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Sound Insulation Measurement using Intensity

Microphones for Intensity Probes and their Calibration

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TECHNICAL REVIEW

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Contents

FIELD MEASUREMENTS OF SOUND INSULATION WITH A BATTERY-OPERATED INTENSITY ANALYZER

by

Torben G. Nielsen

ABSTRACT
The measurement of sound intensity is becoming increasingly popular, and the range of applications is broadening accordingly. The sheer size and cost of the equipment has, however, been an impediment to the widespread use of the sound intensity technique. This paper presents a small, battery-operated intensity analyzer which allows field measurements to be done conveniently in octaves and broadband. To illustrate the usefulness of the analyzer, a measurement of sound insulation between two rooms in a building is described.

SOMMAIRE
Les mesures d'intensité sonore se répandent de plus en plus, ainsi que leur gamme d'applications. Jusqu'à présent, la taille et le coût des équipements constituait toutefois un obstacle à l'utilisation généralisée de l'intensité sonore. Cet article présente un petit analyseur d'intensité, alimenté par accumulateurs, qui permet d'effectuer des mesures sur le terrain d'une façon pratique, en octaves et en large bande. Une mesure d'isolement sonore entre deux pièces d'un bâtiment illustre l'utilité de l'analyseur.

ZUSAMMENFASSUNG
Die Messung der Schallintensität gewinnt immer mehr an Popularität und mit ihr wächst auch deren Anwendungbreite. Schon die Kosten und Größe der Ausrüstung waren dem verbreiteten Gebrauch der Schallintensitätsmeßtechnik bisher immer ein Hinderungsgrund. Dieser Artikel stellt Ihnen einen kleinen, batteriebetriebenen Intensitätsanalysator vor, der bequeme Messungen vor Ort ermöglicht. Um die Zweckmäßigkeit des Analysators zu demonstrieren, wird die Messung der Schalldämmung zwischen zwei Räumen eines Gebäudes beschrieben.

Introduction

Many useful investigations using sound intensity may be devised in the laboratory. The natural environment for this technique is, however, the acoustically undefined surroundings found in the field, e.g. the factory floor, cars and aeroplanes or dwellings. Up to now, the size and cost of the equipment has limited the amount of intensity measurements done in the field.

This paper presents a small battery-operated sound intensity analyzer. The measurement of the apparent sound reduction index between two rooms in a house illustrates the use of the instrument.

Instrumentation

The following section presents intensity measurements which were made with a small, battery-operated intensity analyzer, the B & K Type 4433. The Type 4433 weighs less than 6 kg and runs for more than 7 hours continuously on its internal batteries. Its small size (138 mm × 251 mm × 300 mm) allows it to be brought right to the measurement site for easy monitoring of results even when space is very restricted.

The analyzer allows measurement of pressure and particle velocity and intensity to be made in octaves from 63 Hz to 8 kHz. Broadband (linear and A-weighted) measurements can also be made. Furthermore, it is possible to A-weight the octave measurements directly. Automatic scanning of the filters and setting of the input and output amplifiers makes the instrument easy to use. Stored spectra may be transferred to external equipment via the built-in serial and parallel interfaces.

The analyzer is designed to be used with a probe which consists of two phase-matched microphones. The ½ inch matched pair Type 4183 is equipped with phase correctors (Ref. [1], [2]) that ensure close phase matching between the microphones at low frequencies.

It is principally the phase mismatch between the two channels which determines the ability of an intensity system to make general measurements of sound fields. This phase mismatch, expressed as the Residual Intensity Index $L_{K,0}$ (Ref. [3]), has been measured for an intensity system (Fig.1).

The systems will allow measurements with less than 1 dB error in sound fields where the difference L_K between the measured intensity and pressure levels is numerically 7 dB smaller than $L_{K,0}$ (Ref. [3]).

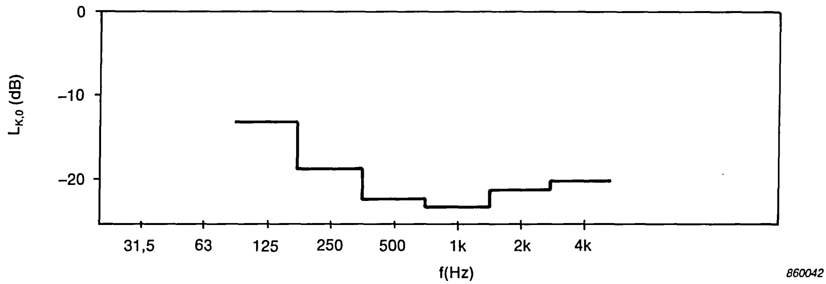

Fig. 1. The measured Residual Intensity Index for the 4433/Probe for a microphone spacing of 12 mm

Measurement of Sound Insulation between Two Rooms in a Building

This section compares the result of a classical sound insulation measurement with the sound insulation found by using the portable intensity analyzer. The individual contributions from party wall and flanking walls are also determined.

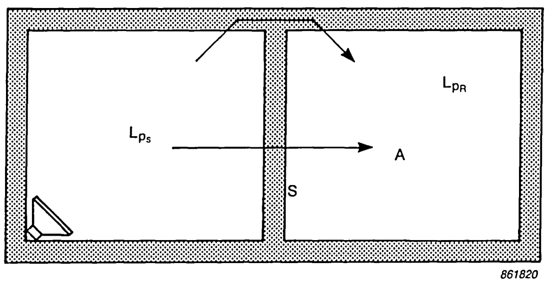

Fig. 2. Classical measuremnet of sound reduction index

Classically, ISO 140/IV (Ref. [4]) gives the apparent sound reduction index R', see Fig. 2,

$$R' = L_{pS} - L_{pR} + 10\log(S/A) \qquad (1)$$

L_{pS} : Average sound pressure level in source room
L_{pR} : Average sound pressure level in receiving room
A : Absorption area in receiving room
S : Area of party wall

The sound fields in both rooms are assumed to be diffuse.

With the intensity method, only the sound field on the source room side needs to be diffuse. The power impinging on the party wall is, as in eq. (1), estimated from the average sound pressure in the source room. The power injected into the receiving room through any surface with area S_n is determined by direct measurement of the average intensity level L_{I_t} normal to that surface. R' is now given by, (see Fig. 3):

$$R' = L_{pS} - 6\text{ dB} + 10\log_{10}(S_n/S_0) - 10\log_{10}\sum_{n=1}^{6} 10^{\frac{1}{10}\left(L_{In,t} + 10\log_{10}(S_n/S_0)\right)} \quad (2)$$

$S_0 = 1\ m^2$

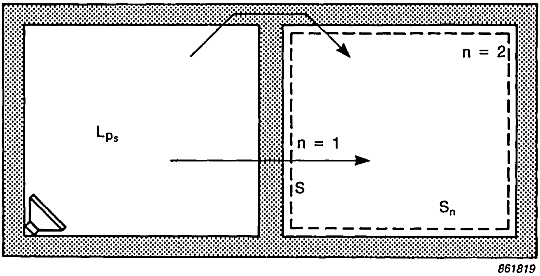

Fig. 3. Sound reduction index measurement using intensity

For the nth wall (Ref. [5]):

$$R' = L_{pS} - 6\text{ dB} - L_{I_t} + 10\,\text{Log}\,(S/S_n) \quad (3)$$

Measurement Precautions

The measured intensity in the receiving room is a superposition of intensity emitted from the walls and intensity absorbed by the walls. The latter must therefore be insignificant in order for the measured intensity to be a correct estimate of the emitted intensity. Ref. [5] shows that the error on the emitted intensity estimate on wall n due to absorption is given by:

$$\epsilon_n = 10\log\left(1 - \frac{A_n}{A}\cdot\frac{W}{W_n}\right) \quad (4)$$

A : Total absorption area in receiving room
A_n : Absorption area of surface n
W : Total power injected into receiving room
W_n : Power injected into receiving room by surface n

In a given situation ϵ_n may be minimized by increasing A, i.e. by adding absorption to the central part of the receiving room. This will also numerically decrease the Reactivity Index L_K and thus reduce instrumentation bias errors. Reference [5] gives an approximate expression for the Reactivity Index $L_{K,n}$ in front of surface n:

$$L_{K,n} \cong -10 \log \left(\frac{8\ WS_n}{A\ W_n} \right) \tag{5}$$

Absorption of wall	i) Flanking Wall		ii) Party Wall	
α	ϵ_1 dB	$L_{K,1}$ dB	ϵ_2 dB	$L_{K,2}$ dB
0,01	−0,2	−14,6	−0,05	−10
0,1	−1,8	−16,3	−0,5	−10,5

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Table 1.

Table 1 illustrates errors and Reactivity Index (as an example) for a room of 38 m^3, reverberation time 0,5 s, party wall area 8,3 m^2, and the area of one flanking wall of 18,6 m^2. It is assumed that 3/4 of the power is injected through the party wall and the remaining 1/4 is injected via the flanking wall.

Measurement Conditions

The measurements were done on the ground floor in a two-storey building belonging to the Building Research Establishment (BRE) in Watford, England. A ground plane drawing of the building is shown in Fig. 4. The party wall, consisting of 225 mm bricks with plaster on both sides, extends up to the roof. No signifcant transmission was therefore estimated to take place via the ceiling. Neither the concrete floor nor the back wall was likely to contribute very much. It was therefore decided to measure only the party wall and the two flanking walls. The absorption coefficient of the walls was estimated to be around 0,01.

Measurements

For comparison, a classical measurement of apparent sound reduction index was first made. The average reverberation time in the receiving room with three persons present was 1,4 s. Assuming that one quarter of the total power is emitted from each of the flanking walls, ϵ_n and $L_{K,n}$ for these walls was found to be −0,5 dB and −19 dB. Wall absorption could then be neglected. It was nevertheless necessary to introduce additional

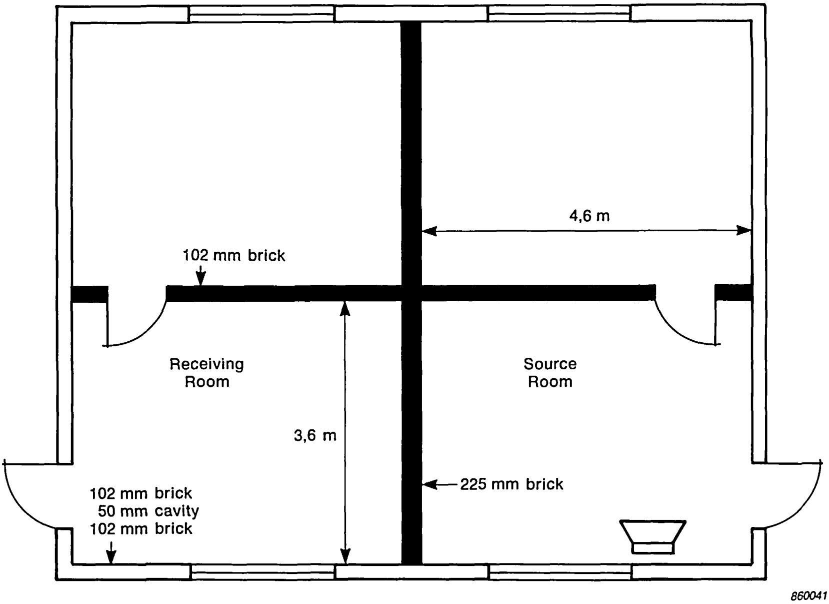

Fig. 4. Ground plane drawing of building

absorption in the room to decrease the magnitude of $L_{K,n}$. Fig. 1 shows that the 4433/4181 combination allows measurements with less than 1 dB error to be done with $|L_{K,n}| < 14$ dB at 2 kHz. Foam blocks were now placed in the room, the average reverberation time decreased to 0,5 s., and $L_{K,n} \cong -15$ dB was found to be close enough for a start. During the measurement the foam was placed along the wall behind the operator to provide more absorption efficiently. First, the contribution from the party wall was determined. The wall was divided up into 30 areas, 0,3 m^2 each, and the normal intensity was measured at 30 points about 20 cm from the wall. The distance was not critical and it emerged that there was very little variation of the intensity level along the surface, so that much less than 30 points could have been used. The flanking walls were then divided in only 10 and 11 segments respectively, and the segments were laid out to follow the door and the window. With segments of approximately 1 m^2 in size it was decided to move the probe in a circle instead of carrying out a point measurement. The level in the receiving room was very low and a true sweep measurement tended to create too much background noise from the operator. The frequency range from 125 Hz to 250 Hz was measured with a microphone spacing Δr = 50 mm, whereas Δr = 12 mm was used for the rest of the frequency range.

Discussion of Measurement Results

Fig. 5 shows the measurement results. There is a very good agreement between the classical measurement and the sum of the contributions from the party wall and the two flanking walls from 250 Hz and up to 4 kHz. In the bands around 250 Hz and 500 Hz the major contribution comes from the party wall whereas the flanking walls are just as important at higher frequencies. The discrepancy between the two sets of measurements in the 125 Hz octave band is probably due to measurement inaccuracy of the classical method. The uncertainty is known to be about 2 dB at 125 Hz.

The Reactivity Index L_K was found to be −8 to −10 dB for the party wall and −10 to −13 dB for the flanking walls.

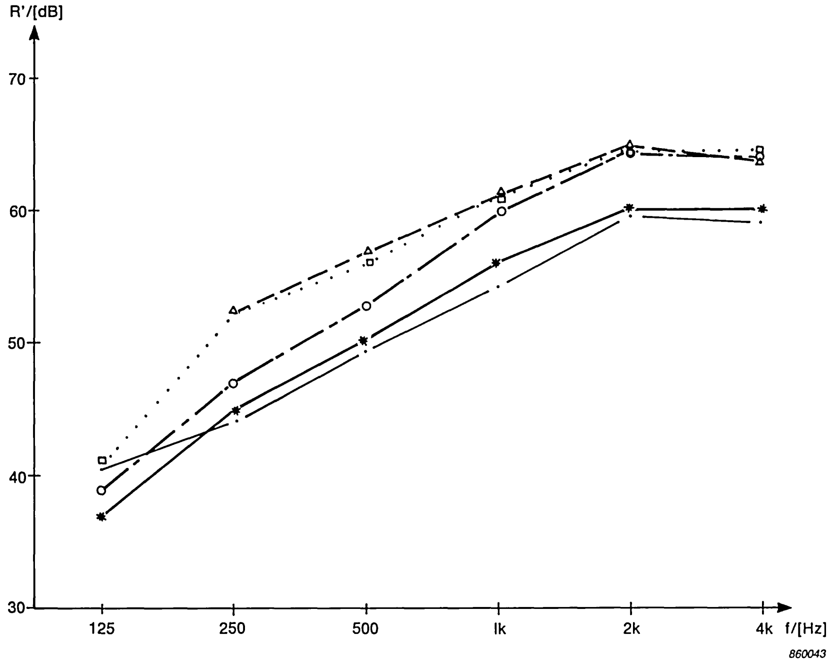

Fig. 5. Measurements of apparent sound reduction index R′.
·—· Classical measurement.
**—* Intensity measurement (party wall + 2 flanking walls)*
O-·-O Intensity measurement, party wall.
Δ---Δ Intensity measurement, flanking wall with window.
□···□ Intensity measurement, flanking wall with door

Conclusion

A battery-operated intensity analyzer was used to measure sound insulation between two rooms in a house. Information was obtained about the relative importance of flanking transmission, and the overall apparent sound reduction index shows very good agreement with results obtained by the classical method.

Acknowledgement

I would like to thank the staff at the BRE acoustics department for their assistance with the sound insulation measurements.

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PRESSURE MICROPHONES FOR INTENSITY MEASUREMENTS WITH SIGNIFICANTLY IMPROVED PHASE PROPERTIES*

by

Erling Frederiksen
and
Ole Schultz

ABSTRACT

Pressure microphones are widely used for intensity measurements even if stringent requirements are set on similarity of their phase characteristics. Frequency range and accuracy of systems are limited by phase errors at low frequencies and in reactive fields. Microphones are therefore carefully selected to match each other in pairs. New microphone types have been developed; they are partly characterized by a significantly smaller low frequency phase spread which makes formation of closer matched pairs possible. Properties of the microphones, their phase calibration and some advantages in their use and calibration are described.

SOMMAIRE

Les microphones de type pression sont largement utilisés pour les mesures d'intensité même s'il doivent satisfaire des conditions draconiennes en ce qui concerne leurs caractéristiques de phase. La gamme de fréquence et la précision des systémes sont limitées par les erreurs de phase à basse fréquence et dans les champs réactifs. Les microphones sont donc soigneusement appariés. De nouveaux modèles de microphones ont été conçus: ils sont entre autres caractérisés par une dispersion de phase plus faible à basse fréquence, ce qui rend possible des appariements plus proches. On trouvera une description des propriétés des microphones, de leur étalonnage en phase, de leurs avantages en ce qui concerne leur utilisation et leur étalonnage.

* First printed in ICA Proceedings 1986

ZUSAMMENFASSUNG

Druckmikrofone werden vielfach für Intensitätsmessungen angewendet, selbst wenn strenge Anforderungen an deren Phasencharakteristik gestellt werden. Frequenzbereich und Systemgenauigkeit sind bei niedrigen Frequenzen und in reaktiven Feldern durch Phasenfehler begrenzt. Daher werden Mikrofone paarweise sorgfältig so ausgewählt, daß deren Phasengang übereinstimmt.
Es wurden neue Mikrofontypen entwickelt; diese zeichnen sich u.a. durch eine deutlich kleinere Phasenstreuung bei niedrigen Frequenzen aus und ermöglichen somit die Bildung von Mikrofonpaaren mit näher beieinanderliegenden Phasengängen. Eigenschaften der Mikrofone, ihre Phasenkalibrierung, einige Vorteile bei der Anwendung und Kalibrierung werden beschrieben.

Introduction

Application of pressure microphones for sound intensity measurements places stringent requirements on the microphone phase characteristics. No particular characteristic is required, but the chracteristics of microphones used together should ideally be identical. This is especially necessary at low frequencies and in highly reactive fields where very small phase differences must be detected.

Microphones cannot be produced within the needed phase tolerances even under carefully controlled production conditions. Sets of matching microphones are therefore obtained by selection; in spite of this the microphones are the limiting factor in intensity measurement systems of today.

New microphones and a new phase calibration method have been developed. This is described together with extended possibilities for the measurement of sound intensity opened by these new microphones.

Traditional Microphones

There are a number of mechanical and acoustical elements which determine the phase response characteristic of a microphone. Most of them are in this connection of no importance as in production they can be reproduced very accurately.

Two mechanisms cause significant phase spread between microphones within a type.

At higher frequencies the diaphragm damping causes a spread which is practically proportional to the frequency; at 1000 Hz it is typically 2 deg., while the phase discrepancy is less than 0,2 deg. for selected pairs of the same type. Comparison of this discrepancy with the differences in actual sound fields shows that damping has a minor frequency independent influence on the intensity measurement accuracy.

At low frequencies the pressure equalization causes a spread which is very disturbing for intensity measurements due to the small phase differences of low frequency sound fields.

To ease the explanation of the ideas behind the new microphones the reasons for the phase shift of the traditional ones will initially be discussed.

The diaphragm's deflection and thus the microphone's output signal is determined by its front and rear-side pressure. The rear pressure is the pressure in the internal cavity which is connected to the outside via the venting channel. Due to the nature of the cavity (compliance) and the vent (resistance) an external pressure signal causes a cavity pressure with a magnitude which decreases proportional to frequency and with a phase lag of about 90 deg. above 20 Hz.

This phase lag rear-side pressure leads to a resulting phase lead of the microphone's low frequency response which is typically between 2 and 6 deg. at 20 Hz. The significant variation is mainly due to technical reproducibility problems with the vent resistances.

Microphones in sets are selected to be typically within 0,2 deg. at 20 Hz, which together with the independent selection at high frequencies makes the selection a time consuming task.

New Microphones

To solve the low frequency phase problem the influence of the diaphragm's rear-side pressure should be minimized. Two different solutions have been analyzed theoretically and experimentally; see Ref.[1].

The significant influence which the rear-side pressure has on the phase response can be reduced by attenuation of the pressure's magnitude and by a change of its phase.

Both effects were present in the first experimental microphones; they were designed with an extra resistance-compliance network connected in series with the primary vent.

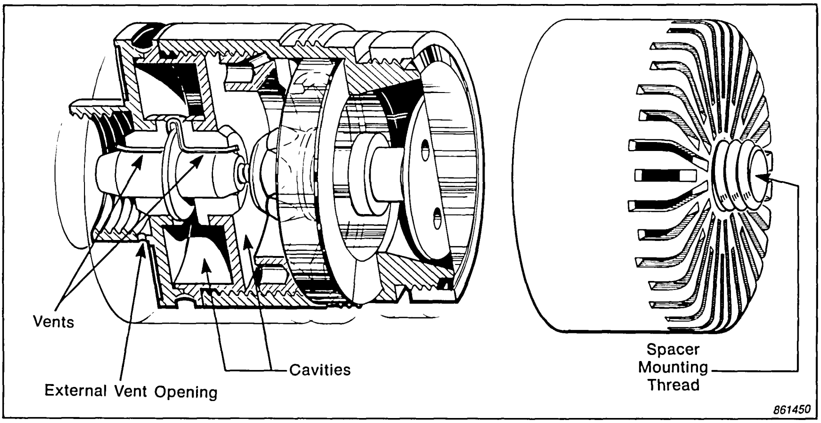

Fig. 1. New pressure microphone with two extra RC-networks*

The extra network had a cut-off frequency corresponding to that of the primary venting system; it caused a phase shift of a further 90 deg. and an extra magnitude reduction which at 20 Hz was about 20 dB.

This modification gave a significant phase characteristic improvement which was partly due to the favourable phase shift (about 180 deg. in total), and partly due to the attenuation of the rear pressure.

The second type of microphones contained two extra RC-networks; after analysis this solution was preferred for the new types which were developed; the two networks are built into an extension of the microphone housing; see Fig. 1. The combined effect of all three networks is a phase lag of the diaphragm's rear pressure of about 270 deg. (a lead of 90 deg.). This angle is actually as critical as the lag of 90 deg. in the traditional microphones but the magnitude of this non-desired pressure signal in the new microphones is typically 55 dB lower at 20 Hz and it decreases for increasing frequency by 18 instead of 6 dB/oct.

This explains why the new types have far less low frequency phase spread than earlier types and additionally they have very low sensitivity to sound pressure at the external opening of the pressure equalization system. Advantages of this last mentioned property will be discussed later.

* B & K patent pending

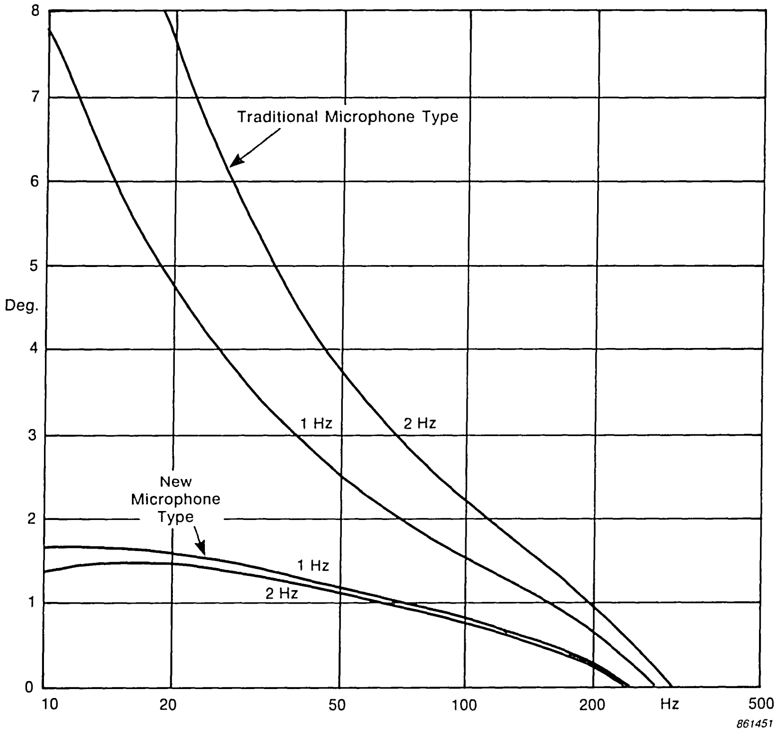

Fig. 2. Phase characteristics for cut-off frequencies of 1 Hz and 2 Hz of primary venting systems

Mathematical microphone models have been made for all the types which have been mentioned. The models used are quite detailed; for instance they include the heat conduction effect which especially at low frequencies influences the impedance of cavities.

Calculated phase response characteristics are shown in Fig. 2 for a new and for a traditional type; in both cases calculations are made for cut-off frequencies of the primary venting network of 1 Hz and 2 Hz respectively. Notice the significantly smaller phase deviation of the new type, however, there is an influence from the production tolerances of the extra networks but the resulting spread is reduced by more than a factor of 15.

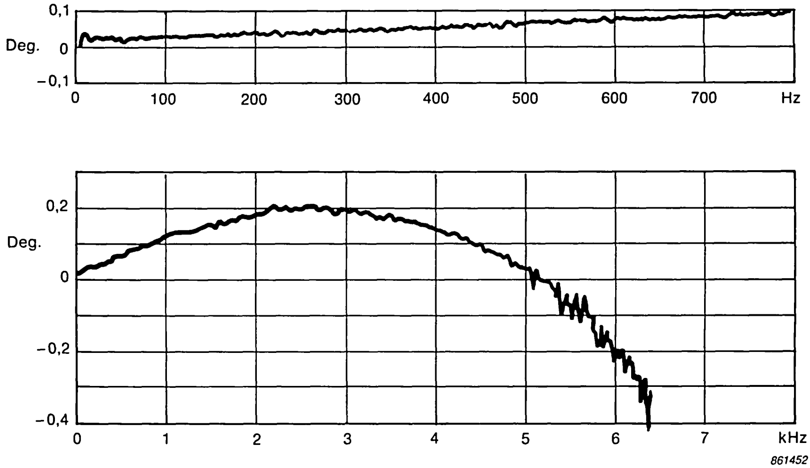

Fig. 3. Phase calibration for typical pair of new microphones

Sets of the new microphones are selected to a low frequency matching better than 0,05 deg. which corresponds to a reduction of a factor of 4 in comparison with existing microphone sets. Further reduction is actually possible but of no practical use due to dominating phase discrepancies of the associated intensity instrumentation. Fig. 3 shows a phase calibration of a typical new microphone set.

Advantages gained for Intensity Measurements

The frequency range, dynamic capability and measurement accuracy of intensity instrumentation can be improved by the new and better matched microphone sets due to reduced system phase errors below about 300 Hz; system errors are typically reduced by a factor of 2 at 20 Hz, and are dominated by electronic mismatch. Measurement ranges for probes with new and old microphone sets are calculated and shown in Fig. 4.

Other advantages are related to the fact that the new microphones have a very low vent sensitivity which brings them close to the ideal of being sensitive only to the diaphragm pressure – they have become single-port microphones.

One consequence of this is that most practical calibrations can be made simpler, for instance by the use of small (wide band) couplers, as only the diaphragms have to be exposed to the sound pressure; phase

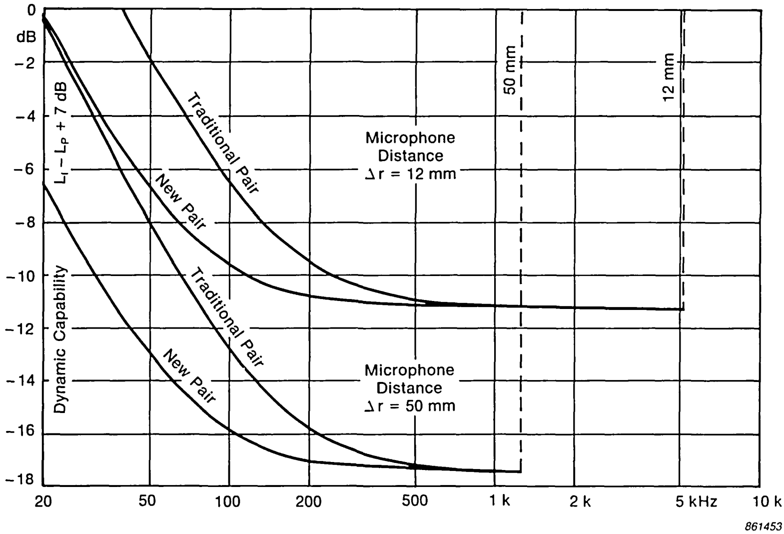

Fig. 4. Measurement ranges (minimum) for probes with new and traditional microphone pairs, for an error < 1 dB

calibration by electrostatic actuators in parallel has also become a possibility for these microphones.

Furthermore point source measurements are improved; this is described in Appendix B and Ref.[1].

Phase Calibration Method

To measure the small phase errors of the new microphone sets a better method had to be found.

As a phase measurement system having sufficiently small absolute phase errors is not available the interchange principle which excludes system phase errors is applied. The phase discrepancy between the microphones is found by two measurements where the second measurement is performed with interchanged microphones.

The set-up shown in Fig. 5 was chosen due to its good resolution and stability. The sound source of the phase clibration coupler is excited by the pseudo random noise generator of the Type 2032 analyzer. The cross and auto spectra of the two microphone signals are measured before

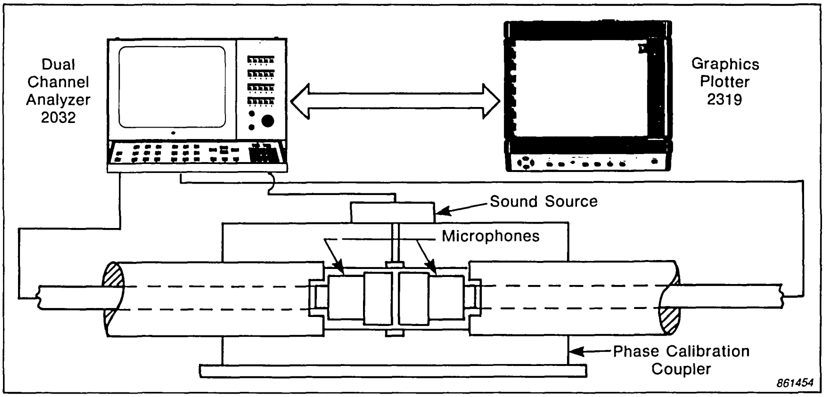

Fig. 5. Measurement set-up for phase calibration

and after the interchange of the microphones. In equalized frequency response mode the phase result (in radians) is equal to half of the imaginary part of the ratio between the two frequency response functions. The results are only valid for small phase discrepancies, but this condition is fully satisfied for the actual application.

Measurements of phase discrepancies below 1 deg. have been performed with an accuracy of 0,005 deg. and a resolution of 0,001 deg. by the use of the analyzer, Type 2032.

A wide-band phase calibration coupler has also been developed. In this cylindrical coupler the two microphones are placed closely together on the coupler axis with their protection grids facing each other. The microphone vents are also inside the coupler cavity even though this is of no importance above 20 Hz for the new microphones, due to their extremely low vent sensitivity.

The sound inlet to the coupler which consists of a number of ports is designed to produce a rotational symmetrical sound field inside the coupler over the frequency range from 20 Hz to about 6 kHz. During calibration the microphones are excited from the periphery as when they are slit-mounted in intensity probes.

Examples of calibration results covering 0–800 Hz and 0–6,4 kHz respectively are shown in Fig. 3. See also Appendix A.

Conclusion

New microphone types characterized by a very low vent sensitivity and a small low frequency phase spread have been developed. Improved intensity microphone sets are selected from these. Existing intensity measurement systems can utilize most of the advantageous properties which are obtained.

Before the reduced phase discrepancy can be fully used one has to wait for a reduction of phase errors in the electronic equipment which at low frequencies has taken over the role of being the limiting factor.

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Appendix A

Measurement of Small Phase Differences between Microphones

As the ICA–paper had to be very condensed more details shall be given in this Appendix on the application of Type 2032 for Measurement of small Phase Differences between Microphones. In *Dual Spectrum Averaging* mode two measurements are performed. The microphones are interchanged between the first and the second measurement. *Pseudo Random Noise* excitation is used.

Measurement Result (1) $$MR_1 = \frac{p_A \times M_1 \times A_A}{p_B \times M_2 \times A_B}$$

Measurement Result (2) $$MR_2 = \frac{p_A \times M_2 \times A_A}{p_B \times M_1 \times A_B}$$ where

p_A, p_B : Sound pressure at microphones in channels (A) and (B) respectively
M_1, M_2 : Sensitivities of microphones (1) and (2) respectively
A_A, A_B : Amplification of channels (A) and (B) respectively.
All parameters are complex.

In *Equalized Frequency Response* mode the following Equalized Result *ER* is calculated and displayed:

$$\frac{MR_2}{MR_1} = ER = \frac{M_2^2}{M_1^2} = \frac{S_2^2\,(\cos\phi_2 + j\sin\phi_2)^2}{S_1^2\,(\cos\phi_1 + j\sin\phi_1)^2}$$

$$ER = \frac{S_2^2}{S_1^2}\left\{\cos\big(2(\phi_2-\phi_1)\big) + j\sin\big(2(\phi_2-\phi_1)\big)\right\}$$ where

S_1, S_2 : Sensitivity magnitudes of microphones (1) and (2) respectively
ϕ_1, ϕ_2 : Absolute phase angles of microphones (1) and (2) respectively.

Data Presentation
Although the Analyzer Type 2032 could display the magnitude and phase differences directly, the result should be displayed in terms of *Real* and *Imaginary Parts* as this leads to the high resolution which is needed for this application.

Division of the Equalized Result, *ER* contained in the 2032 memory by twice its *Real Part, ER* (re.) would lead to the following result,

$$ER\,/\,(2 \times ER\,(\text{re.})) = 0{,}5 + j\,0{,}5 \tan\,(2\,(\phi_2 - \phi_1))$$

This division can in practice be achieved by post adjustment of the value in the *Calibration Field* of Type 2032 for one of the microphone channels to the number which makes the *Real Part* of the result, *ER* (re.) equal to "0,5".

Of course a computer could be utilized to calculate the angle exactly, but for angles as small as those of interest in connection with phase matching intensity microphones, the desired angle difference is very close to the imaginary part of the adjusted result,

$$\phi_2 - \phi_1 \approx ER\,(\text{im.})\,/\,(2 \times ER\,(\text{re.}))\quad (\text{radians})$$

The imaginary part of the adjusted result becomes equal to the angle in degrees if its real part is adjusted to 28,65 (equal to $180/2\pi$).

The approximation errors are less than:

0,1% for $(\phi_2 - \phi_1) < 1{,}57$ degrees (0,027 radians)
1,0% for $(\phi_2 - \phi_1) < 4{,}92$ degrees (0,086 radians)

Note that a correct adjustment should be made at each frequency, but microphones having nearly equal phase characteristics will also be nearly equal with respect to magnitude response, and therefore only small errors will occur in the actual frequency range if equalization for practical reasons is only made at one frequency.

High resolution and accuracy can therefore be obtained in this way for small angle differences; the result can be displayed directly on the screen of Type 2032 or it can be recorded on an X–Y recorder Type 2308 as shown in the main text.

Appendix B

Additional Advantage of New Microphones

The low sensitivity to the sound pressure at the outside opening of the venting system, which is a characteristic of the new microphones, means that they will lead to more accurate measurement results than microphones of the traditional design. For example, measurements close to point sources can be made more accurately.

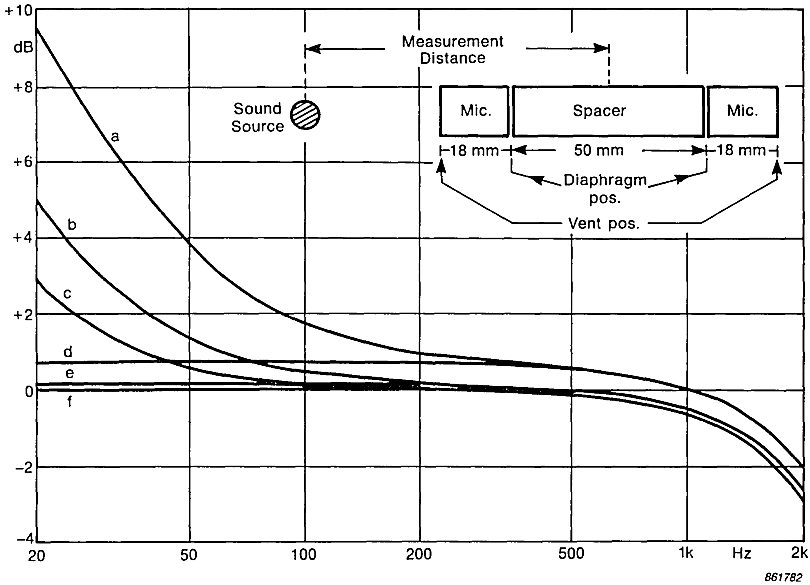


Fig. B1. Intensity Probe Frequency Responses close to a Point Source when equipped with Traditional Microphones of 2 Hz cut-off frequency and with New Microphones
a), b) and c) Traditional Microphones; source distances are 63 mm, 125 mm and 250 mm respectively
d), e) and f) New Microphones; same distances respectively.
The curves which are calculated are valid for the indicated distances between source and centre of spacer

Selection of pairs of traditional microphones are made with the same signal amplitude at the diaphragm and the vent. In practice this condition exists in a plane wave but not close to point sources for sound incidence along the intensity probe axis. The phase response of the two microphones will therefore in such cases be different and thus lead to wrong results, which corresponds to a change in the frequency response of the intensity probe including the microphone pair. The change depends on the distance from the source to the probe, but also on the microphone spacing and the distance between the diaphragm and the vent opening.

To show the advantages of the new microphones, frequency responses have been calculated for probes with traditional and new microphones for various source distances, see Fig. B1. It is clearly seen that new microphones should be preferred for point source measurements at low frequencies. Practical tests have indicated similar results.

MEASUREMENT OF ACOUSTICAL DISTANCE BETWEEN INTENSITY PROBE MICROPHONES

by

Erling Frederiksen
and
Morten Piil

ABSTRACT

For accurate intensity measurements, one of the most important parameters is the phase difference between the microphone signals or the acoustical distance between the microphones of the intensity probe. This article describes a laboratory method for accurate measurement of this distance as a function of frequency, and gives practical details to be taken care of during calibration. Measurement results for two probe configurations are presented.

SOMMAIRE

Pour des mesures d'intensité précises, un des paramètres les plus importants est la différence de phase entre les signaux microphoniques ou la distance acoustique entre les microphones d'une sonde d'intensité.
Cet article décrit une méthode de laboratoire pour une mesure précise de la distance en fonction de la fréquence et donne le détail pratique des précautions à prendre pendant l'étalonnage. Les résultats de mesure pour deux types de sonde sont présentés.

ZUSAMMENFASSUNG

Die Phasendifferenz zwischen den Mikrofonsignalen, d.h. der akustische Abstand der Intensitätssondenmikrofone, ist einer der wichtigsten Parameter bei genauen intensitätsmessungen. In diesem Artikel wird eine Labormethode zur präzisen Messung dieses Abstands als Funktion der Frequenz beschrieben. Praktische Hinweise zur Durchführung der Kalibrierung werden gegeben und Meßergebnisse für zwei Sondenkonfigurationen vorgestellt.

Introduction

The most frequently used intensity probes today are those which are equipped with two or more pressure microphones. For accurate measurement of sound intensity careful analysis of the probe and microphone properties are required. One of the important parameters is the phase difference between the microphone signals or the acoustical distance between the microphones of the probe.

This distance for the intensity probe placed in a plane progressive sound wave can be calculated from the phase difference between the signals picked up by the microphones:

Acoustical Distance = Wavelength × Phase Angle Difference (degrees)/360

Due to diffraction and reflection caused by the body of the probe itself, the acoustical distance can vary as a function of frequency and thus differ from the geometrical distance. The acoustical distance also depends on the orientation of the probe in the sound field. It is a function of the angle between the probe axis and the propagation direction of the sound wave.

The distance for 0° incidence to the propagation direction is especially important as it must be taken into account by the intensity measurement system. Knowledge about distances valid for other angles of sound incidence on the probe is useful for evaluation of the quality of different types of probes.

Acoustical Measurement Requirements

For accurate measurement of the acoustical microphone distance the measurement distance between the sound source and the probe has to be typically about 1 m, so that the field around the entire probe can be considered to be a plane wave field.

As undesirable reflections from room walls and other disturbing objects can lead to significant errors, the pressure of the reflected waves must be very small in comparison with the direct wave.

It is also important to choose a source which has a well defined position of its acoustical centre for all frequencies of interest; it should preferably be rotationally symmetrical and the sound should be emitted from only one rather small outlet to minimize uncertainty with respect to angle of sound incidence on the probe.

Even if distance measurements are made in good anechoic rooms disturbing reflections will usually lead to significant phase or distance errors. Therefore, to exclude the influence of the disturbing reflections and to obtain good measurement resolution and reproducibility, the following microphone distance measurement method was utilized.

Measurement Procedure

The measurement set up is shown in Fig. 1. The main instrument is the Dual Channel FFT Analyzer, B & K Type 2032. As the measurements were found to be very sensitive to environmental low-frequency noise a Measuring Amplifier, B & K Type 2610, is connected in series in each of the two analyzer channels. These amplifiers are equipped with high-pass filters of 140 Hz cut-off frequency (20 dB/decade). The built-in generator of Type 2032 supplies the necessary measurement signals.

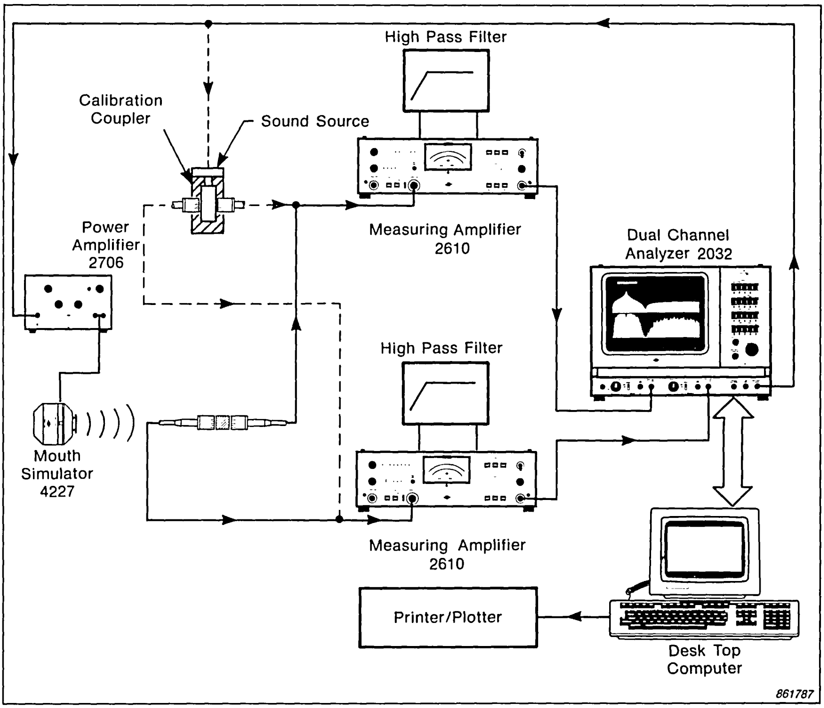


Fig. 1. Measurement Set-up

Two different measurements were carried out. In the first measurement, a system phase calibration was made to determine the generally small (but quite important for accurate measurements) phase differences between the two system channels which include microphones and preamplifiers. The diaphragms of the microphones of the dismantled probe are exposed to exactly the same sound pressure in a small cavity (about 1 cm^3). With the generator in its *Pseudo Random Noise* mode and the analyzer in *Dual Spectrum Averaging* mode two hundred spectra were averaged to obtain the resulting two Auto Spectra and the Cross Spectrum. The result was stored in the analyzer memory to be used for post correction of the second measurement from which the distance is determined.

Because of the small dimensions of the coupler and close face to face positioning of the microphones (distance 2 mm) this pressure calibration can be made with an error significantly lower than 0,05 deg. below 1 kHz and below 0,1 deg. up to 6,4 kHz.

As the set-up and the actual microphones which were calibrated revealed high stability, the result obtained could be used for correction of several measurements which were performed afterwards. After the phase calibration the probe was assembled and placed in an anechoic room about one meter in front of a Mouth Simulator, B & K Type 4227, which acted as the sound source. The mouth is operated via a Power Amplifier, B & K Type 2706 from the generator of Type 2032, which is set to its *Impulse* operating mode.

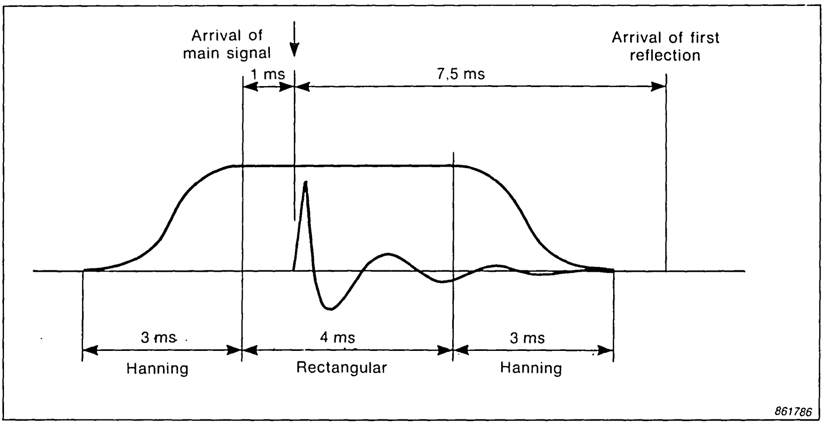


Fig. 2. Time window applied to the signals

The impulses picked up by the microphones are led to the analyzer which is triggered by the generator. A time weighting function or time window as shown in Fig. 2 is applied to the time signals. The analyzer is kept in *Dual Spectrum Averaging* mode where two hundred spectra are averaged to get the Auto and Cross Spectra to achieve the result of this measurement.

In the display mode *Equalized Frequency Response* the desired phase difference is obtained. The phase data are transferred to the Desk Top Calculator which converts phase to distance and plots the results as a function of frequency.

The attenuator setting and calibration level which are selected for this measurement should also be chosen for the first measurement in order to ensure that the minor phase differences which might be present between attenuator positions will not give rise to uncertainty of the final measurement result.

Measurement Results and Comments

A probe configuration and the corresponding measurement result is shown in Fig. 3. The configuration consists of two 1/2″ microphones and two 1/4″ preamplifiers with a nominal 12 mm spacer.

An anechoic room was chosen for all the measurements due to its low back ground noise level, and not because of its small amount of

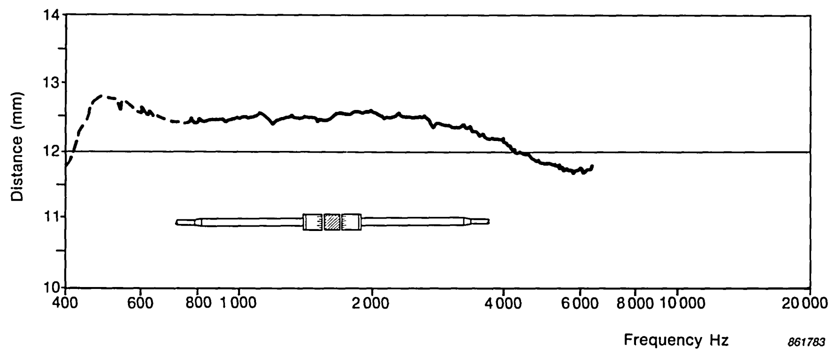


Fig. 3. Acoustical distance as a function of frequency for configuration with 1/2″ Microphones and 1/4″ Preamplifiers using coupler measurements for system phase correction

reflections as they are effectively excluded by the time window. The smoothing on the front and rear part of the flat window was used to reduce the influence on the high frequency content of the spectrum by low frequency environmental noise and by the tail of the impulse signal. The time window was shut approximately 0,5 ms before the arrival of the first reflections originating from the wire mesh floor of the room which was about 1,6 m below the source and the probe. The results are not valid below approximately 800 Hz because of the application of the time window. With more space available this could be improved by expansion of the time window.

To obtain good results for larger microphone distances the time window for one of the channels should be delayed according to the delay time of the signal.

As described, the result shown in Fig. 3 was obtained as a distance measurement in which the system phase errors were eliminated using the results from the coupler measurements.

To ensure that the coupler measurements can be used for eliminating system phase errors some extra measurements were made with symmetrical probes, i.e. probes which are identical in opposite directions. For such probes no coupler measurement is necessary. However, two free field measurements have to be carried out; after storage of the first measurement result the probe is turned 180° around for the orientation

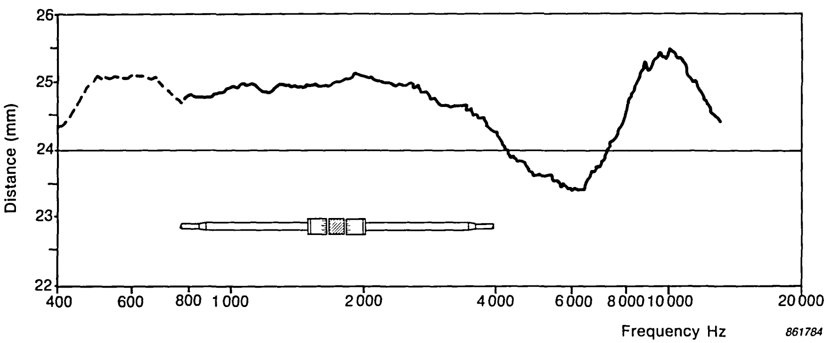


Fig. 4. Acoustical distance (2 times) as a function of frequency for configuration with 1/2″ Microphones and 1/4″ Preamplifiers using two free field measurements

used for the second measurement. The result is again obtained in *Equalized Frequency Response* mode. It is equal to twice the desired phase difference (microphone distance) and contains no system phase errors, as they are equal for the two measurements and are subtracted in the equalization mode. Fig. 4 shows a measurement result obtained in this manner. This method can be applied to higher frequencies as the calibration which limits the frequency range is not required.

Theoretically this method is more accurate than the first one mentioned but it can only be applied with symmetrical probes.

Results shown in Figs. 3 and 4 are valid for the same probe. Since the acoustic distance measured as a function of frequency found by the first method is very close to half that found by the second, it can be concluded that a pressure calibration using a small coupler can be used for correction of measurements of acoustical microphone distance. This is important as the method of inverting the probes is only valid if they are symmetrical.

Attention should also be paid to the measurement result and probe configuration which are shown in Fig. 5. This configuration should be very close to ideal as the mechanical dimensions are practically uniform over the whole probe. This is confirmed by the measurement result in Fig. 5 as the microphone distance is nearly independent of frequency which supports the validity of this method.

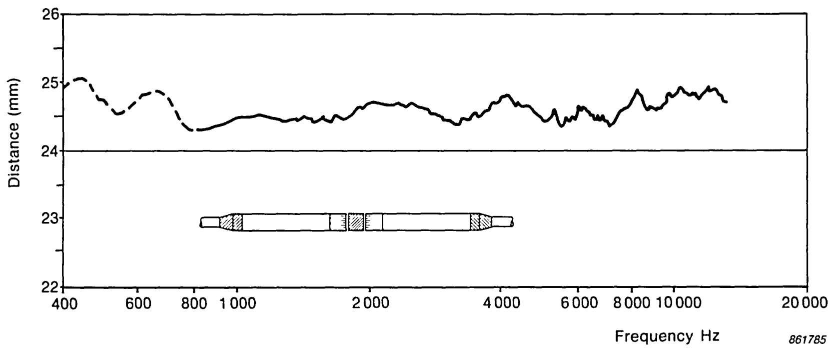


Fig. 5. Acoustical distance (2 times) as a function of frequency for configuration with 1/2″ Microphones and 1/2″ Preamplifiers using two free field measurements

Conclusion

A description is given of a practical and fast method for determination of acoustical microphone distance for intensity probes as a function of frequency.

It has been shown that accurate results can be obtained, as acoustical room reflections are suppressed and as corrections for system phase errors can be carried out. The system phase errors are found by a pressure calibration method which makes use of a small coupler.

Note: The measurement results in the paper, "Microphone Configurations used in Acoustic Intensity Probes" presented by Dr. P.V. Brüel at the 2nd Congress on Acoustic Intensity in Senlis (France) 1985 were obtained by using the method described above.

WIND AND TURBULENCE NOISE OF TURBULENCE SCREEN, NOSE CONE AND SOUND INTENSITY PROBE WITH WIND SCREEN

by

M. Brock

ABSTRACT

This article describes measurements carried out to determine the noise levels induced by different degrees of wind and turbulence in three different transducer configurations: the turbulence screen UA 0436 attached to a ½″ microphone Type 4133, the nose cone UA 0387 attached to the same microphone, and the sound intensity probe Type 3519 with the ellipsoidal wind screen UA 0781. Based on these results, recommendations are given for selecting the optimal microphone configuration for a given measurement situation.

SOMMAIRE

Cet article décrit des mesures effectuées pour déterminer les niveaux sonores produits par différentes forces de vent et de turbulences sur les trois configurations suivantes: Écran antiturbulence UA 0436 ou Ogive pour microphones ½ pouce UA 0387 adapté sur un microphone ½ pouce Type 4133, et sonde d'intensité sonore Type 3519 avec écran antivent éllipsoïdal UA 0781. Au vu de ces résultats, des recommandations sont établies pour choisir la configuration de microphone optimale dans une situation donnée.

ZUSAMMENFASSUNG

Dieser Artikel beschreibt Messungen zur Bestimmung von Schallpegeln, in drei Meßwandlern unterschiedlicher Gestalt durch verschiedene Windstärken und Turbulenzen hervorgerufen: Dem Turbulenzschirm UA 0436 und des Nasenkonus UA 0387, die jeweils an ein ½″-Mikrofon 4133 aufgesteckt werden, sowie der Schallintensitäts-Sonde 3519 mit dem Ellipsoiden Windschirm UA 0781. Auf diesen Ergebnissen basierend, werden Empfehlungen zur Wahl der für die entsprechende Meßsituation optimalen Mikrofongestalt gegeben.

Introduction

The performance of the turbulence screen UA 0436 has only been documented in relation to the performance of the nose cone UA 0387 when measured in an extremely turbulent environment. In many cases, however, it can be an advantage to have direct knowledge of the noise levels induced by wind and turbulence, and these were therefore measured on a set-up which included a fast rotating boom in an anechoic chamber. The results of these measurements are reported below.

Measurements

Three different transducers were tested: The turbulence screen UA 0436, the nose cone for 1/2″ microphones UA 0387 and the sound intensity probe 3519 with the ellipsoidal wind screen UA 0781. The latter transducer was measured in both sound intensity and sound pressure mode. The transducers were rotated at three different speeds, 10 m/s, 20 m/s and 30 m/s, and at four different degrees of turbulence. The turbulence was generated by mounting a stiff plate at a given distance in front of the transducers.

All measurements were performed using third octave digital filtering on the 3360 Sound Intensity Analyzer operating in either pressure or – for the 3519 measurement – in sound intensity mode. A Type 4133 free-field microphone was used for the pressure measurements, and a phase-matched pair of 4133 for the sound intensity measurements.

Results

Fig. 1.a. shows the wind-induced noise of the turbulence screen, the nose cone and the 3519 with windscreen (both pressure and intensity mode) measured at 10 m/s with no turbulence. Figs. 1.b and 1.c show the same curves, measured at 20 m/s and 30 m/s respectively. The 1/3 octave step curves have been smoothed out for the sake of clarity. In the case of no turbulence, the nose cone performs better than the turbulence screen at all frequencies, and above 250 Hz, the windscreen UA 0781 (pressure mode) performs even better than the nose cone. When sound intensity is measured, the wind-induced noise level becomes even lower at frequencies above 400 Hz. The explanation for this is that at these frequencies, the wind noise generated in front of and behind the windscreen is of about the same magnitude, and is thus cancelled out when sound intensity is measured.

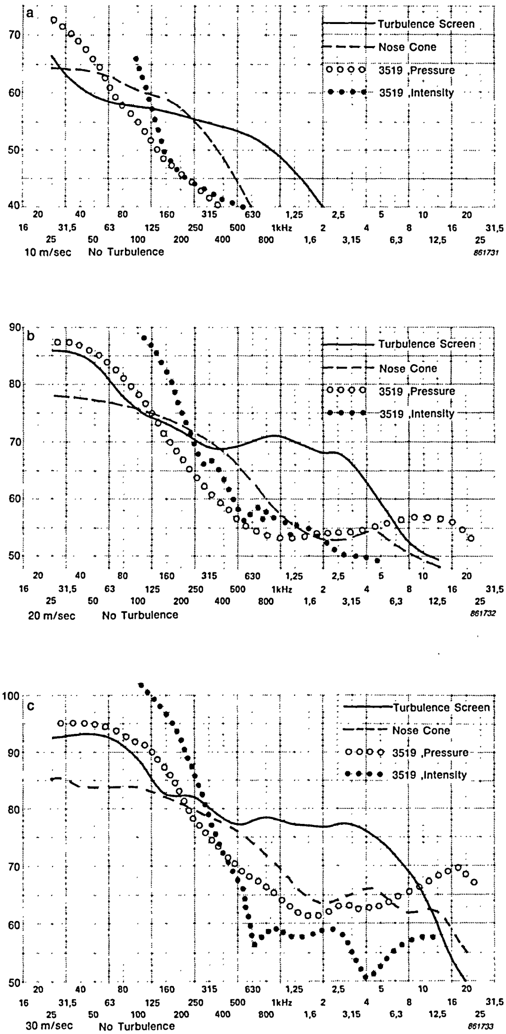


Fig. 1.a. Wind-induced noise at 10 m/s. No turbulence
b. Wind-induced noise at 20 m/s. No turbulence
c. Wind-induced noise at 30 m/s. No turbulence

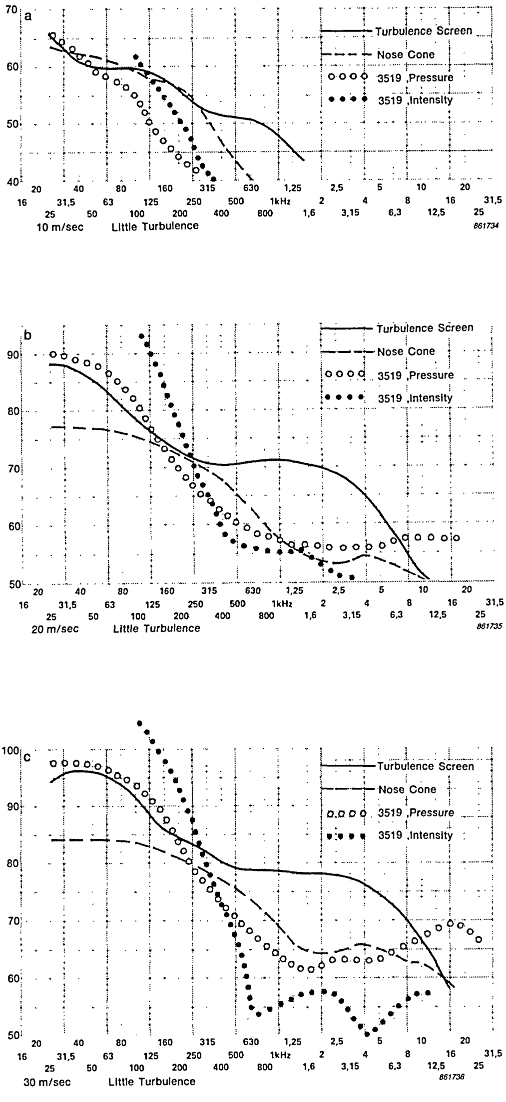


Fig. 2.a. Wind-induced noise at 10 m/s. Little turbulence
b. Wind-induced noise at 20 m/s. Little turbulence
c. Wind-induced noise at 30 m/s. Little turbulence

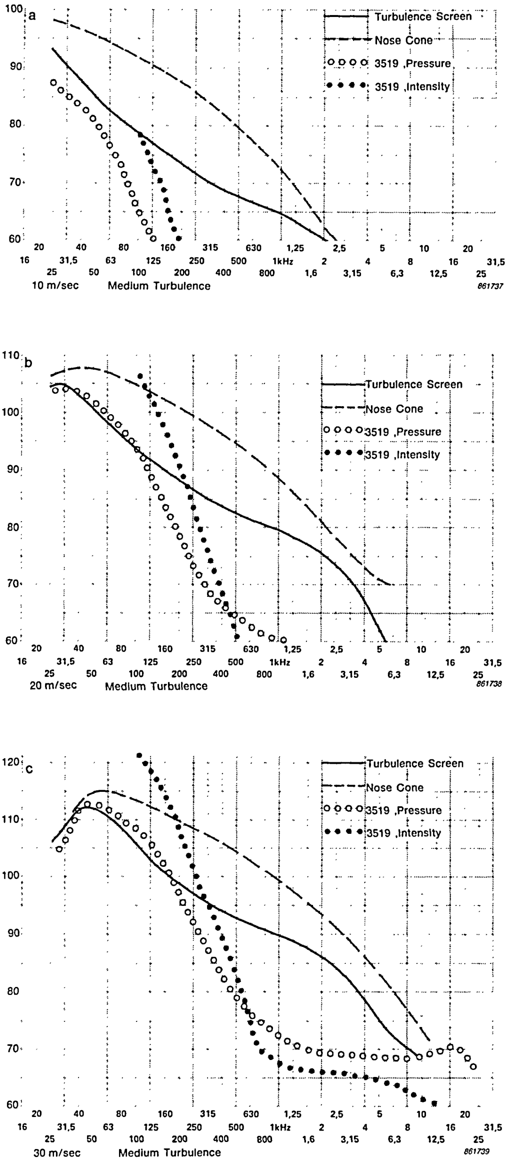


Fig. 3.a. Wind-induced noise at 10 m/s. Medium turbulence
b. Wind-induced noise at 20 m/s. Medium turbulence
c. Wind-induced noise at 30 m/s. Medium turbulence

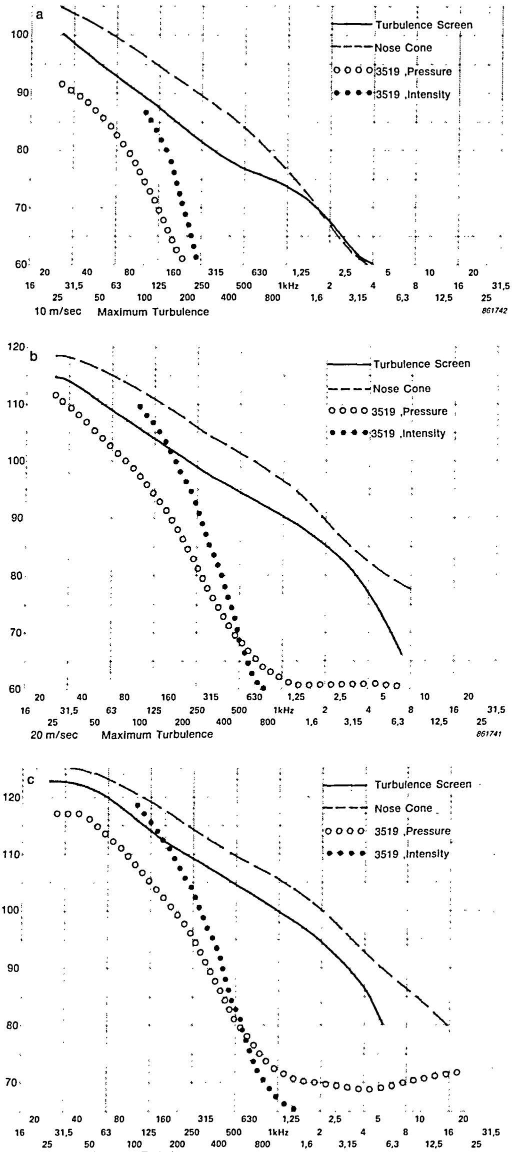


Fig. 4.a. Wind-induced noise at 10 m/s. Maximum turbulence
b. Wind-induced noise at 20 m/s. Maximum turbulence
c. Wind-induced noise at 30 m/s. Maximum turbulence

Fig. 2.a.–c is equivalent to Fig. 1.a.–c, but now the wind has become a little turbulent. In this case the turbulence was generated by mounting a stiff plate with a diameter of 200 mm on the opposite side of the rotating boom corresponding to a distance of 6 meters in front of the microphone. The influence of this plate is marginal and can only be seen at very low frequencies (below 100 Hz).

Fig. 3.a.–c shows the results for the case where the wind has become more turbulent. A stiff plate, 50 × 150 mm, has now been placed perpendicular to the wind direction, 550 mm in front of the microphone. The increase of wind-induced noise is now in the order of 30 dB compared to the non turbulent case. The measurements show that with this degree of turbulence, the turbulence screen is more effective than the nose cone in reducing the wind-induced noise. The improvement is between 5 and 15 dB. However, it appears that the 3519 with UA 0781 in pressure mode is even more effective. Especially above 200 Hz, the improvement, compared to the turbulence screen, is dramatic, and at 1 kHz, the improvement is close to 20 dB. In the sound intensity mode, the noise level is very high at low frequencies, but above 400 Hz, the wind-induced noise is lower than it is for the turbulence screen, while above 600 Hz it becomes even lower than the noise of the 3519/UA 0781 in pressure mode. Again, the explanation is that the noise generation effect is "symmetrical" at both ends of the windscreen so that the sound intensity level, which is a measure of the net flow of sound energy, is lowered.

Finally, measurements were performed in an even more turbulent field. A plate with a diameter of 200 mm was now placed perpendicular to the wind direction, 550 mm in front of the microphone. The result of these measurements is shown in Fig. 4.a.–c, and the wind/turbulence induced noise level has now increased by a further 5 – 10 dB compared to Fig. 3.a.-c. Basically, the same result as in Fig. 3 is obtained, although at an even higher sound pressure level. However, the 3519 probe with wind shield appears to be better than the turbulence screen at all frequencies when the sound pressure only is measured. Above 800 Hz, the noise induced for the intensity mode is even lower than for the pressure mode.

Conclusion

In these experiments, the degree of turbulence was not measured exactly. However, the type of mechanical arrangement used to create the turbulence and the drastic increase in wind noise indicate that different levels up to a very high degree of turbulence were measured.

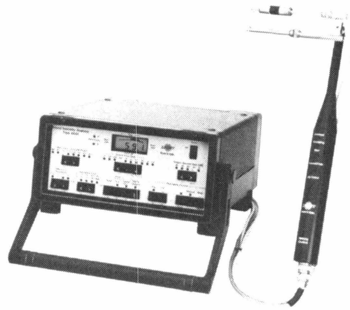
It is important to notice that in case of little or no turbulence, the nose cone performs better than the turbulence screen at all frequencies. Between 250 Hz and 4 kHz, the normal windscreen is slightly better than the nose cone, and above 500 Hz it might be advantageous to measure sound intensity. Thus the turbulence screen should never be used “just in case”.

In more turbulent wind, the turbulence screen induces less noise than the noise cone does. However, especially at frequencies above 200 Hz, the 3519 probe in pressure mode with UA 0781 performs even better than the turbulence screen. And again, above 800 Hz it can be an advantage to measure sound intensity instead of sound pressure as far as wind/turbulence-induced noise reduction is considered.

In general, it should be possible from these measurements to select the optimal microphone configuration in a given measurement situation, depending on the type of wind noise and the frequency range chosen.

News from the Factory

Sound Intensity Analyzer Type 4433
Sound Intensity Probe Type 3520 and
Sound Intensity Microphone Pair 4183



The portable Sound Intensity Analyzer Type 4433 is ideal for reliable field measurements of sound intensity. It weighs 5,5 kg (12 pounds), is battery powered, and has an IEEE 488 parallel interface and a B & K serial interface. The Type 4433 is particularly easy to operate with an automatic scan for sequential octave analysis and automatic ranging. It is easily calibrated, and there is a choice of three microphone sensitivities and 200 V, 28 V and 0 V microphone polarization voltage.

In the case of measurements at a number of points over a surface, the average intensity level is measured and the power is then calculated by multiplying by the area of the surface. When sound power is measured, the surface area is entered into the analyzer for automatic inclusion in the calculation. In addition, corrections to account for air density variation are automatically performed from user-entered values of temperature and pressure. A sound power determination can be done literally in minutes - in the field and to a high degree of accuracy. Other applications include sound intensity mapping to locate noisy components, and measurement of sound transmission in building acoustics.

The 4433 operates with either Sound Intensity Probe Type 3519 or Type 3520. These are two-microphone probes which use the pressure gradient technique. The Type 3520 was specially developed for use with the 4433 and includes a remote control handle so that measurements can be made without having to touch the instrument front panel. Type 3520 contains the phase- and amplitude-matched microphone pair Type 4183 which features the recently developed phase corrector units. Very close and stable phase matching is maintained between the measurement channels so that accurate measurements can be made in the difficult acoustical environments likely to be encountered in the field.

Besides sound intensity, the 4433 can also be operated in the sound pressure and particle velocity modes, where the octave SPL and octave particle velocity levels are measured.

Stereo Microphone Sets Type 3529 and 3530

The Stereo Microphone Sets Type 3529 and 3530 consist of two carefully matched pairs of omni microphones for "spaced apart" (A-B) stereo recording. The sharp, clear stereo image which is gained by this recording method depends on close matching of the individual microphones for sensitivity, time and frequency response. Brüel & Kjær's matched pairs have been hand-picked from microphones which have already undergone numerous stringent quality control procedures, final testing and individual calibration.

The best possible stereo image has been ensured by matching the microphones in the 3529 and 3530 kits to within 1 dB in amplitude response over the entire frequency range 20 Hz to 20 kHz and within 10° in phase over the range 50 Hz to 20 kHz.

The method of powering the microphones differs. Type 3529 is intended for use with B & K's own power supply Type 2812 (included with the Set), which gives a transformerless high level output. Type 3530 utilizes standard P 48 Phantom systems. Both Sets are delivered in an attractive Samsonite® case.

In addition to standard accessories such as cable clips, windscreens, and a sonically designed mounting boom, the 3529/30 Sets include two additional types of protection grid which allow the frequency response of the microphone to be tailored to individual recording needs.

Precision Sound Level Meter Type 2235

The Precision Sound Level Meter Type 2235 is a versatile, comprehensively equipped IEC Type 1 instrument, suitable for general purpose measurements and a wide range of applications including building acoustics, audiometer calibration and frequency analyses. It measures sound pressure levels from 24 dB up to 130 dB, a range which can be extended to 150 dB with the addition of the 20 dB Attenuator Type ZF 0020.

The Type 2235 can measure the maximum or instantaneous sound pressure level with automatic (1 s) or manual reset in accordance with IEC and Japanese standards. Measurements can be made with RMS or Peak detector modes, with Slow, Fast or Impulse time weighting, and with A, C or Lin. frequency weighting. Measurements are displayed with 0,1 dB resolution on a digital display which also indicates overload conditions (in which case the measurement is suppressed) and depleted batteries.

AC and DC outputs are provided for chart or tape recordings and audio monitoring of measurements. The linear free-field frequency response of a microphone can be corrected to give linear diffuse-field measurements in accordance with IEC or ANSI standards. The Polarization Voltage can be set to 0 V or 200 V to suit a wide range of microphones, allowing the Type 2235 to be used in a variety of applications.

Filter sets Type 1624 and 1625 can be added to the Type 2235, providing 1/3-octave or 1/1-octave frequency analysis of sound pressure levels. Using one of the filter sets and a Type 4144 pressure microphone, the Type 2235 becomes the ideal instrument for audiometer calibration.

Hand-Arm Vibration Set Type 4392

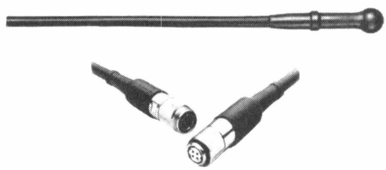
Hand-Arm Transducer Set Type 4392 from Brüel & Kjær is a welcome innovation which will be particularly appreciated by occupational hygienists and others involved in the field measurement of hand-arm vibration. The set does away with the necessity of mounting accelerometers directly on the tool handle. Consequently, there is considerable saving in time and effort.

The main components of the set are Hand Adaptor UA 0891, Handle Adaptor UA 0894 and Accelerometer Type 4374. The metal adaptors transmit the vibration from the tool handle/operator hand interface to one or more accelerometers mounted on the adaptors — without interfering with the operator's grip.

The Hand Adaptor is used with tools of low frequency vibrations such as chain saws and grinders. Three accelerometers can be mounted at once, allowing simultaneous triaxial measurement and recording. The Handle Adaptor is fixed on the handle and is generally used for percussive drills, chip-hammers, and other tools with dominating high frequency vibrations. It has two mounting positions for accelerometers.

Compatible Brüel & Kjær vibration meters are Integrating Vibration Meter Type 2513 (which incorporates hand-arm weighting filters) and Human--Response Vibration Meter Type 2512 (which incorporates both hand-arm and whole-body weighting filters).

Spherical Hydrophone Type 8105



The Spherical Hydrophone Type 8105 has excellent omnidirectional characteristics over the full frequency range of 0,1 Hz to 160 kHz. In particular, the 8105 is omnidirectional over 270° in the vertical plane. It is robust and can be used at ocean depths of up to 1000 m.

As with other B & K Hydrophones, the Type 8105 can be calibrated in the field with Hydrophone Calibrator Type 4223. A special adaptor has been developed for this purpose to fit the coupler otherwise used for the Type 8101.

Underwater Connectors JP/JJ 0415 are suitable for use with B & K Hydrophones Types 8101/4/5. The connectors are compatible with the older type, but are more robust and can be mounted in the field. This makes cable and connector repairs much easier as they no longer have to be made at the factory.

PREVIOUSLY ISSUED NUMBERS OF BRÜEL & KJÆR TECHNICAL REVIEW

(Continued from cover page 2)

SPECIAL TECHNICAL LITERATURE

Brüel & Kjær publishes a variety of technical literature which can be obtained from your local B & K representative.
The following literature is presently available:

Mechanical Vibration and Shock Measurements (English), 2nd edition
Modal Analysis of Large Structures–Multiple Exciter Systems (English)
Acoustic Noise Measurements (English), 3rd edition
Architectural Acoustics (English)
Strain Measurements (English, German)
Frequency Analysis (English)
Electroacoustic Measurements (English, German, French, Spanish)
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Product Data Sheets (English, German, French, Russian)

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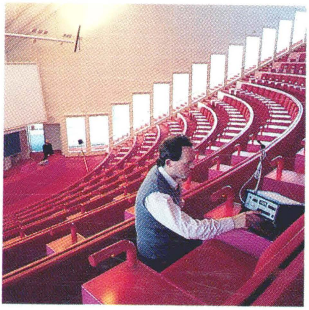

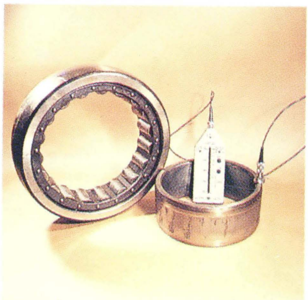

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Brüel & Kjær

DK-2850 NÆRUM, DENMARK · Telephone: + 45 2 80 05 00 · Telex: 37316 bruka dk