These rooms are laboratory rooms and must not be larger than 300 m³ for measurements at frequencies larger than 3000 Hz. Many manufacturers for large pieces of ventilation equipment have much larger rooms. There is no method for in situ measurements either. Such methods would also be of interest for ventilation laboratories not specialized in acoustic testing.

The rather recently developed methods for sound intensity measurements, such as [2] and [3], should be suitable for the testing of air terminal and similar devices. However, because of the special problems involved supplementary specifications concerning measurement distance, measurement surface and acceptable air flow speeds are desirable.

1.2 Aim

The aim of this project is to propose a Nordtest method for the determination of the sound power level of air terminal and similar devices using sound intensity. In addition a limited Round-Robin shall be carried out to prove the validity of the new test method in relation to the traditional ISO 5135 method.

1.3 Carrying out

This project is coordinated with Nordtest project 968-91 which deals with Round-Robin measurements on air terminal devices according to ISO 5135, see [4]. Both projects have the same project group.

This project was first discussed at a project group meeting of NT 968-91. Preliminary measurements were carried out at SP and a first draft method was written and sent to the project group for comments. After that a new version was circulated together with the test objects and the measurements were carried out. The result was discussed together with the test report at a final project group meeting. Only editorial changes of the proposal for Nordtest method were made.

2 Considerations and preliminary measurements

2.1 General

A problem with sound intensity measurements on air terminal devices and similar equipment is the air flow. Intensity measurements are normally carried out close to the test object and sound intensity probes are much more sensitive to turbulence and flow than normal pressure microphones. In addition the sound power levels to be determined are often rather low.

In ISO 9614-1, [2], the problems with flow is discussed in an informative annex and in the main body of the standard it is stated that the probe shall not be placed in or very close to any stream of flowing gas of which the mean speed exceeds 2 m/s. According to the standard the measurement distance to the closest parts of the machine under test shall exceed 0,5 m. In the scanning method of [3] the smallest measurement distance is 0,2 m if the level of extraneous noise is low and 0,1 m if it is high. As the sound power level of air terminal devices often is rather low it is desirable to have rather small measurement distances to minimize interference from the background noise.

Comfort criteria in rooms normally require that the flow speed is less than 0,2 m/s where people are staying. The speed is normally inversely proportional to the distance, or in some cases to the square root of the distance, from the outlet. Thus, in normal rooms we will normally not have more than 1 m/s 0,5 m from the outlet. However, in large rooms like offices and industrial halls higher speeds may be expected.

As the speed of the air flow will vary from one air terminal device to another it will be necessary to have a measurement procedure which will guarantee that the flow speed at the measurement probe will not exceed permissible values. One way could be to measure the speed, for example with a hot wire anemometer. Another way could be to repeat the measurement with a different measurement surface and different probe positions and make sure that the result does not change.

In the following the pressure-intensity indicator is denoted pI , where

$$pI = L_p - L_{In} \quad (3.1)$$

where L_p = the surface averaged sound pressure level and L_{In} = the normal sound intensity level on the measurement surface. In ISO 9614-1 the notation F_2 is used and in the proposal for Nordtest method in clause 6 the notation F is used.

2.2 Some measurements

2.2.1 General

The measurements described below have been carried out at the Acoustics Laboratory of the Swedish National Testing and Research Institute in a 200 m³ reverberation room in compliance with ISO 3741, [6], and ISO 354. The room is also used for routine measurements in accordance with ISO 5135. The measurement equipment is listed in Annex A.

The intensity measurements have been carried out with a 2 microphone probe with a wind screen. The whole measurement chain was calibrated with an intensity calibrator prior to each measurement series. The air speed at the probe has been measured by a hot wire anemometer. Other flow data has been determined with equipment complying with ISO 5135.

No corrections have been made for the frequency response of the sound intensity probe during the preliminary measurements. Corrections, in accordance with the manufacturer's specifications, have, however, been made for the final measurements reported in 3.3. For 12 mm microphone spacing, without these corrections, we will thus underestimate the sound intensity level by about 0,8 dB at 4000 Hz and by about 4 dB at 8000 Hz. For 50 mm spacing the underestimate will be about 0,8 and 4 dB for 1 kHz and 2 kHz respectively.

Because of background noise problems measurement data at 63 Hz and 8000 Hz have from time to time been excluded. In some cases, as to ISO 5135, measured values at 125 Hz have been corrected for background noise. In some cases the correction has exceeded the normal maximum of 1,3 dB by a few tenths of a dB.

The measurements have been carried out on air terminal outlets where most of the air flow was directed perpendicular to the duct axis parallel to the wall. The terminals have been mounted in the middle of a wall at least 1,5 m from the other walls of the room.

2.2.2 The effect of flow speed at the probe

In Figure 2.1 and 2.2 the effect of flow at the intensity probe is shown. The intensity results are based on single point measurements on different measurement radii. Some intensity values have been omitted because of negative intensity flows or high or negative pI-indicators. Other measurements have been carried out although they are not reported here because of flows in the negative direction and negative or very high pI-indicators. Such consequences seem to be common when the flow velocity is too high.

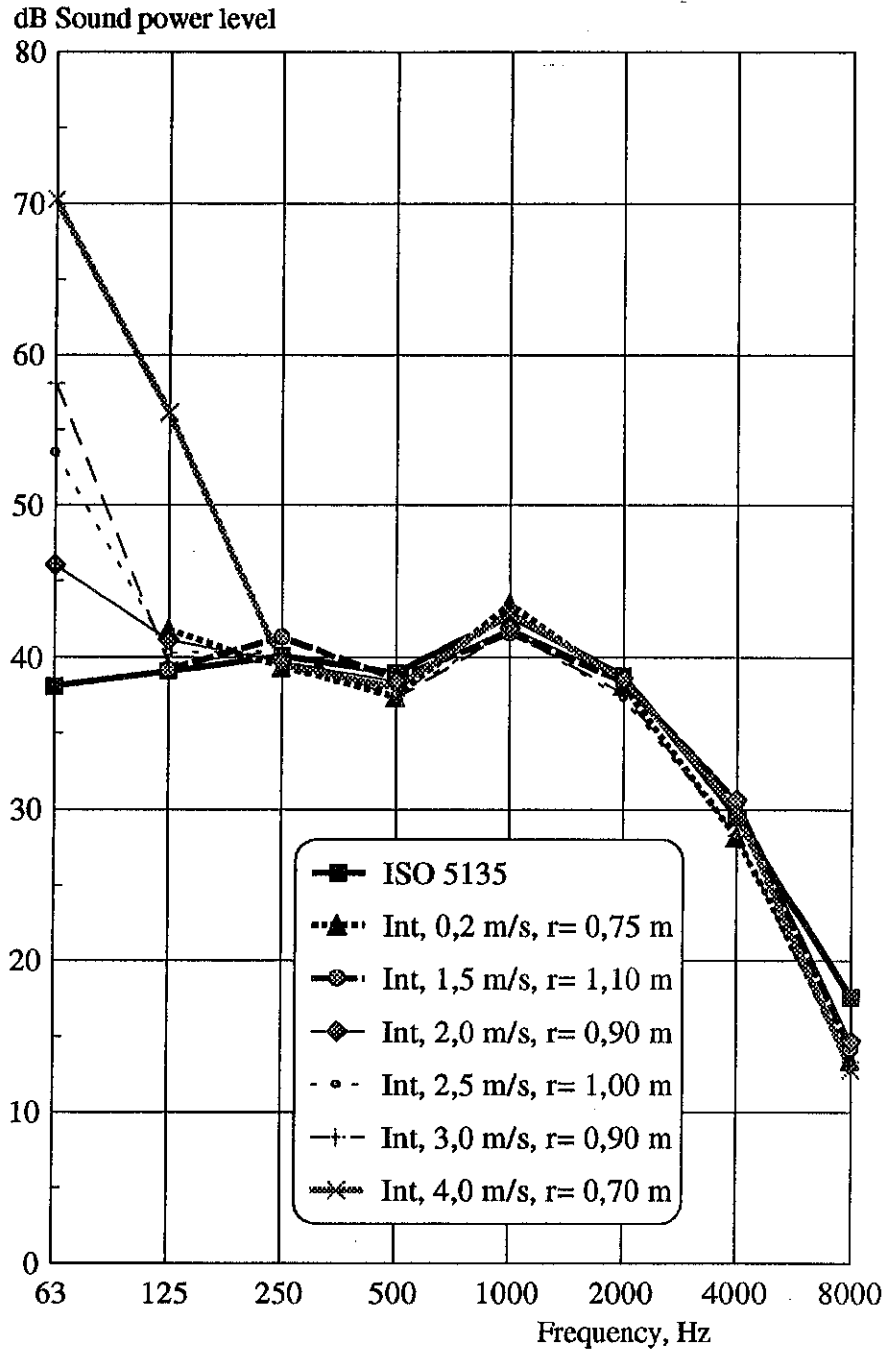


Figure 2.1 Air terminal device. Duct diameter 0,25 m. Measurement surface: Half sphere. Measurement radius: r. One measurement point. 12 mm intensity probe(m:\updrag\F3604006).

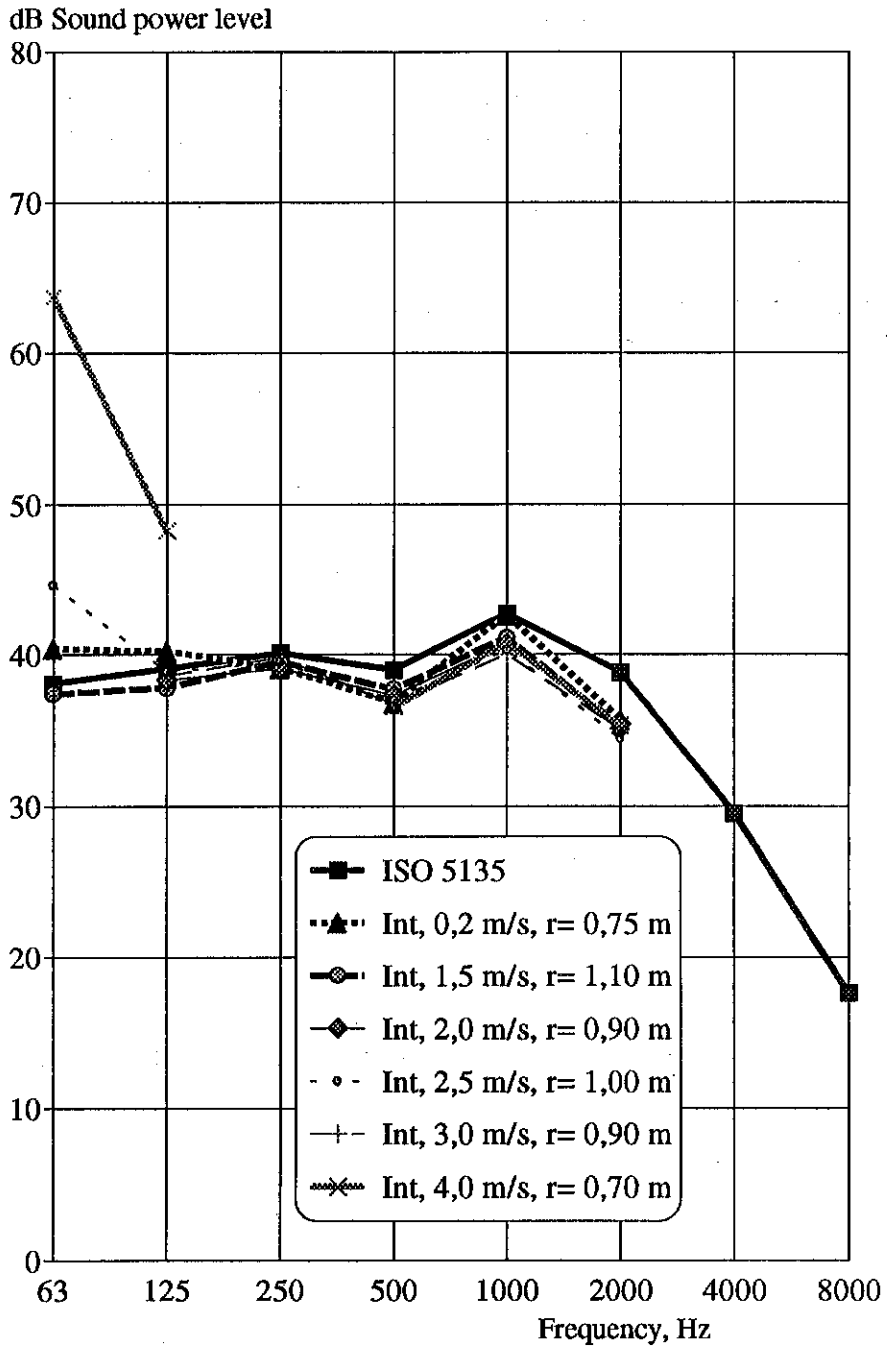


Figure 2.2 Air terminal device. Duct diameter 0,25 m. Measurement surface: Half sphere. Measurement radius: r. One measurement point. 50 mm intensity probe(m:\uppdrag\F3604006).

The figures indicate that the air speed is most critical at low frequencies, as expected, and that 4 m/s is obviously not acceptable. The limit 2 m/s stated in ISO 9614-1 seems to be reasonable, although somewhat conservative. If only frequencies above 125 Hz are of interest it seems to be possible to accept rather high flow speeds.

2.2.3 Number of probe positions

In ISO 9614-1 it is recommended to use at least 1 position/m² and totally at least 10 positions. For small test objects like most air terminal devices this seems to be a rather large number. The A-weighted frequency spectrum of air terminal devices is often dominated by medium high frequencies between 250 and 2000 Hz.

In Figure 2.3 a comparison between ISO 5135 and sound intensity using different numbers of probe positions is given. All positions have been out of the main air stream, that is not too close to the wall.

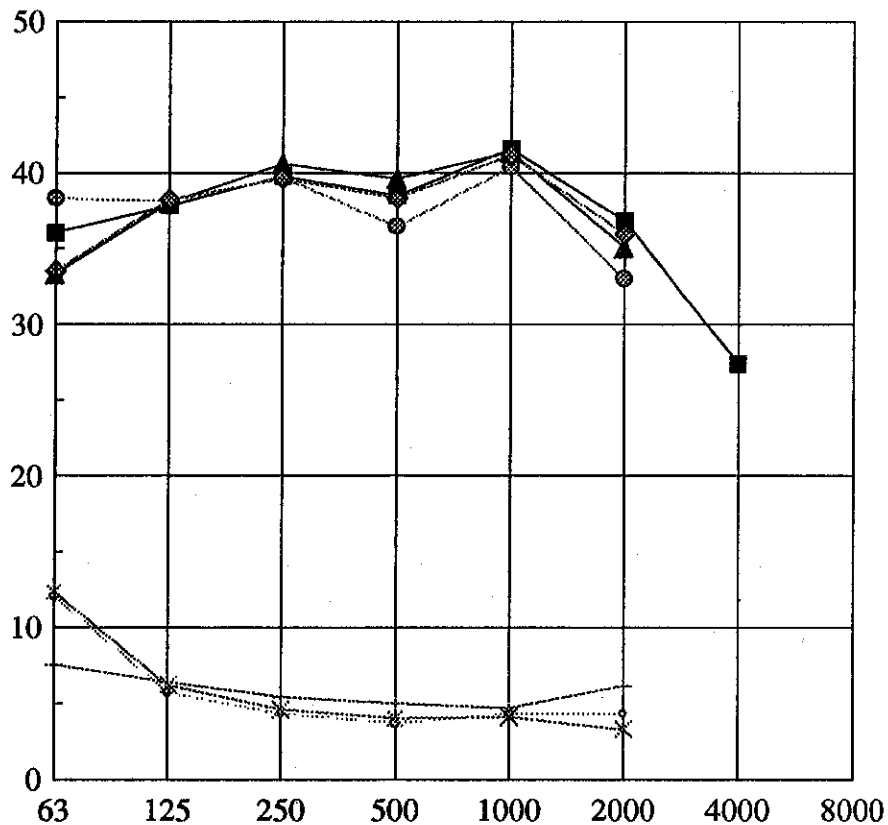
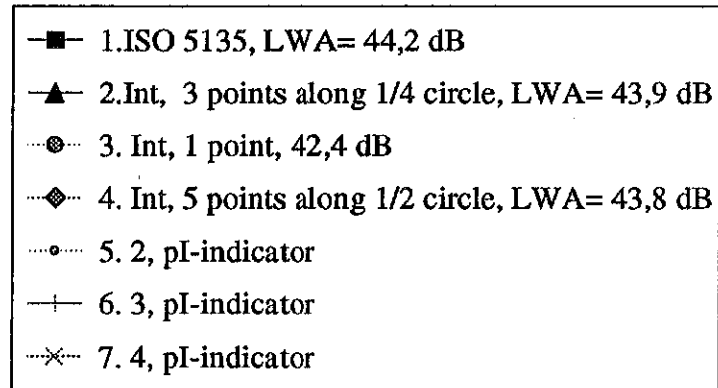


Figure 2.3 Air terminal device. Duct diameter 0,25 m. Air flow: 217 l/s. Estimated outlet speed: 10,7 m/s. Measurement surface: Half sphere. Measurement radius: 0,75 m. Surface area: 3,53 m². Measurement points out of main air flow. 50 mm intensity probe(m:\updrag\F3604003).

The agreement between 3 and 5 discrete points and ISO 5135 in Figure 2.3 is very good except for 63 Hz where there has been some background noise problems and where the field indicator was higher than 10 dB. It indicates that good results can be obtained even with a rather small number of positions. In Figure 2.4 it is shown that the repeatability of the sound intensity measurements is very good. In this case the agreement between the sound intensity method and the traditional is not quite as good. The reason for this is not known. Maybe background noise during the traditional measurement created some trouble. The sound power levels are very low. Another comparison with good agreement for 9 measurement points is shown in Figure 2.5.

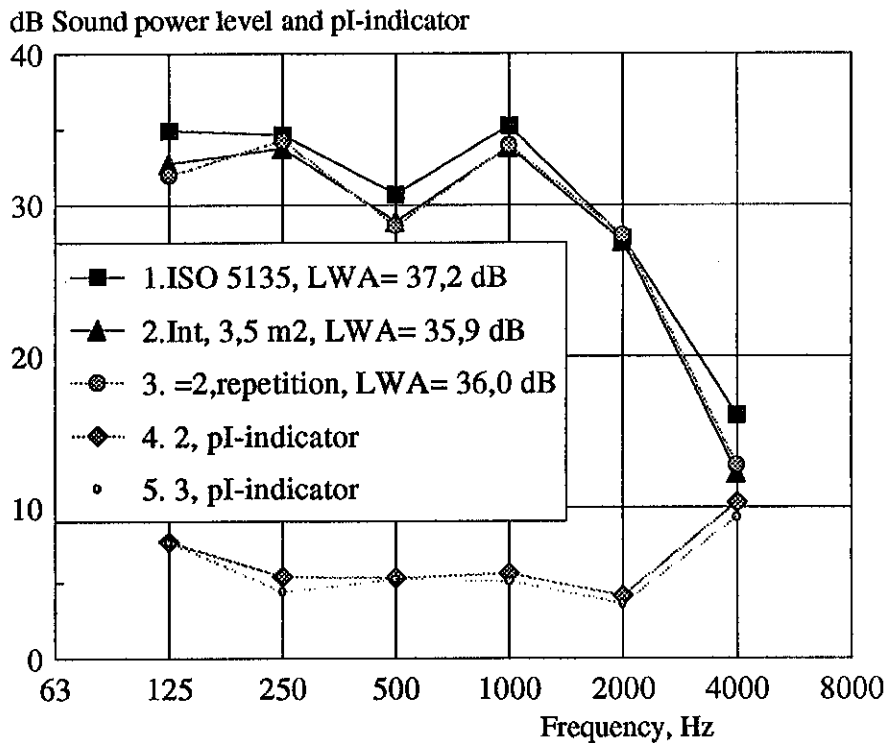


Figure 2.4 Air terminal device. Duct diameter 0,25 m. Air flow: 167 l/s. Estimated outlet speed: 8,2 m/s. Measurement surface: Half sphere. Measurement radius: 0,75 m. Surface area: 3,53 m². Measurement points: 5 along a quarter circle out of main air flow. 12 mm intensity probe. (m:\uppdrag\F3604001).

From these very limited measurements it is of course very difficult to draw any firm conclusions as to the necessary number of measurement points. However, under nice conditions, such as in the laboratory above, it does not seem necessary to have more than about 5 positions for a hemispherical measurement surface. On the other hand, if we are interested in frequencies higher than about 2000 Hz where the source may be very directional or if the pI-indicator is high due to extraneous noise it may become necessary to have more positions, especially if the air terminal unit is unsymmetrical.

2.2.4 Scanning versus discrete points

In Figure 2.5 scanning is compared with discrete point sampling. As expected the agreement is very good. However, it must be borne in mind that this assumes that the scanning can be carried out without entering high flow areas and without creating disturbing background noise.

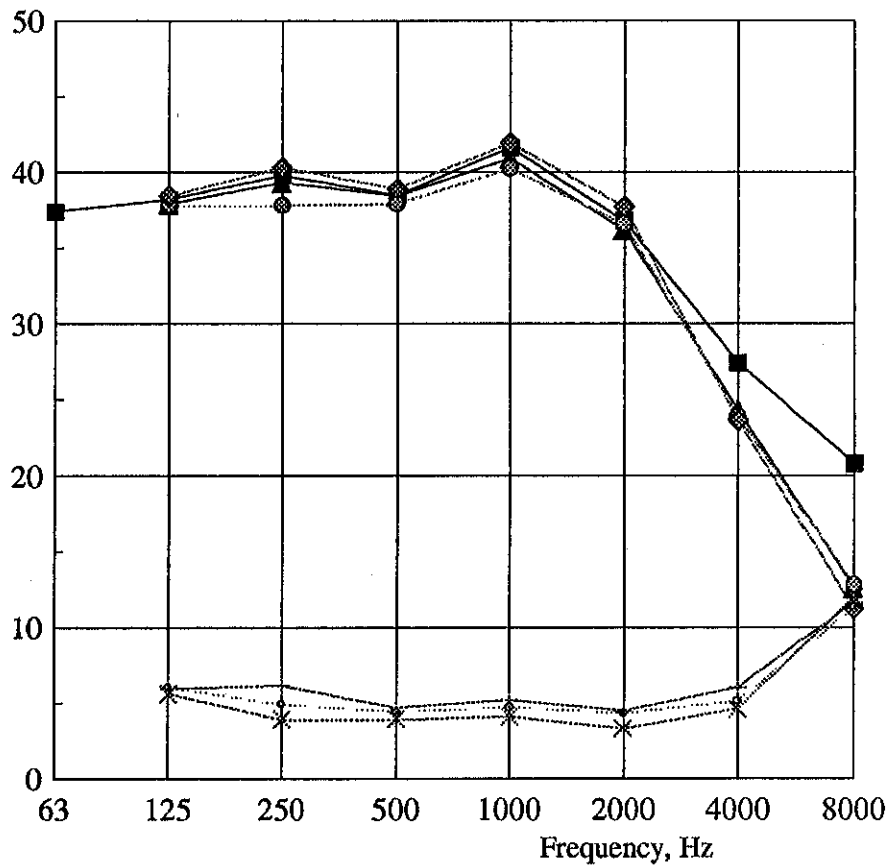
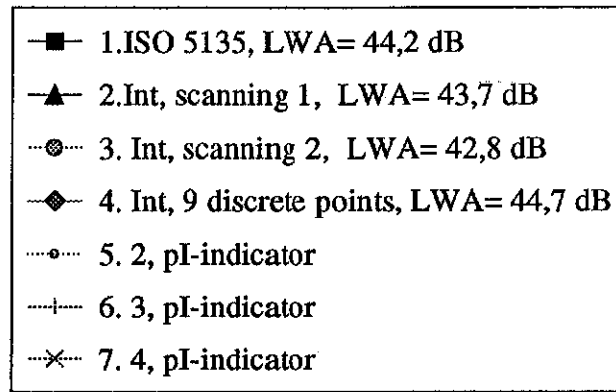


Figure 2.5 Air terminal device. Duct diameter 0,25 m. Air flow: 217 l/s. Estimated outlet speed: 10,7 m/s. Measurement surface: Half sphere. Measurement radius: 0,75 m. Surface area: 3,53 m². Discrete measurement points: 9 along a half circle out of main air flow. 12 mm intensity probe(m:\updrag\F3604004).

Because the risk of creating disturbing noise during the scanning procedure it should be desirable to follow the same procedure as the one proposed in [5] for sound insulation measurements. Repeat the measurement once. The measurements are approved if the maximum difference in any frequency band between the two measurements is less than 1 dB. The result is given by the arithmetic average of the two measurements.

3 Within and between laboratory comparisons

3.1 General

4 different laboratories have tested one non-adjustable air terminal unit and one damper with fixed setting. Unfortunately the results of one laboratory could not be used. That laboratory was designed to cope with very large pieces of equipment and it turned out to be impossible to make reliable measurements on the small units used in this investigation. This means that the statistical basis for conclusions is not quite satisfactory.

Two methods were used. One was the traditional ISO 5135 and one the proposal for Nordtest intensity method. The intensity measurements were made in the same reverberation room as the traditional measurements. In order to decrease the problem with low noise levels the measurements were carried out with a rather high air flow. The test objects were:

1. Damper with $\Phi=250$ mm, tilted 75° from the axis, flow rate: 70l/s.
2. Air terminal unit, $\Phi=250$ mm, non adjustable opening, flow rate: 145 l/s.

The equipment used by the different laboratories is given in annex A.

3.2 Individual measurements

dB Sound power level and pI-indicator

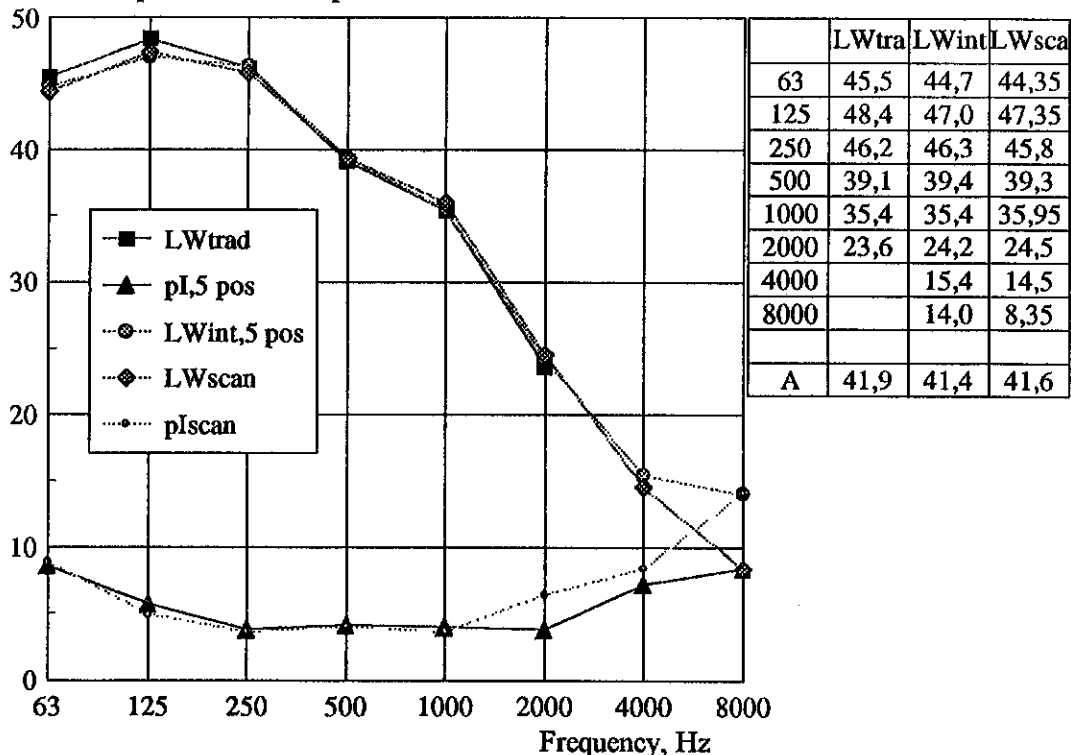


Figure 3.1 Air terminal unit measured at SP. Measurement radius: 0,74 m(m:\nordtest\donint1)

dB Sound power level and pI-indicator

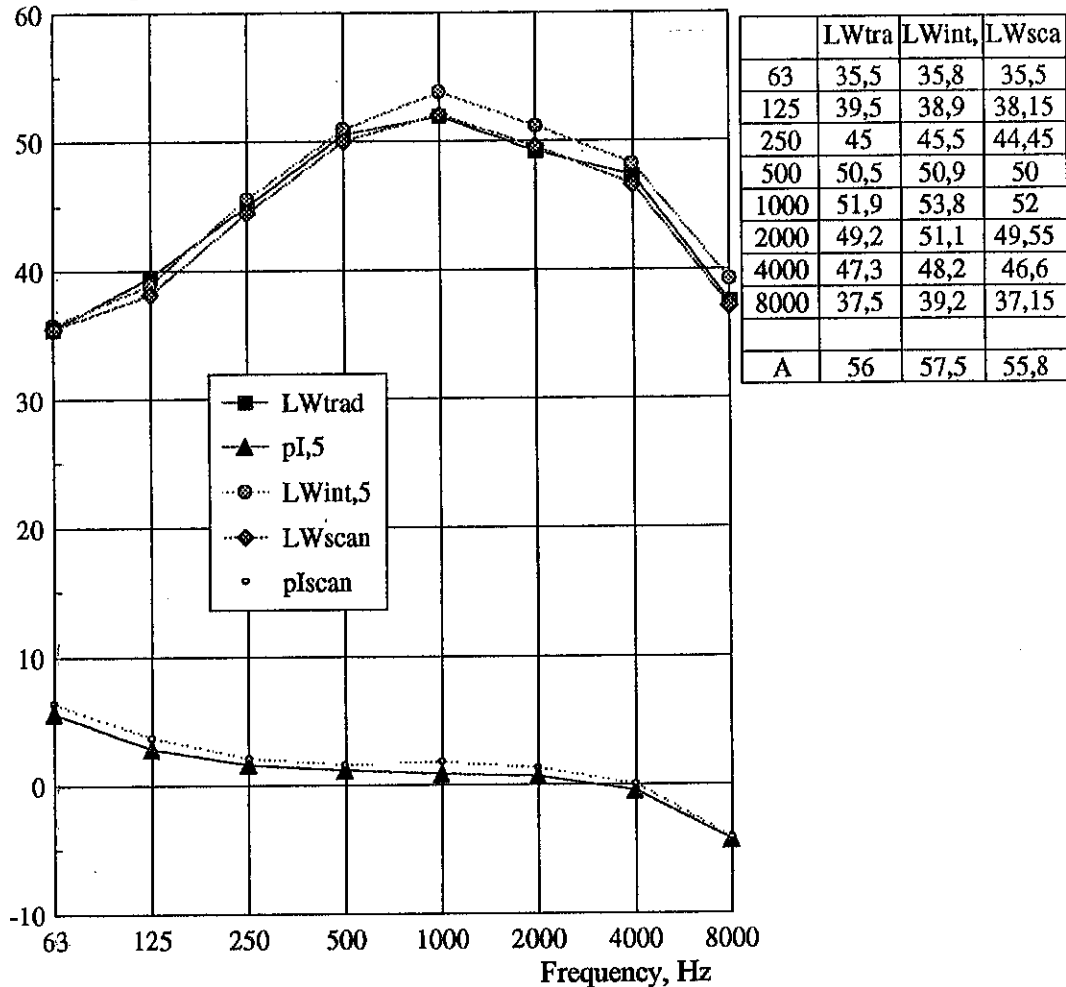


Figure 3.2 Damper measured at SP. Measurement radius: 0,625 m
(m:\nordtest\donint4)

The results from SP given in figure 3.1 and 3.2 indicate an excellent agreement between the two methods. Figure 3.2 indicates that 5 positions may not be enough. As the scanning method seems to be most reliable the results of this method will be used in the following comparisons.

The results of Farex are given in figure 3.3 and 3.4. Farex had problems with high background noise and low noise levels of the test objects. Measurements were performed both with Norsonic(Ns) equipment and Brüel & Kjaer(B&K) equipment. 5 discrete probe positions were used. The Ns equipment included a velocity ultra sound transducer. In the following the Ns data are used for all comparisons because the pI-indicator is not known for the B&K measurements.

The results of VTT are given in figure 3.5 and 3.6. The agreement between the two methods is excellent for the air terminal unit but not quite as good for the damper. One reason may be that a box shaped measurement surface has been used for the damper measurement. We then introduce an angle error as we are only supposed to measure the sound energy perpendicular to the measurement surface. According to the proposal for intensity method a hemi spherical surface is to prefer in this case. A box shaped surface should preferably only be used if the characteristic dimension(=250 mm) is large in relation to the measurement distance.

dB Sound power level and pI-indicator

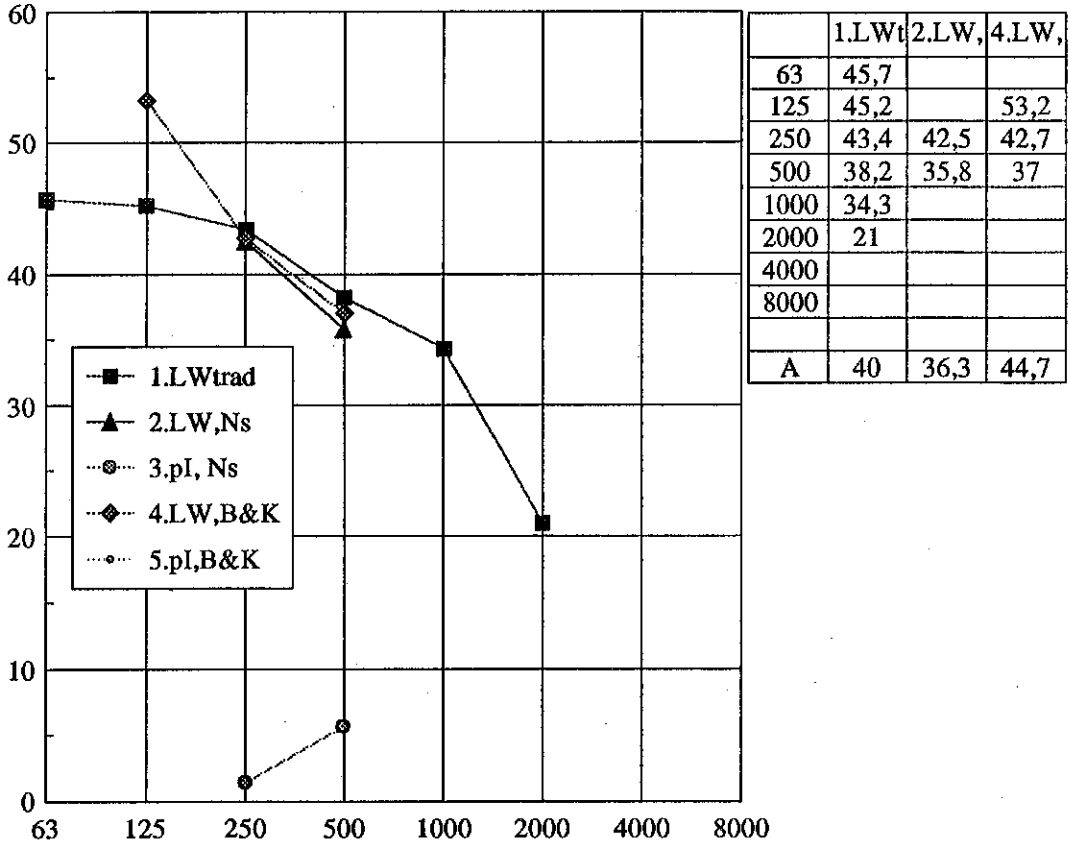


Figure 3.3 Air terminal unit measured at Farex. Measurement radius: 0,5 m, flow rate: 145 l/s. (m:\nordtest\donint5)

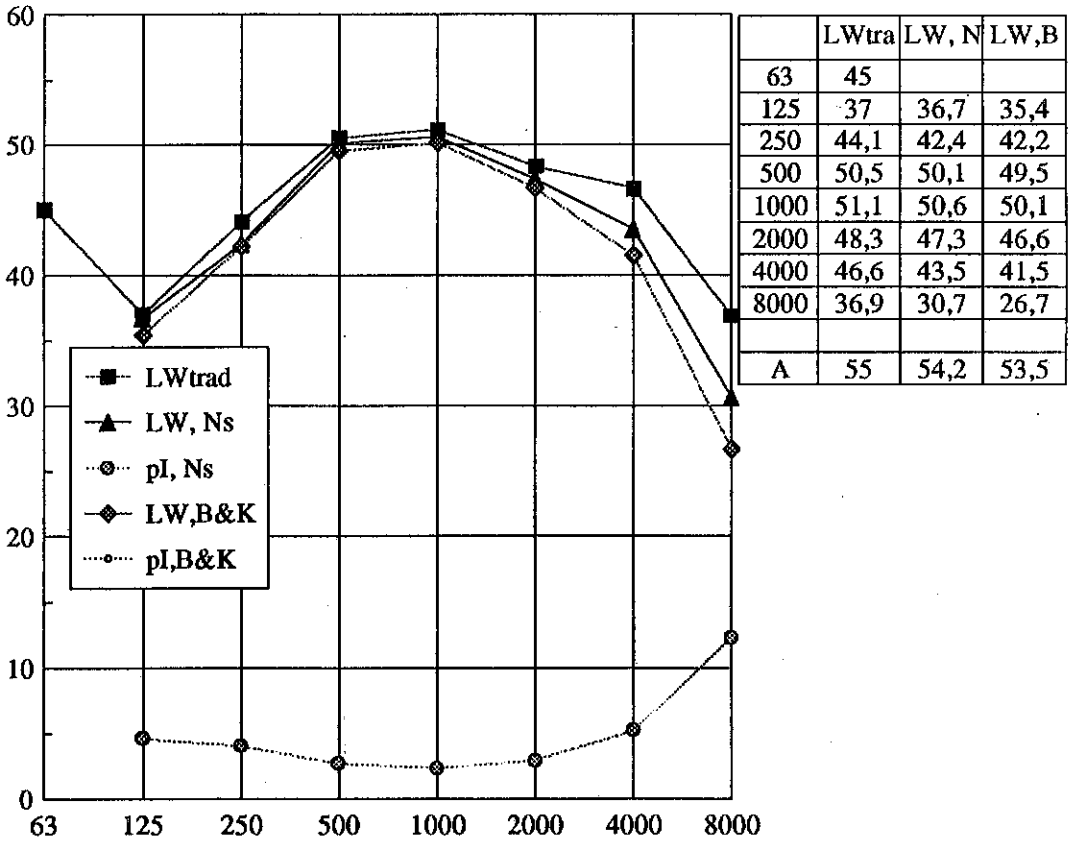


Figure 3.4 Damper measured at Farex. Measurement radius: 0,5 m, flow rate: 70 l/s. (m:\nordtest\donint6)

dB Sound power level and pI-indicator

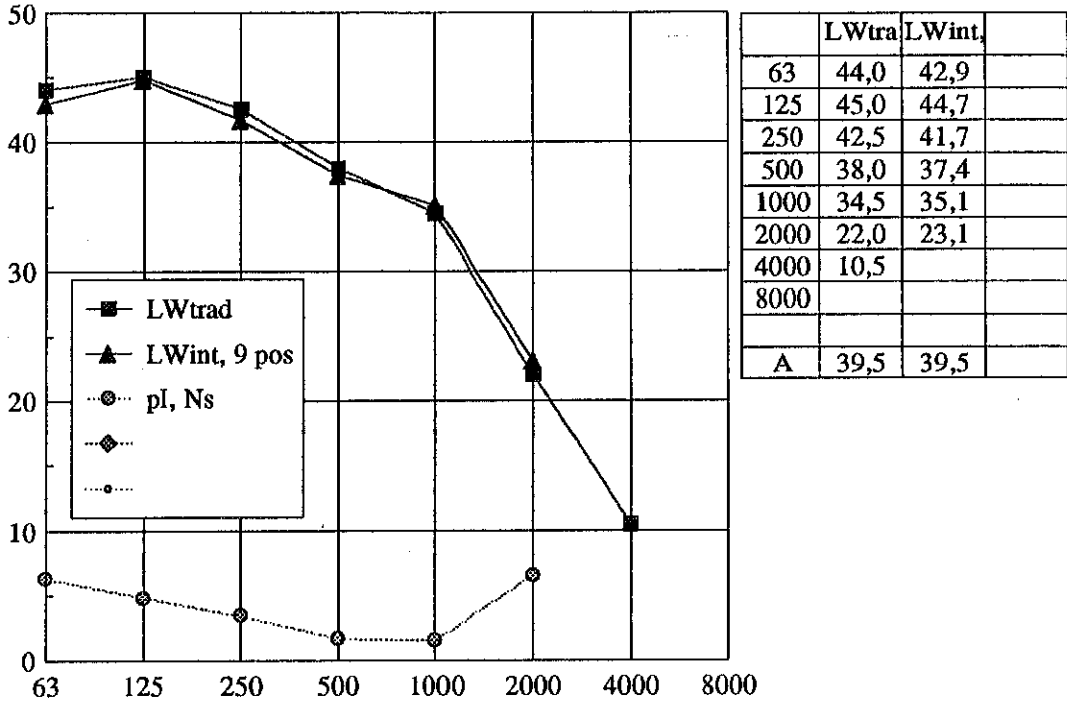


Figure 3.5 Air terminal unit measured at VTT. Measurement radius: 0,75 m, 9 discrete positions. Flow rate during ISO 5135: 141,3 l/s.

(m:\nordtest\donint7)

dB Sound power level and pI-indicator

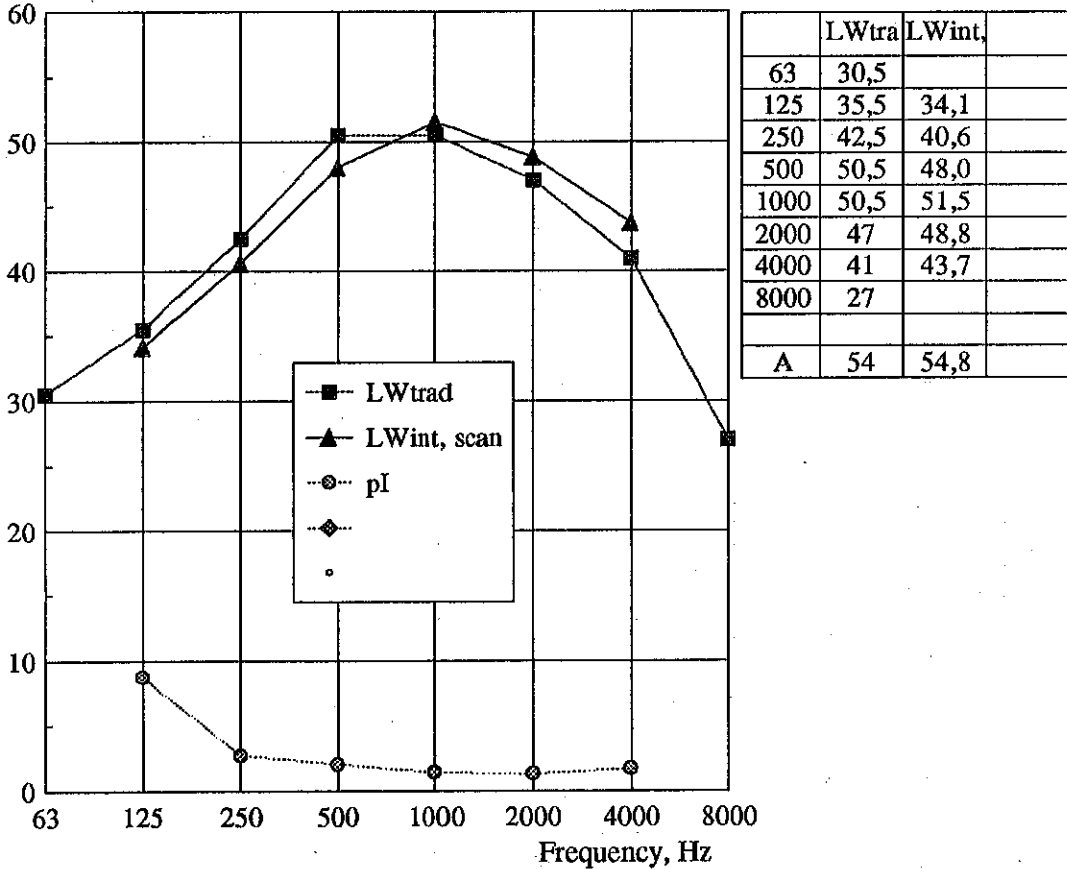


Figure 3.6 Damper measured at VTT. Box shaped measurement surface: 1,05 m². Flow rate during ISO 5135: 66,7 l/s. (m:\nordtest\donint8)

3.3 Comparison of measurements

In the tables below the Finnish measurement results have been corrected upwards 0,8 dB for air terminal units and 1,1 dB for the damper because of the lower flow rate used during the Finnish measurements, 141,3 l/s in stead of 145 l/s and 66,7 l/s in stead of 70 l/s respectively. The corrections have been obtained from the following regression equations derived by SP:

$$L_{WA} = -42 + 53 \lg(\text{flow rate}) \text{ for the damper}$$

and

$$L_{WA} = -106,7 + 68,3 \lg(\text{flow rate}) \text{ for the air terminal unit respectively.}$$

Because the correction was small (1,1 dB and less) the same equations have been used for all frequencies.

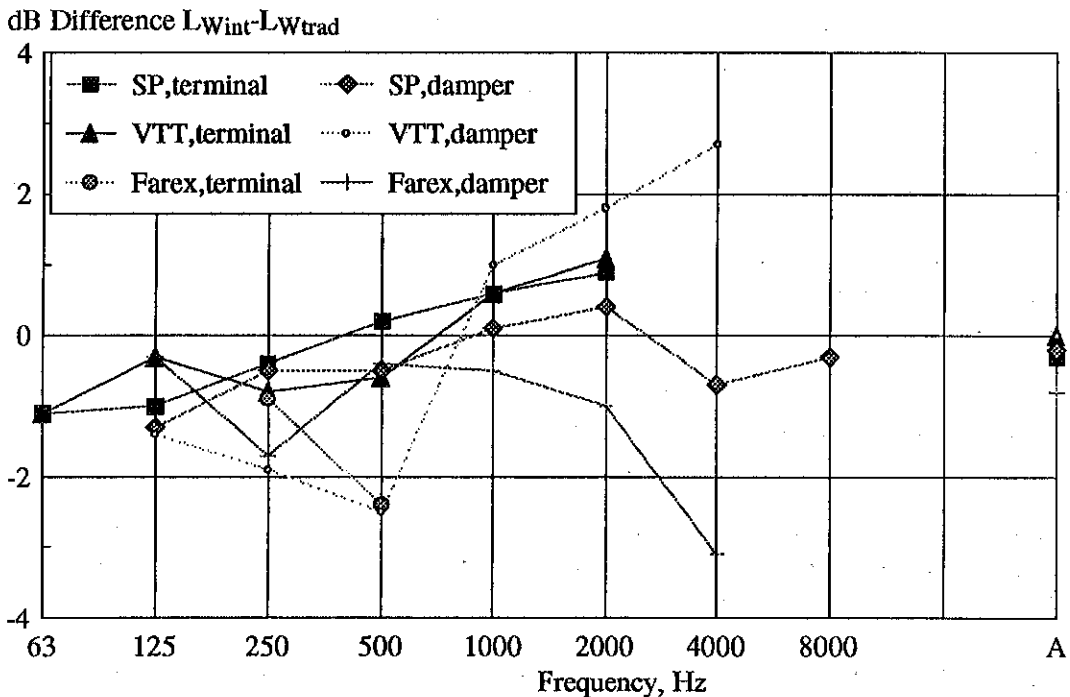


Figure 3.7 The within laboratory difference between the sound intensity method and the traditional ISO 5135 measurement. (m:\nordtest\doninum)

Figure 3.7 indicates very small within laboratory differences in the A-weighted sound power level. However, there seems to be a small tendency to measure lower levels at low frequencies and higher levels at high frequencies when using intensity. It is hardly possible to explain the differences within the frame of this investigation. Some differences may depend on errors in the application of the traditional

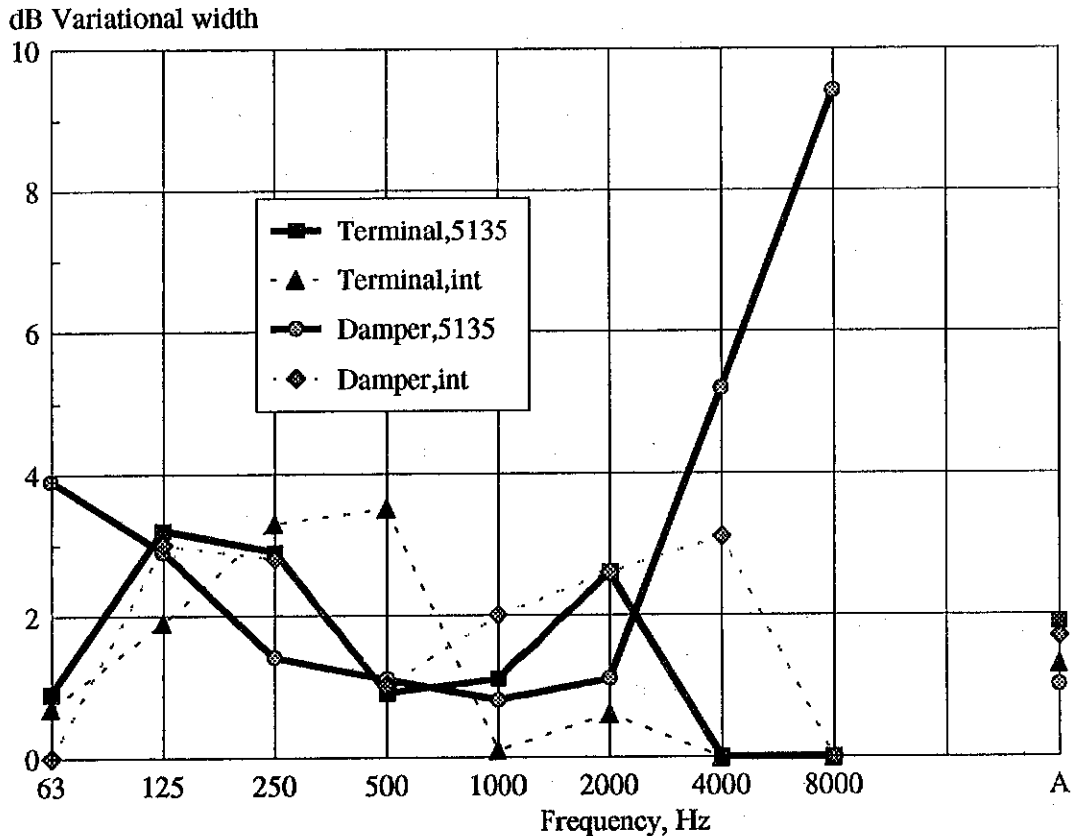


Figure 3.8 The between laboratory variational width of the sound intensity method(dotted curves) and the traditional ISO 5135 method(full lines).
(m:\nordtest\doninsum)

Figure 3.8 indicates that the between laboratory spread is similar for both methods. Sometimes one is better than the other but the rank order changes all the time with test object and frequency.

In figure 3.9 the standard deviations of all the different sound power measurements are summarized test object by test object together with those of ISO 3741. In figure 3.10 and 3.11 the complete results are given.

Figure 3.9 indicates that sound intensity measurements, within the frame of ISO 3741, can be considered to be equivalent to traditional sound pressure measurements. Actually, the bad results at 4000 and 8000 Hz depend on bad ISO 5135 reproducibility and not on the intensity measurements, see figure 3.8.

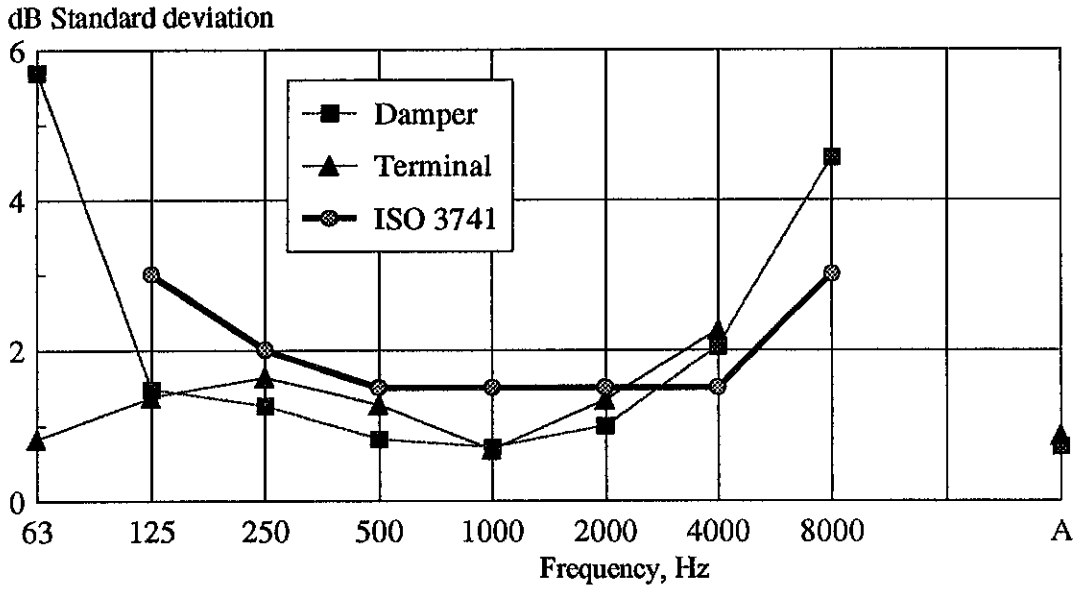


Figure 3.9 The standard deviation of all measurements in all laboratories, both according to the proposal for intensity method and ISO 5135.

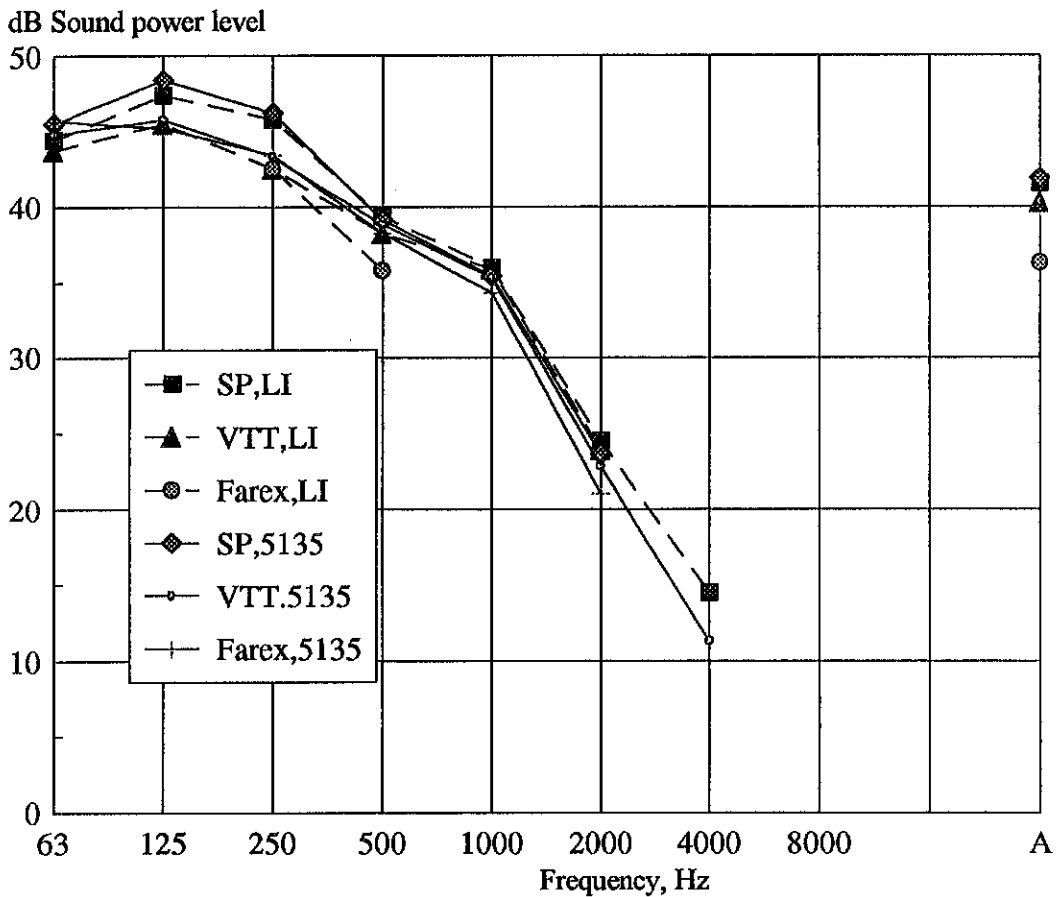


Figure 3.10 Measured sound power levels of the air terminal unit.(m:\nordtest\doninsum).

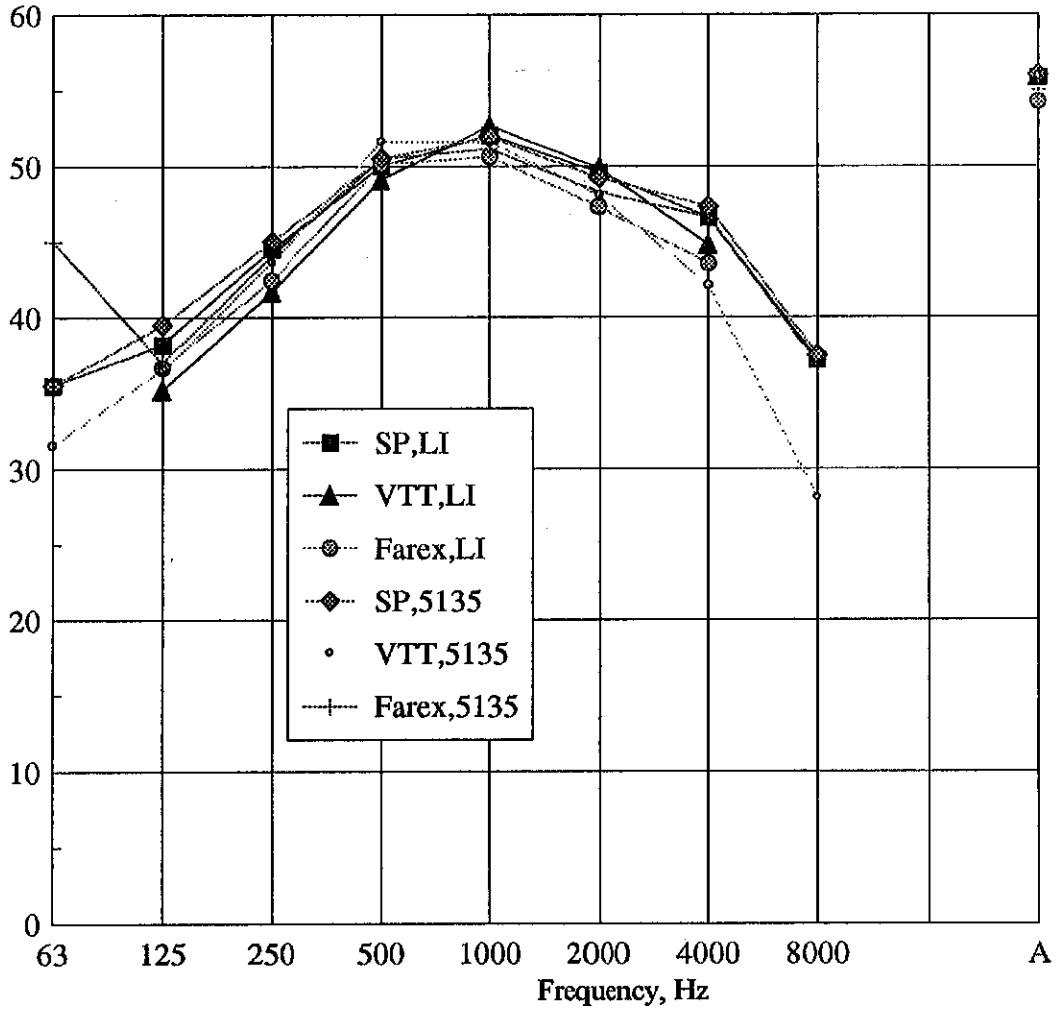


Figure 3.11 Measured sound power levels of the damper.(m:\nordtest\doninum).

4 Conclusions

Unfortunately the number of data available is not enough to calculate any uncertainties. However, the results indicate clearly that sound intensity can be used to measure the sound power level of ventilation equipment. The difference in A-weighted sound power level between the intensity method and the traditional sound pressure method is not likely to exceed 1 dB. The within laboratory difference between the two methods will in most cases be smaller than the between laboratory difference.

Intensity measurements will fall within the frame of the uncertainties given in ISO 3741, that is within the frame of this standard. Intensity measurements and traditional measurements can be considered to be equivalent.

5 References

- [1] ISO 5135:1984, Acoustics - Determination of sound power levels of noise from air terminal devices, high/low velocity/pressure assemblies, dampers and valves by measurement in a reverberation room
- [2] ISO 9614-1:1993, Acoustics - Determination of sound power levels of noise sources using sound intensity - Measurement at discrete points
- [3] DS/INSTA 121(SS 459 01 10):1990, Acoustics - Determination of sound power levels of noise sources using sound intensity measurements - Scanning method for use in situ.
- [4] Andresen, Geir; Determination of sound power levels of air terminal units according to ISO 5135. Nordic intercomparison programme. Nordtest project 961-91, SP Report 1993:
- [5] Jonasson, H.G., Measurements of sound reduction index with intensity technique, SP Report 1991:23
- [6] ISO 3741:1988 Determination of sound power levels of noise sources - Precision methods for broad-band sources in reverberation rooms

6 Proposal for Nordtest method

**Air terminal units, air terminal devices,
dampers and valves:
Determination of sound power levels using
sound intensity**

1 Scope and field of application

1.1 General

This NORDTEST method specifies how to determine the sound power level of air terminal units, high/low velocity/pressure assemblies, dampers and valves used in air diffusion and air distribution systems using sound intensity. The method applies to all kinds of test environments as long as the requirements on background noise and field indicator are fulfilled.

The method is applicable to equipment operating under steady state conditions and emitting broad-band noise with or without discrete-frequency or narrow-band components. The method yields results comparable with those of ISO 5135.

1.2 Measurement uncertainty

The uncertainty of this Nordtest method is not known.

Note 1 Comparison measurements carried out between 3 Nordic laboratories indicate that this Nordtest method will yield values equivalent to those of ISO 5135 within 1 dB in A-weighted sound power level. The measurements will fall within the frame of uncertainty stated in ISO 3741.

2 Normative references

ISO 5135:1992¹⁾, Acoustics - Determination of sound power levels of noise from air terminal devices, high/low velocity/pressure assemblies, dampers and valves by measurement in a reverberation room.

ISO 9614-1:1993, Acoustics - Determination of sound power levels of noise sources using sound intensity - Measurement at discrete points.

ISO 9614-2:1992¹⁾, Acoustics - Determination of sound power levels of noise sources using sound intensity - Measurement by scanning

IEC 942:1988, Sound calibrators.

IEC 1043¹⁾, Instruments for the measurement of sound intensity.

1) At present at the stage of draft international standard.

3 Definitions

3.1 sound intensity, I :

Time averaged rate of flow of sound energy per unit of surface area oriented in the direction of the local particle velocity. This is a vectorial quantity which is equal to

$$\vec{I} = \frac{1}{T} \int_0^T p(t) \vec{u}(t) dt \quad \text{W/m}^2 \quad (1)$$

where

$p(t)$ is the instantaneous sound pressure at a point, in pascals;

$u(t)$ is the instantaneous particle velocity at the same point, m/s;

T is the averaging time, in seconds;

3.2 normal sound intensity, I_n :

Sound intensity component in the direction normal to the measurement surface.

3.3 normal sound intensity level, L_{In} :

Ten times the common logarithm of the ratio of the unsigned value of the normal sound intensity to the reference intensity I_0 as given by:

$$L_{In} = 10 \lg(| \vec{I}_n | / I_0) \quad \text{dB} \quad (2)$$

where

$$I_0 = 10^{-12} \text{ W/m}^2$$

3.4 pressure-intensity indicator or field indicator, F :

The difference between time and surface averaged sound pressure level, L_p , and the normal sound intensity level, L_{In} , on the measurement surface given by:

$$F = L_p - L_{In} \text{ dB} \quad (3)$$

Note 2- In ISO 9614-1 the notation F_2 is used.

3.5 residual pressure-intensity index, δ_{pI_0} :

The difference between indicated sound pressure level and sound intensity level when the probe is placed in a sound field in such an orientation that the particle velocity in the direction of the probe measurement axis is zero (e.g. in an acoustic coupler or transverse to the direction of propagation of a plane sound wave).

3.6 reference box:

A hypothetical surface which is the smallest rectangular parallelepiped which just encloses the source. It usually terminates on one or more reflecting planes.

3.7 characteristic dimension:

Half the diagonal of the box enveloping the reference box and its images in adjoining reflecting planes.

3.8 measurement radius:

The radius of a spherical or cylindrical measurement surface.

3.9 measurement distance:

The distance between the reference box and a parallelepipedical measurement surface.

4 Instrumentation

4.1 General

The intensity measuring instrumentation shall be able to measure intensity levels re 10^{-12} W/m^2 in decibels in one-third octave bands. It is recommended to measure the intensity in real time if scanning is used. The instrument, including the probe, shall comply with IEC 1043. A probe wind screen shall always be employed.

The residual pressure-intensity index δ_{pI_0} of microphone probe and analyzer shall be higher than $F + 10$ dB in each one-third octave band.

4.2 Calibration

The instrument and the probe shall be calibrated at least at one frequency in the range from 200 to 1000 Hz in accordance with the calibration procedure and at intervals specified by the manufacturer.

The following field checks to test the instrument shall be made before each series of measurements:

a) Carry out a field check according to the instrument manufacturer's specifications.

If no field check is specified by the instrument manufacturer check the instrumentation according to b) and c):

b) Sound pressure level: Check each pressure microphone of the intensity probe for sound pressure level using a class 2 calibrator or better in accordance with IEC 942.

c) Intensity: Calibrate using an intensity calibrator. If such a calibrator is not available or if the probe build up does not allow it make a check as follows:

Place the intensity probe on the measurement surface, oriented normal to the surface, at a position where the noise from the source is characteristic for that source. The intensity probe should be mounted on a stand to retain the same position while carrying out the measurement check. Measure the intensity. Rotate the intensity probe through 180° about a normal to its measurement axis in the same position as the first measurement. Measure the intensity again. For the maximum sound intensity level measured in one-third octave or octave bands the unsigned difference between the two sound intensity levels shall be less than 1,5 dB for the measurement instrumentation to be acceptable.

Note 3 - This test may not be completely appropriate for pressure-velocity probes for which the manufacturer's instruction should apply.

5 Installation and operation of the source

See ISO 5135.

6 Test procedure

6.1 General

Mount the intensity probe in discrete positions, or scan it, on a measurement surface enclosing the object under test. Select the positions to minimize the air flow speed. No positions with speeds exceeding 2 m/s shall be used. The principle is to measure once and then to repeat the measurement a second time using different probe positions or paths. If the difference between the two measurements is small and if certain other criteria are fulfilled the measurement is valid.

Note 4 - If only frequency bands above the 125 Hz octave band are of interest speeds up to 5 m/s are acceptable.

Note 5 - The air speed can be estimated by measuring it with a hot wire anemometer.

Measure the normal sound intensity and the sound pressure in the frequency bands in which the sound power level is to be determined. The averaging time shall be at least 30 s in each probe position. When scanning is used the total averaging time shall be at least 150 s. Calculate a field indicator to assess the acceptability of the results. Depending on the result it may become necessary to use a new measurement surface and a different set up of probe positions.

6.2 Measurement surface

6.2.1 Measurement surface

The measurement surface shall completely enclose the test object. The preferred measurement surface is

- a) a hemisphere (or part thereof if the test object is mounted close to the ceiling, on the floor or in a corner) if the characteristic dimension of the test object is less than half the chosen measurement radius,
- b) a cylinder (or part thereof) if only the x- or y-dimension of the characteristic dimension of the test object is less than half the chosen measurement radius of the cylinder,
- c) a box (or part thereof) if condition a) or b) is not fulfilled.

Note 6 A box shaped measurement surface will introduce errors in relation to a hemispherical surface with large measurement radius because other intensity components than those perpendicular to the measurement surface will contribute to the intensity level. This error is often 1-2 dB.

6.2.2 Measurement radius and measurement distance

Select measurement radius or measurement distance in such a way that microphone positions can be selected in areas where the speed of the gas flow does not exceed 2 m/s. The smallest distance between the measurement surface and the test object shall not be less than 0,1 m and preferably 0,5 m or more. Avoid distances larger than 1 m.

6.2.3 Discrete probe positions

Divide the measurement surface into subareas, S_i , each of which is to be represented by a probe position. The minimum number of positions shall be 5. Evaluate the total sound intensity L_{In} from

$$L_{In} = 10 \lg \left(\frac{1}{S} \sum S_i 10^{L_{Ini}/10} \right) \text{ dB} \quad (4)$$

where i indicates the sub area i and the total area S is given by

$$S = \sum S_i \quad (5)$$

If the sound intensity for a subarea has a negative direction, that is the flow of energy is in the direction towards the test object insert a minus sign before the respective S_i in eq. (4).

Calculate the field indicator, for each one-third octave band, from the following equation:

$$F = 10 \lg \left(\frac{1}{S} \sum S_i 10^{L_{pi}/10} \right) - L_{In} \text{ dB} \quad (6)$$

where L_{pi} = the surface sound pressure level of S_i .

If the measured intensity is negative or if F is not satisfactory, that is if $F > 10$ dB for a sound reflecting test specimen or if $F > 6$ dB for a test specimen with a sound absorbing surface, the measurement environment must be improved. First try to decrease the measurement distance. If this fails add sound absorbing material to the test room. The field indicator requirement is valid for the total measurement surface and not for individual sub surfaces. If the the field indicator $F > 7$ dB or if the difference in sound pressure level or sound intensity level between any two positions in any frequency band of interest exceeds 5 dB the number of probe positions shall be increased to at least 10. If, despite these efforts, it turns out to be impossible to comply with these requirements, the results may still be given in the test report providing that all deviations from the requirements of this method are clearly stated

When the above procedure has been carried out once, repeat it once more with different probe positions, which, however, may represent the same subareas. If the difference between the two measurements is less than 1,0 dB for any one frequency band the measurement result is given by the arithmetic average of the two measurements. If the difference is larger than 1,0 dB the measurements are not valid and number and positions of the probe, measurement surface or measurement environment must be changed and the measurements repeated until the requirement is fulfilled. If, despite these efforts, it turns out to be impossible to comply with these requirements, the results may still be given in the test report providing that all deviations from the requirements of this method are clearly stated

6.2.4 Scanning procedure

As an alternative to discrete positions scanning may be used if the air flow speed is less than 2 m/s all over the measurement surface.

Hold the probe normal to the measurement surface while scanning and arrange it to measure the positive intensity outwards from the object under test.

Divide the measurement surface into one or more subareas. If the averaging is made in real time with the instrument the scanning time of each subarea shall be proportional to the size of the area. Scan with a steady speed between 0,1 and 0,3 m/s. The measurements may be interrupted when going from one subarea to another. Avoid other stops.

Note 7- For small measurement surfaces it may be necessary to scan slower than 0,1 m/s in order to achieve a total integration time exceeding 150 s.

For box shaped measurement surfaces scan each subarea using parallel lines turning at each edge as shown in Fig. 1. The scanning line density depends on how irregular the sound radiation is. A large amount of irregularities requires a higher line density. Normally choose the line density to be equal to the measurement distance. Apply a similar pattern for hemi-spherical surfaces.

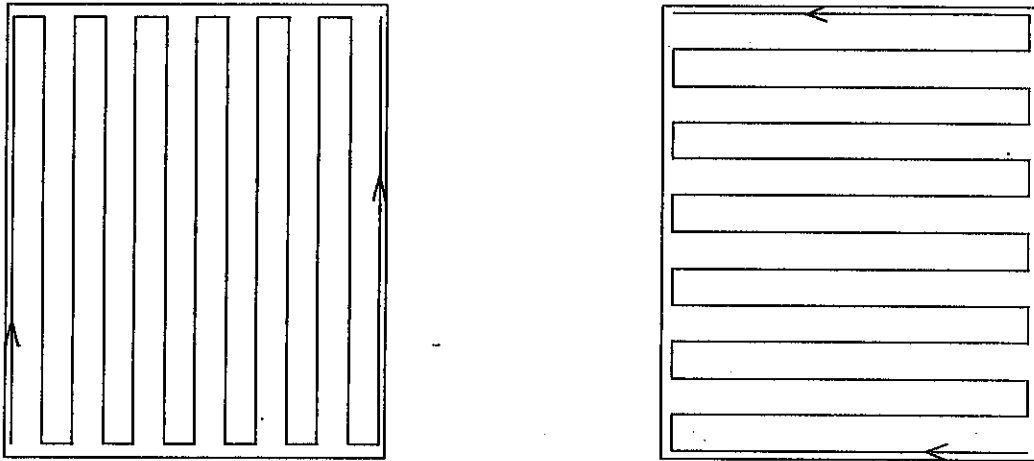


Figure 1. Scanning patterns for the two scans.

Note 8- On test objects with rotational symmetry and for a hemi-spherical measurement surface it may, under good environmental conditions, be sufficient to carry out both scans in the horizontal plane through the centre only.

During the scan measure the time and space integrated sound intensity level L_{In} . If possible measure the time and space integrated sound pressure level L_p simultaneously. If this is not possible, measure the sound pressure level afterwards at the same points or along the same path as during the intensity measurements. Calculate then the field indicator from eq. (6) and change, if necessary, the test environment as given in 6.2.3.

Once the measurement environment is satisfactory carry out two complete scans and compare the results. Turn the scanning path 90 degrees between the two scans. If the difference between the two measurements is less than 1,0 dB for any one frequency band the measurement result is given by the arithmetic average of the two measurements. If the difference is larger than 1,0 dB the measurements are not valid and new scans must be carried out until the requirement is fulfilled. If the requirement cannot be fulfilled change scanning pattern, measurement surface or measurement environment and repeat the measurements until the requirement is fulfilled. If, despite these efforts, it turns out to be impossible to comply with these requirements, the results may still be given in the test report providing that all deviations from the requirements of this method are clearly stated

In stead of scanning the whole measurement surface in one scan it is also possible to scan each subarea separately and carry out the calculations in accordance with 6.2.3.

6.2.5 Frequency range of measurements

The sound pressure level and the sound intensity level shall be measured using octave band filters having the following centre frequencies in hertz:

63 125 250 500 1000 2000 4000

Optionally the measurements can be made in one third octave bands with centre frequencies of at least from 50 to 5000 Hz.

Note 8 - Frequency bands without influence on the A-weighted sound power level may be excluded

7 Information to be reported

In addition to the relevant requirements of ISO 5135 the following shall be reported

- a) The value of the sound power level together with the field indicator F for each frequency band of interest.
- b) The shape and size of the measurement surface.
- c) Description of the operation of the intensity probe during the measurements.
- d) Description of the measurement probe and its calibration.
- e) The total integration time of the measurements.

Annex A Equipment used during the measurements

SP

Instrument	Type	Serial number
Analyzer	Norsonic 830	10760
Calibrator,intensity	B&K 3541	1389390
Pistonphone	B&K 4220	1404336
Matched microphones	B&K 4181	1335794
Anemometer	Alnor GGA-26	900099
13 mm microphone	B&K 4166	1011605
13 mm microphone	B&K 4166	1011610
13 mm microphone	B&K 4166	1072010
13 mm microphone	B&K 4166	1011672
13 mm microphone	B&K 4166	1011722
13 mm microphone	B&K 4166	951476
Preamplifier	B&K 2619	970951
Preamplifier	B&K 2619	970962
Preamplifier	B&K 2619	970996
Preamplifier	B&K 2619	469993
Preamplifier	B&K 2619	883568
Preamplifier	B&K 2619	970880
Multiplexer	Norsonic 834	10050
Reference sound source	B&K 4204	955306

VTT

Instrument	Type	Serial number
Analyzer	Norsonic 830	12717
Pistonphone	B&K 4220	965510
Matched microphones	B&K 4183	1395471
Probe	B&K 3520	1392438
Other microphones	B&K 4166	
Preamplifiers	B&K 2660	
Windshield	B&K UA 0207	
Static pressure upstream	Furness FC012	
Differential pressure	ALNOR MP6KS	
Static pressure	ALNOR MP6KSR	
Atmospheric pressure	Honeywell 140 PC	

Farex

Instrument	Type	Serial number
Analyzer	Norsonic 830	10703
Intensity probe	Norsonic 216	10805
Pistonphone	B&K 4220	894246
Microphone	B&K 4165	424198
Analyzer	B&K 2144	1654183
Calibrator,intensity	B&K 3541	1377180
Intensity probe	B&K 3548	1569219
Mikromanometer	Alnor MP3KDS	
Manometer	R Fuess G4107	
Manometer	Airflow Dev Ltd Mk 5	

