Acoustic Calibrator for Intensity Measurement Systems *

by Erling Frederiksen

Abstract

A description is given of an acoustic calibrator for intensity measurement systems which use microphones of the pressure principle. The calibrator produces signals corresponding to those detected by intensity probe microphones when the probe is placed in a free progressive sound wave with either 0° or 90° incidence.

In the 90°-mode the signals of the calibrator are equal with respect to magnitude and phase. This mode can be used for pressure-sensitivity calibration of intensity systems and for measurement of residual intensity index. Calibrators supplying this type of signals have previously been described in the literature.

However, for a more rigorous calibration it should be verified that the system responds correctly also to a phase difference between the sound field signals when this differs from zero. Therefore this calibrator has also the 0°-incidence mode. In this mode the calibrator signals are equal to the signals at two points in space within a free progressive sound wave. The phase difference corresponds to a certain distance between the points which means that it is proportional to frequency. The signal magnitudes and the phase difference have revealed high stability and calibration accuracy of 0,1 dB is possible. The calibrator can also be used for particle velocity calibration.

Sommaire

Tout d'abord la description d'une source sonore étalon pour les systèmes de mesure d'intensité acoustique par microphones sensibles à la pression

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est donnée. Cette source produit des signaux correspondant à ceux qui sont détectés par les microphones des sondes, lorsque la sonde est exposée à une onde sonore progressive libre avec une incidence de 0 ou de 90°.

Dans le mode 90°, les signaux de la source sont identiques en amplitude et phase. Ce mode peut être utilise pour l'étalonnage de sensibilité en pression des systèmes d'intensité et pour les mesures d'index d'intensité résiduelle. Des sources délivrant ce type de signal ont déjà été décrites dans la littérature.

Cependant, pour un étalonnage plus rigoureux, il faut vérifier que le système répond correctement lorsqu'il y a une différence de phase entre les deux signaux. C'est pour cela que la source dispose d'un mode 0°, où les signaux provenant de la source sont identiques aux signaux engendrés en deux points de l'espace par une onde sonore progressive libre. La différence de phase correspond à une distance donnée entre les points, et elle est donc proportionnelle à la fréquence. L'amplitude des signaux et les différences de phase ont révélé qu'une très grande stabilité et qu'une précision de 0,1 dB sont possibles. La source peut aussi être utilisée pour les étalonnages de vitesse particulaire.

Zusammenfassung

Es wird ein akustischer Kalibrator für Intensitätsmeßsysteme mit Druckmikrofonen beschrieben. Das vom Kalibrator erzeugte Signal entspricht dem von einer Intensitätssonde aufgenommenen, wenn sich dieses in einem freien Schallfeld mit 0°- oder 90°- Einfall befindet.

Beim 90°-Betrieb erzeugt der Kalibrator Signale, die nach Betrag und Phase gleich sind. Hiermit läßt sich der Druckübertragungsfaktor des Intensitätsme#systems kalibrieren sowie der Remanenz-Intensitätsindex bestimmen. Kalibratoren, die diese Signalart erzeugen, wurden bereits früher in der Literatur beschrieben.

Für eine strengere Überprüfung der Kalibrierung sollte auch das Verhalten bei Signalen, die eine unterschiedliche Phasenlage besitzen, untersucht werden. Hierfür besitzt der Kalibrator den 0°-Betrieb. Hier erzeugt der Kalibrator Signale, die den Signalen an zwei räumlich verschiedenen Stellen einer sich frei fortpflanzenden Schallwelle entsprechen. Die Phasendifferenz entspricht einem gegebenen Abstand im Raum, d.h. sie ist frequenzproportional. Der Betrag und die Phasendifferenz der Signale sind hochstabil und eine Kalibriergenauigkeit von 0,1 dB ist möglich. Der Kalibrator läßt sich auch zur Teilchenschnelle-Kalibrierung einsetzen.

Introduction

Today measurement of sound intensity has proved its usefulness for noise analysis. Instruments are constantly improving, but as they are quite complex many users have desired means of calibration to gain further confidence in their measurement results.

Most systems use pressure microphones and practically all field calibrations made today are pressure calibrations of the system channels. In fewer cases the channels are also tested for equality of their phase responses - usually at one frequency only.

An acoustical calibrator for a far more extended calibration has been developed. According to known principles it can be used for pressure level calibration at 250 Hz and for phase check by measurement of residual intensity index between 10 Hz and 5 kHz.

In addition to these features the calibrator has an extra operation mode in which it produces signals for calibration of intensity and particle velocity sensitivity of instruments operated in these modes. This new mode is the main theme of this paper.

Operation Principle of Intensity System with Pressure Microphones

Most measurement systems which employ pressure microphones determine the instantaneous values of particle velocity, $u(t)$ and of the sound intensity, $I(t)$ in accordance with the following expressions:

$$u(t) = \int \frac{p_1(t) - p_2(t)}{\rho_o \Delta r_o} dt \,; \quad I(t) = \frac{p_1(t) + p_2(t)}{2} \int \frac{p_1(t) - p_2(t)}{\rho_o \Delta r_o} dt$$

$P_1(t), p_2(t)$: instantaneous values of the pressure signals

$\Delta r_o, \rho_o$: system parameters for microphone distance and air density

For sinusoidal signals the measured values of the particle velocity, u [rms] and of the time average value of sound intensity, $\bar{I}$ become:

$$u[\mathrm{rms}] = \frac{\left(\left[(P_1 + P_2)\sin\phi/2\right]^2 + \left[(P_1 - P_2)\cos\phi/2\right]^2\right)^{0,5}}{\omega \rho_o \Delta r_o}$$

$$\bar{I} = \frac{P_1 P_2 \sin\phi}{\omega \rho_o \Delta r_o}$$

P_1, P_2: rms-values of the sinusoidal pressure signals
ϕ, ω: phase angle between the pressure signals and angular frequency

Operation of the Sound Intensity Calibrator

The formulae above show that the measurement results are functions of four signal parameters. Therefore a calibrator has to produce signals for which these parameters are stable as functions of time and perform in a predictable way under common environmental conditions.

A calibrator which statisfies these requirements has been developed. It consists of a sound source and of a special coupler with two cavities, (a) and (b), see Fig. 1. The cavities have ports (1, 2 and 3) for connection of intensity probe microphones. One of the cavities (a) is directly connected to the source while the second cavity (b) is coupled to (a) via an acoustical coupling element which contains a resistance and a mass in series connection.

At low frequencies the acoustical network formed by the coupling element and by the compliance of cavity (b) creates cavity signals with a phase difference which is proportional to frequency and with magnitudes which are nearly equal. These properties exactly comply with the pressure at two points in a space where a plane sound wave is propagating. Thus for a pressure microphone probe the calibrator can simulate a free field wave with definable levels of sound pressure, particle velocity and intensity.

The coupler has been designed to create a phase difference corresponding to that valid for 50 mm microphone distance with an angle of zero degrees between the probe axis and the wave's propagation direction. The coupler properties are independent of the choice of sound source but a well defined source is needed for sensitivity calibration, therefore a piston-

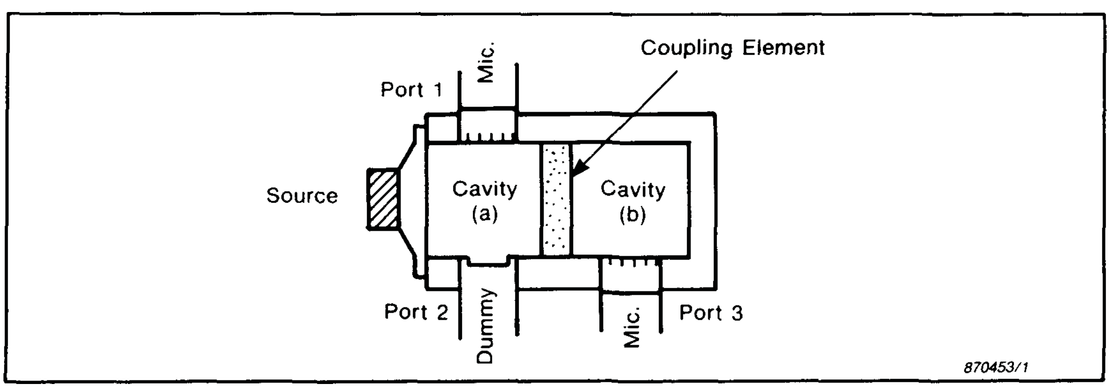

Fig.1. Principle of the intensity calibrator. The microphones are placed in the ports (1) and (3) for calibration of intensity sensitivity

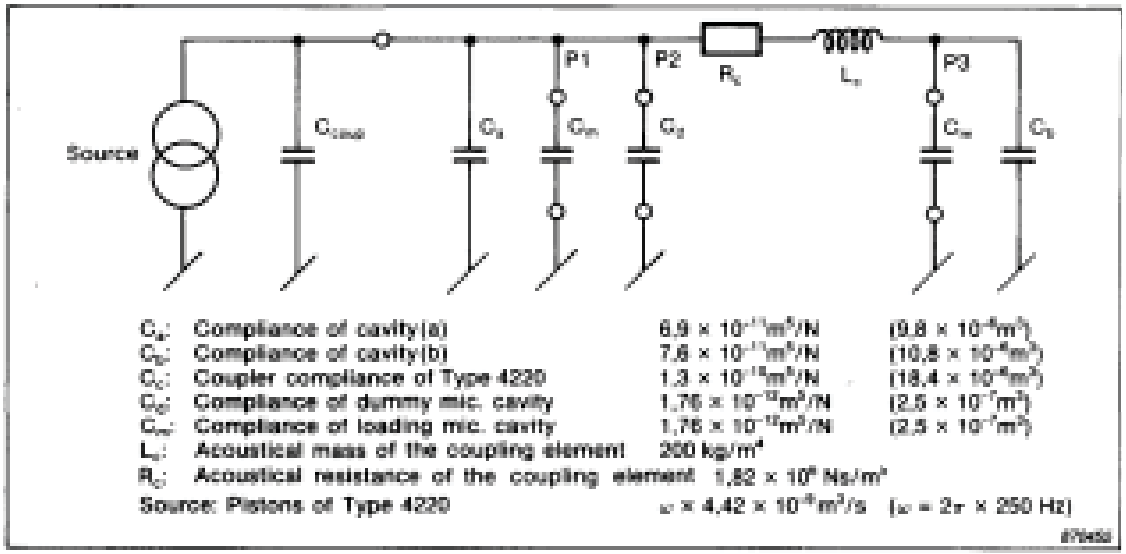

Fig.2. Model of the calibrator driven by the pistonphone with values valid at 1013 mbar and 20° C. The microphones are placed in the ports (1) and (3) for intensity or velocity calibration

phone, B & K Type 4220 was chosen for operations of this mode. See a model of the calibrator in Fig. 2.

The magnitude and phase differences between the pressure of the cavities, (b)-(a) have been measured and calculated, see Fig. 3 which also shows that within the range from a few Hz to about 500 Hz the phase difference between the ports is nearly equal to the free-field phase lag for points 50 mm apart. When driven by a pistonphone at 250 Hz the sound

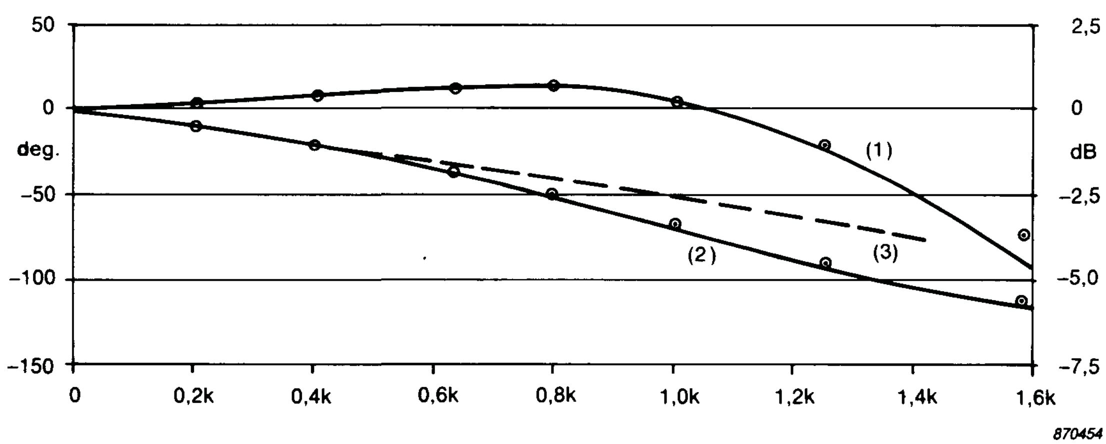

Fig. 3 Magnitude difference (1) and phase difference (2) between the pressure of the calibrator cavities, (b)-(a) were measured (curves) and calculated (points). The dotted line (3) shows the free-field phase lag for points 50 mm apart at 20° C

pressure levels of the cavities are nominally 118 dB therefore the particle velocity and intensity levels are also close to this value.

Due to the phase linearity with frequency the levels are not critical with respect to frequency. At 250 Hz the slopes are as small as + 0,7 x 10^{-3} dB/Hz for intensity and + 1,5 x 10^{-3} dB/Hz for velocity.

Environmental Influences

The pressure and intensity levels as functions of the ambient pressure were measured with an FFT-analyzer and together with the particle velocity level they were also calculated by use of the model. The results are listed in the table below.

Attention should be paid to the agreement between the measured and the calculated results and to the fact that the intensity level is practically independent of the ambient pressure. Notice that the pressure level follows the ambient pressure (last line of the table) while the particle velocity level shows the same changes but in the opposite direction.

By measurement and calculation the temperature coefficient of the intensity level has been found to be + 0,024 dB/°C.

Amb. pressure, p_a	mbar	700	800	900	994	1000	1013
L_I measured	dB	-0,12	-0,07	-0,02	0	+0,01	-
L_I calculated	dB	-0,06	-0,03	-0,01	0	0	0
L_p cav.(a) measured	dB	-2,89	-1,80	-0,82	0	+0,05	-
L_p cav.(a) calculated	dB	-2,87	-1,79	-0,82	0	+0,05	+0,16
L_v calculated	dB	+2,93	+1,82	+0,83	0	-0,05	-0,15
20 log (P_a/994)	dB	-3,05	-1,89	-0,86	0	+0,05	+0,16

Notes for Application of the Calibrator

The calibrator is designed for laboratory as well as field use. The calibrator supplies sound pressure to the microphone diaphragms only. The calibrator works correctly with the newly introduced microphone types which are especially designed for intensity measurements and which have extremely low vent-sensitivity.

In the calibration mode for intensity sensitivity only very small errors will occur with ordinary measurement microphones while significant errors might occur in the mode for measurement of residual intensity index, especially at low frequencies.

Accuracy and Calibration of the Intensity Calibrator

Determination of the calibrator's intensity and particle velocity levels requires calibration of sound pressure, frequency and of the phase difference between the cavities which is more simple to measure than might be expected as microphones with known phase characteristics are not needed.

Calibration can be made with any two microphones which load the coupler correctly, i.e. with 250 mm^3. During the first phase measurement the microphones are inserted arbitrarily in the ports (1) and (3) while they are interchanged before the second measurement. The difference between the results is twice the phase difference between the cavities. The method eliminates a possible phase difference between the channels of the applied phase meter. The resulting calibration levels are found by inserting the measured values in the formulae given under the discussion of the measurement principle.

An accuracy of the intensity calibration level better than 0,15 dB is rather easy to obtain and seems relevant in practice as artificial stability tests have given very promising results for the calibrator.

Conclusion

An intensity calibrator with a possible accuracy of 0,1 dB has been developed. The calibrator can simulate two angles of sound incidence on the intensity probe, 0° or 90°. In the 0°-mode sensitivity of measurement systems can be calibrated while in the 90°-mode the residual intensity index can be measured.

It might be necessary to correct the calibrator's intensity level for the temperature but the ambient pressure has practically no influence at all.

The principle is new but the properties of the calibrator have been measured under different environmental conditions and a model has been worked out. The good agreement between the behaviour of the calibrator and the model shows that all significant physical effects are known.

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