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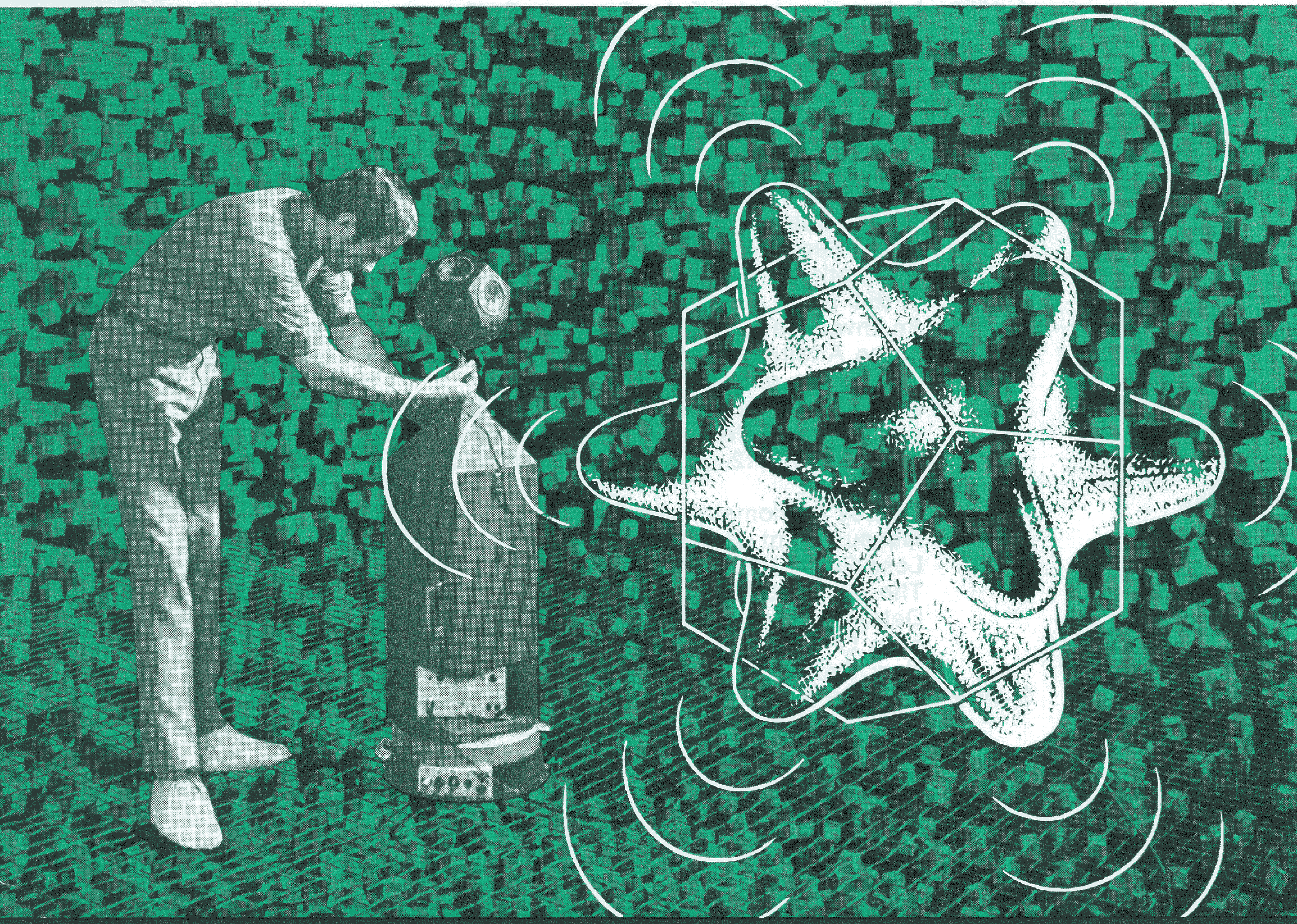

Underwater Impulse • Noise Dose Comparison • Isotropic Radiation

Brüel & Kjær

PREVIOUSLY ISSUED NUMBERS OF BRÜEL & KJÆR TECHNICAL REVIEW

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TECHNICAL REVIEW

No. 4—1974

Contents

Underwater Impulse Measurements

by

Peter A. Levin, M. Sc.

ABSTRACT

This article investigates the ability of hydrophones to measure shock waves in water generated by explosives. The peak pressures and decay rates obtained from time histories of shock waves registered on the oscilloscope from the hydrophones are used to compute the energy flux density and impulse per unit area. The results obtained are found to be in good agreement with those obtained from a tourmaline transducer normally used for shock measurements.

SOMMAIRE

Cet article étudie l'aptitude des hydrophones à mesurer les ondes de choc sous-marines produites par les explosifs. Les pressions de crête et temps de descente obtenus à partir du tracé sur oscilloscope des ondes de choc recueillies par des hydrophones ont servi à calculer la densité de flux d'énergie et l'impulsion par unité de surface. Les résultats se sont avérés en bon accord avec ceux obtenus à l'aide d'un capteur à tourmaline, d'emploi normal pour les mesures de choc.

ZUSAMMENFASSUNG

Der Verfasser untersucht die Möglichkeit, mit Hilfe von B & K-Hydrophonen Explosions-Schockwellen unter Wasser zu messen. Hierbei wurde der zeitliche Schockwellenverlauf auf einem Oszilloskop dargestellt und fotografiert. Anhand der daraus gewonnenen Schalldruckspitzen und Abfallzeiten wurde dann die flächenbezogene Energie und der flächenbezogene Impuls berechnet. Die so erhaltenen Resultate sind in guter Übereinstimmung mit den über einen Turmalin-Wandler gewonnenen, wie sie normalerweise für Schockmessungen unter Wasser benutzt werden.

Introduction

The purpose of this research was to investigate, whether commercial underwater transducers — primarily intended for other applications — can be used for measurements of shock waves in water generated by explosives.

A tourmaline pressure transducer is widely used for recording of main parameters of interest e.g. peak pressure and decay constants, from which all the other parameters such as energy flux density and impulse per unit area are derived.

However, the high cost of tourmaline as a natural crystal may not make its use economically feasible. Another possible draw-back of tourmaline is that its sensitivity is very low compared to piezo-electric ceramic transducers. The lower capacitance of the tourmaline may also restrict its low frequency response.

Pressure transducers based upon quartz have also been used for measurements of underwater explosions, but due to the lack of ability of quartz to measure hydrostatic pressure in one direction without protection in the two other mutually perpendicular directions, a rather limited use of this material has been made.

Theory

The theory of underwater shock wave propagation is generally known. According to Cole (1) the investigated shock wave can be represented by the following expression:

$$P = P_m\,(W,R)\,e^{-t/\Theta\,(W,R)} \qquad t \geqslant 0 \qquad [\text{bar}] \;\ldots\ldots (1)$$

where P_m is the peak pressure and θ is the time constant of the exponential pressure decay. W is explosive charge weight in kg and R is the distance from the explosion in m.

In measuring shock waves from underwater explosions it is usually desired to determine four basic quantities: peak pressure P_m, decay time constant Θ, impulse I per unit area, and energy flux density E, where I and E can be approximated as follows:

$$I = \int_0^\infty P(W,R)\,dt \qquad \left[\frac{N}{m^2}\cdot s\right] \;\ldots\ldots (2)$$

$$E = 1/\rho C \int_0^\infty P^2\,(W,R)\,dt \qquad \left[\frac{\text{Joule}}{m^2}\right] \;\ldots\ldots (3)$$

where ρ is the density of water and C is the velocity of sound in water.

It can be shown that all parameters in connection with shock waves can be expressed by means of the formulae given in Table 1 established on empirical basis

$P_m = K_1 \left(\frac{W^{1/3}}{R}\right)^{\alpha}$	$I = K_3 (W^{1/3}) \left(\frac{W^{1/3}}{R}\right)^{\gamma}$
$\Theta = K_2 (W^{1/3}) \left(\frac{W^{1/3}}{R}\right)^{\beta}$	$E = K_4 (W^{1/3}) \left(\frac{W^{1/3}}{R}\right)^{\delta}$

Table 1.

where K_1 .... K_4 and α, β, γ, δ are empirically established constants listed in Table 3.

When using a piezoelectric transducer for shock measurements two parameters are especially important:

a) transducer size
b) the low limiting frequency (LLF) of the measuring set-up

In the first case the result of integration will introduce errors in the recording of high frequency components and thus distort the leading edge of the shock wave. In the second case there will be an incorrect representation of the low frequency components, (and thus a distortion of the tail of the shock wave) and the zero crossing will occur earlier than for a true peak-pressure trace.

A low leakage resistance has no influence on the recorded rise time and peak pressure of the shock waves. On the other hand the influence of the recorded pressure decay after the leading edge can be quite considerable, thus causing errors in determining the impulse and energy flux density of the shock.

During the experiment, however, a high input impedance amplifier was used so that the effect of lower limiting frequency could be virtually eliminated.

Measurement Procedure

The experiments were carried out in a small watertank with dimensions of 2 × 3 × 2 m. The detonators employed consisted of a primary charge of 0,25 g with 70% azide and 30% lead trinitroresorcinate, and a base charge of 0,55 g tetryl.

The detonators were ignited electrically, and the shock waves produced were measured by means of two Brüel & Kjær production hydro-

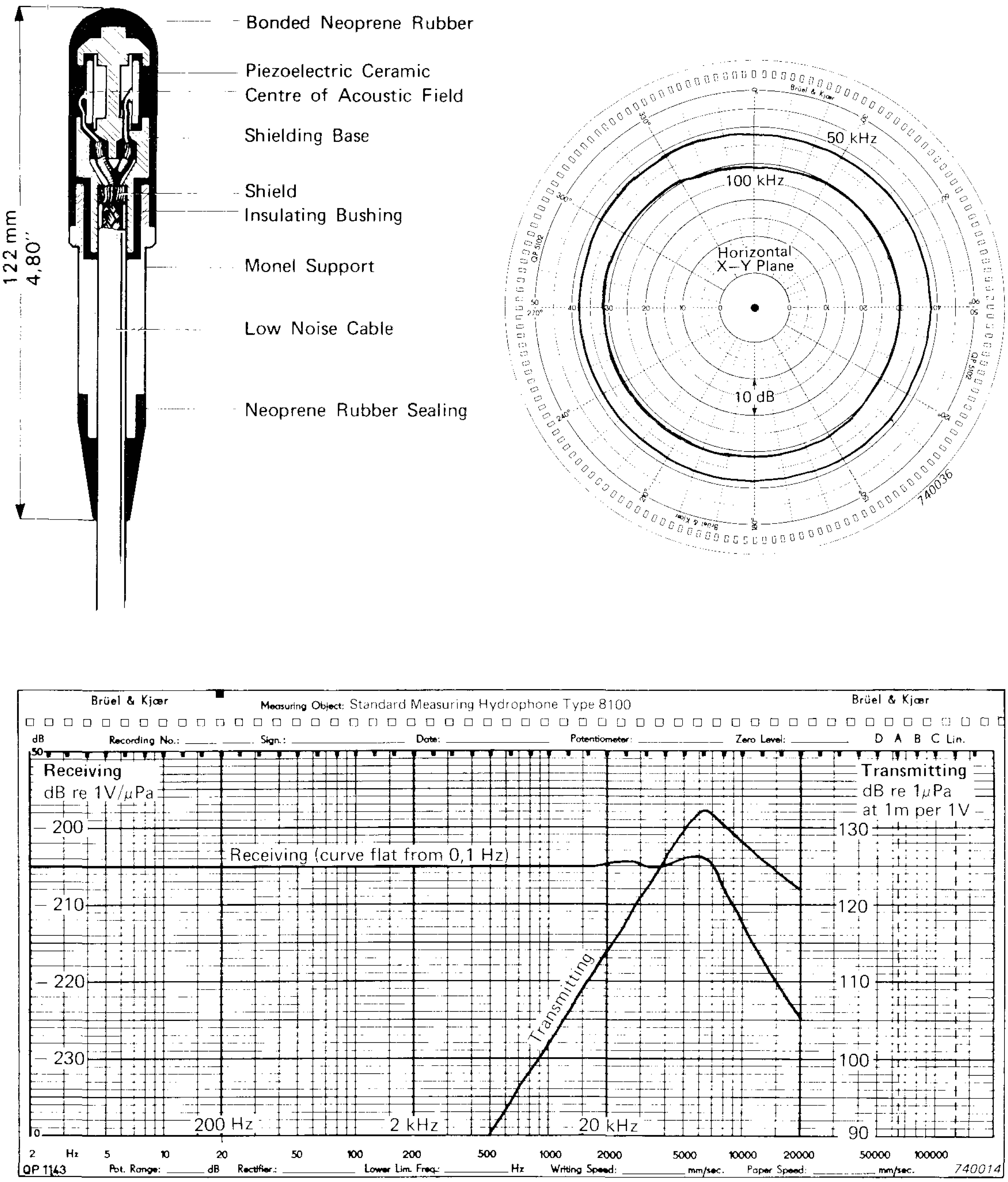


Fig. 1. Schematic drawing, frequency response and directional characteristics of Hydrophone Type 8100

phones Type 8100 with a sensitivity of −205 dB re 1 V/μPa and Type 8103 with a sensitivity of −210 dB re 1 V/μPa.

The frequency response curves, directivity patterns and physical dimensions of the hydrophones are shown in Figs. 1 and 2.

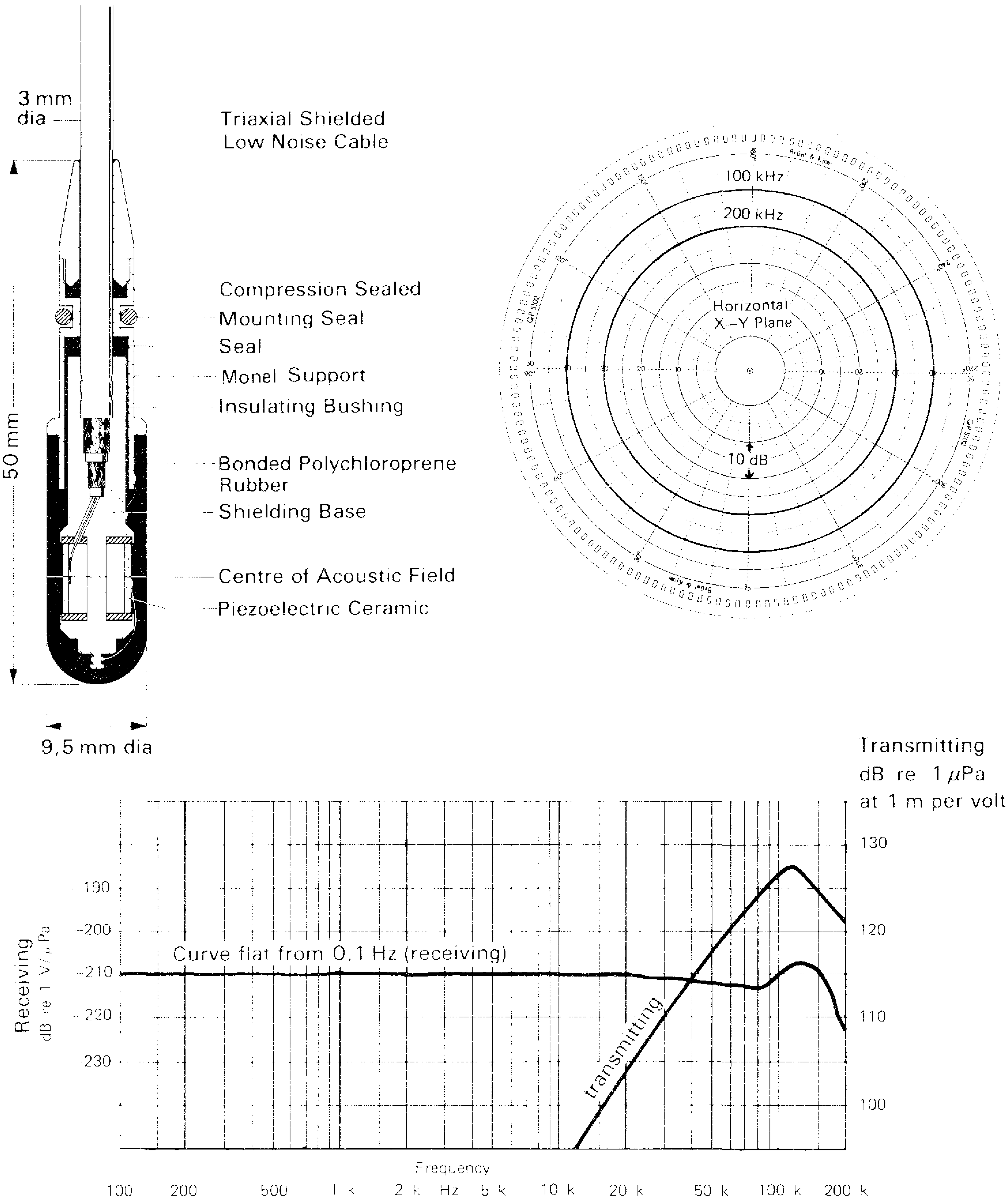


Fig. 2. Schematic drawing, frequency response and directional characteristics of Hydrophone Type 8103

The transducer output signals were recorded directly on a Tektronix 555 oscilloscope with an upper frequency limit of 30 MHz to ensure that the trasducers were the only components in the set-up that limited the frequency response.

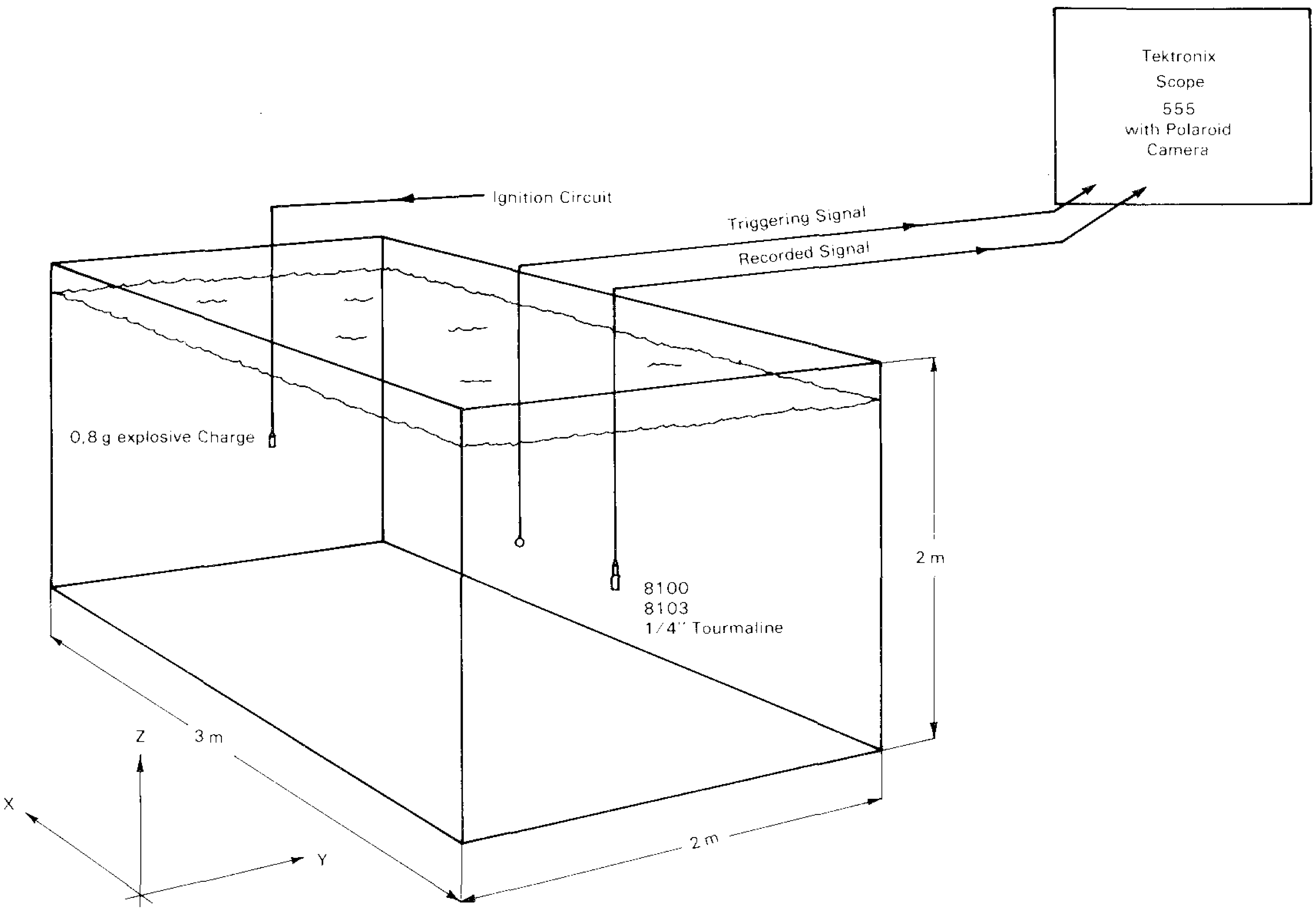


Fig.3. Position of transducers in water tank

The oscilloscope sweep was triggered by a signal from a small transducer placed a short distance in front of the measuring transducers, see Fig.3. The pressure-time curves were taken by a Polaroid camera. The transducers were oriented in the horizontal plane (X-Y plane).

Fig.4 shows some typical measurements of the pressure-time variations.

These curves have a characteristic form for shock waves — a steep front followed by an exponential pressure decay to approx. 30% of Peak pressure followed by another exponential decay.

The influence of the transducer's finite dimensions can easily be seen. According to Osborne (6), the rise time of the shock wave is considerably less than 1 μs. However, the rise time according to the results shown in Fig.4 is approximately 2,5 μs for the 8103 hydrophone and the tourmaline gauge and approximately 5 μs for the 8100 hydrophone.

These results are in good agreement with the resonance frequencies of the respective transducers (55 kHz for Type 8100, 110 kHz for Type

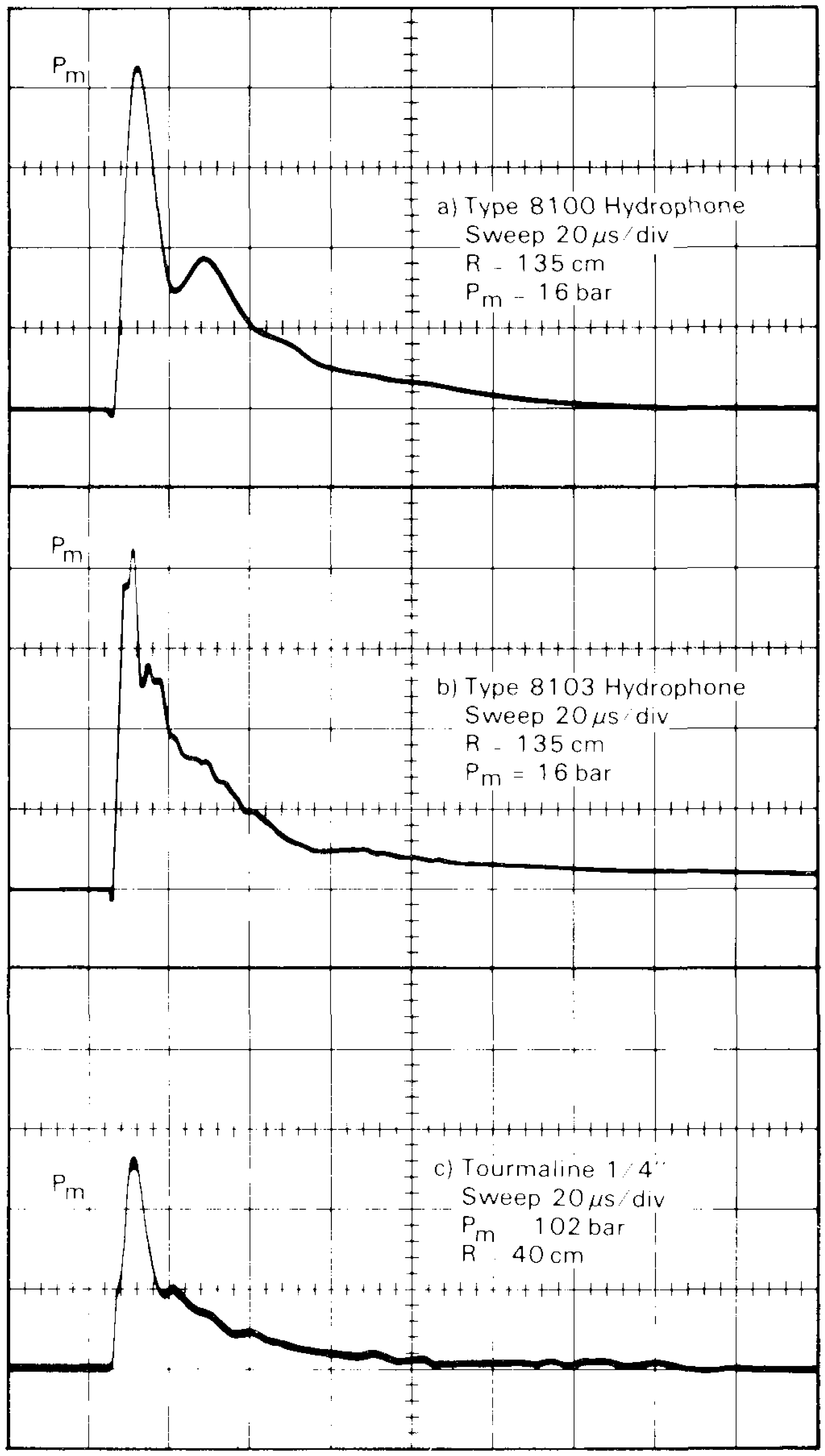
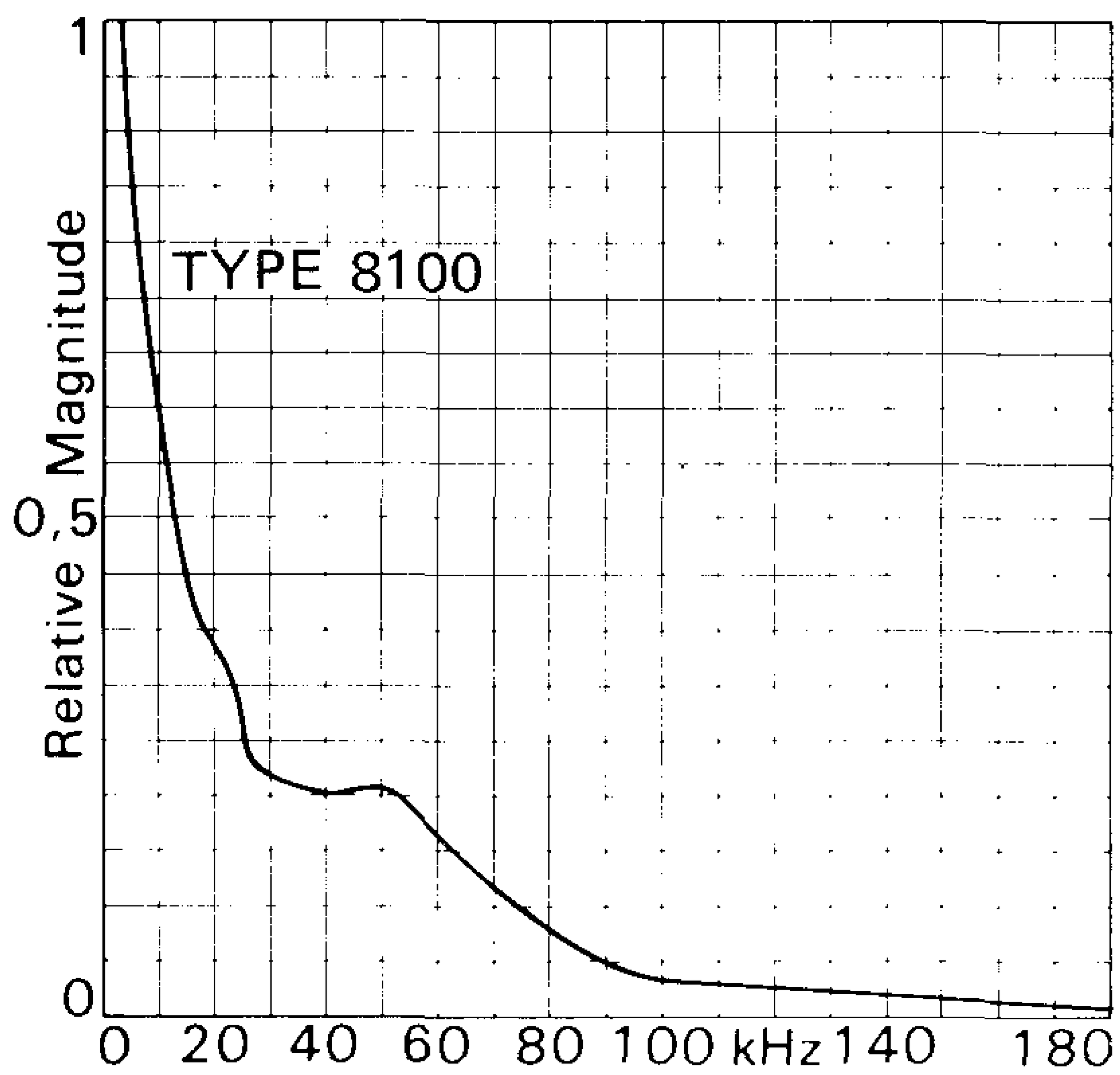


Fig.4.   Time history recordings of shock waves

8103) or the integration time (the passage time for the shock wave across the transducers diameter) of the tourmaline gauge.

The Fourier energy-spectra, Fig.5 which were calculated by means of a digital computer, based upon the pressure-time traces measured by the Brüel & Kjær hydrophones, confirm the existence of these resonance frequency components.

The maximum pressure measured was about 10 — 15% higher than could be expected from the theoretical calculations. However, this fact



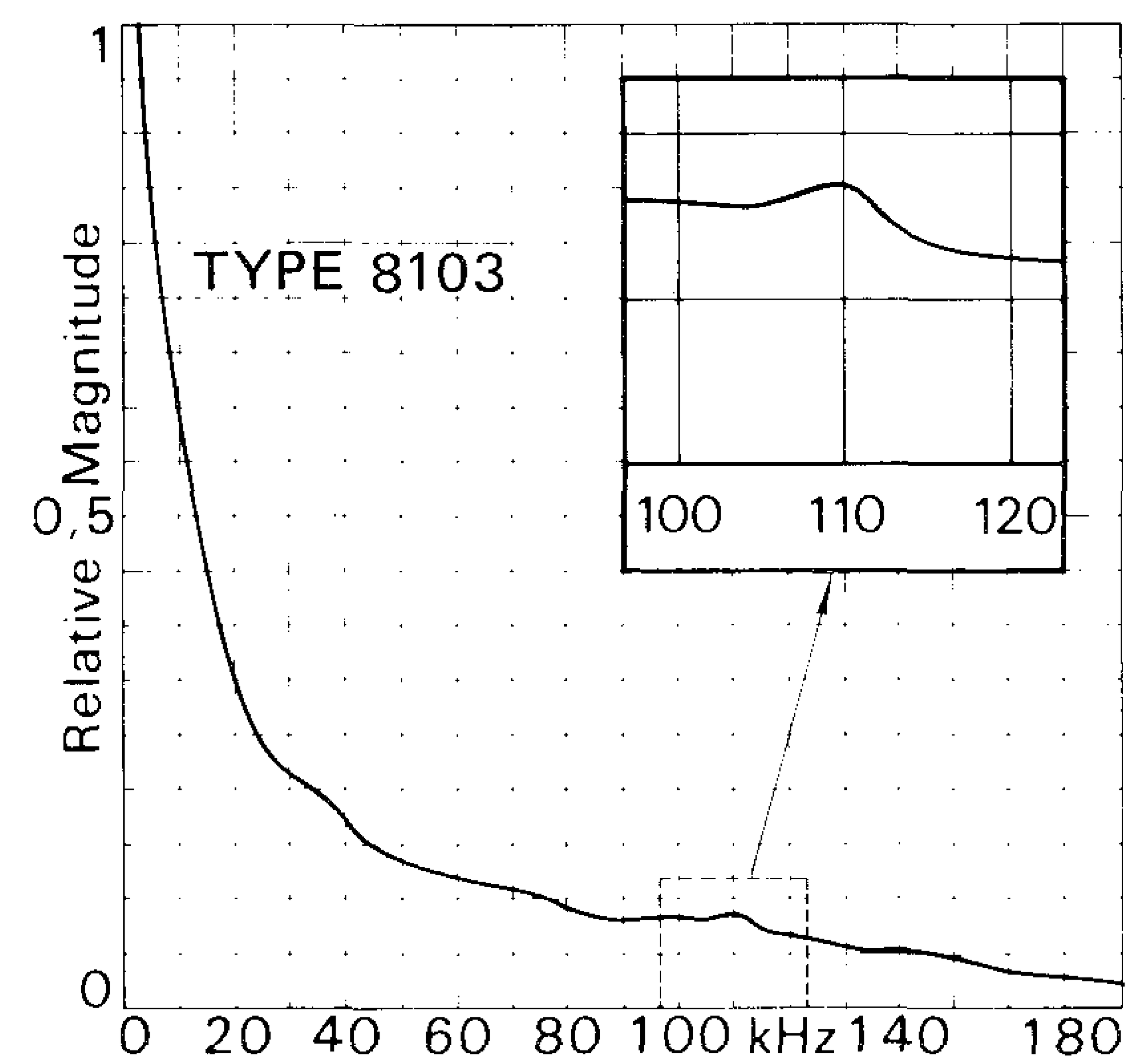


Fig.5. Energy Spectra of shock waves recorded by Hydrophones Types 8100 and 8103

can readily be explained when looking at the frequency response curves of the hydrophones in figures 1 and 2. They have a Q factor of approximately 1 — 2, which directly leads to the 10 — 15% peak deviations.

The measured parameters for shock waves corrected for the hydrophones' Q factor are listed in Table 2. The results obtained for Types 8100 and 8103 hydrophones are in good agreement with the results obtained from a tourmaline transducer.

Fig.6 shows a graph of peak pressure P_m as function of distance from the explosion for a fixed charge weight as **measured** by the Hydrophones Types 8100 and 8103.

R [m]	P_m [bar]			θ [μs]		
	8100	8103	*Tourmaline*	8100	8103	*Tourmaline*
0,80	47,8	47,7	47,3	13,41	13,30	13,26
0,90	41,7	41,3	42,3	13,72	13,69	13,70
1,00	36,1	35,8	36,6	14,05	13,96	13,78
1,10	26,7	26,3	26,8	14,17	14,10	13,92
1,20	22,2	21,7	22,3	14,32	14,26	14,11
1,30	18,5	18,3	18,4			
1,40	16,1	15,8	15,9			

Table 2.

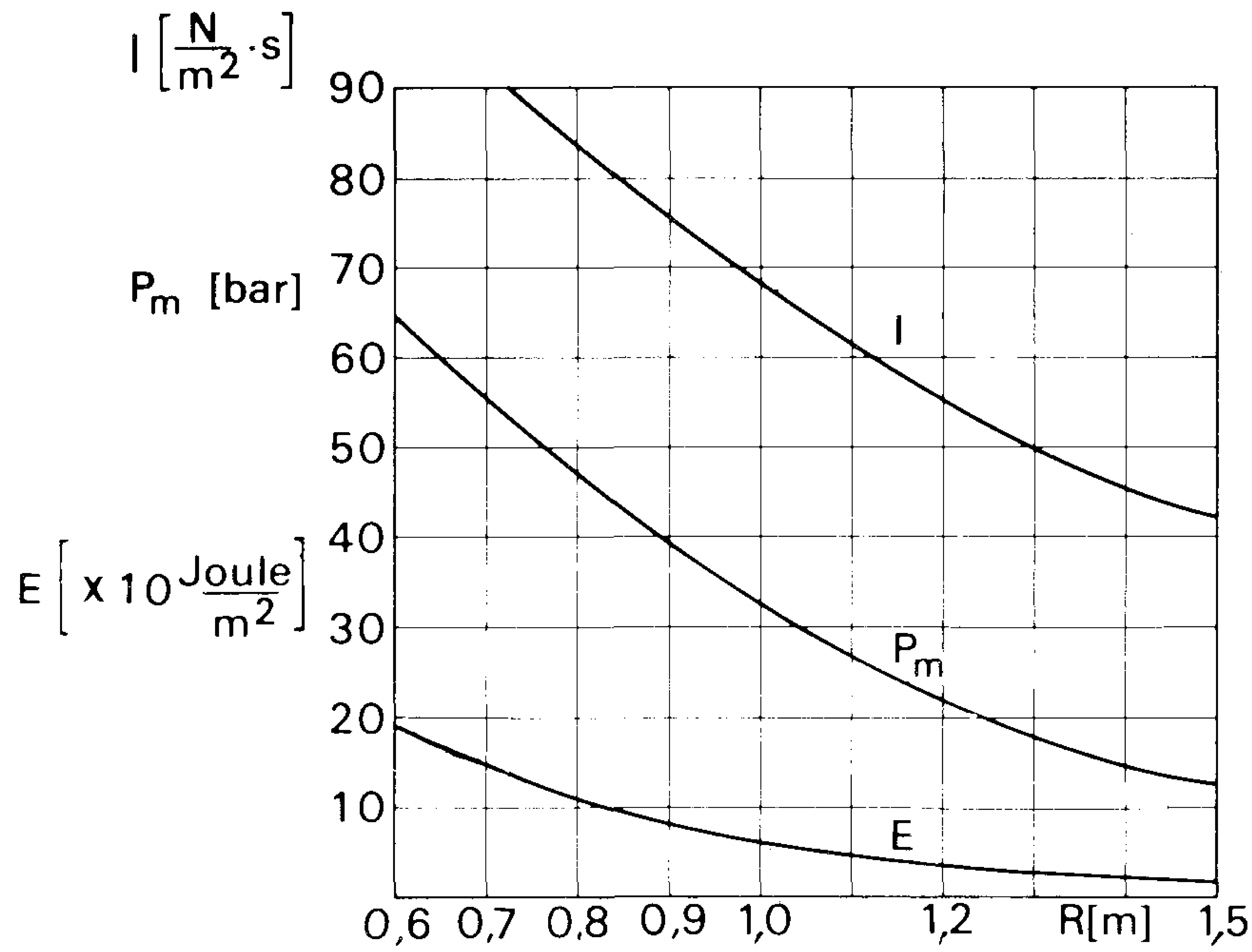


Fig.6. Peak Pressure, Impulse and Energy Flux Density as functions of Distance from Explosion

From equations (2) and (3) it can be seen that the area under the pressure-time curve and the pressure^2-time curve gives the impulse I per unit area and energy flux density E respectively. For each of the distances, I and E were thus evaluated and plotted against distance as shown in Fig.6.

These curves when made to fit equations given in Table I would yield constants K_1 K_3 K_4 and α, γ, δ. One of the methods of obtaining the constants is by plotting the measured data on a log-log paper. How-

		COLE.	SLIFKO & FARLEY	ARONS.	BJØRNØ.	B & K 8100 8103
Explosive		TNT	TNT	TNT	Tetryl	Tetryl
P_m (bar)	K_1	521,6	494,1	521,6	506	508
	α	1,13	1,11	1,13	1,10	1,09
θ (μs)	K_2	96,5	83,6	92,5	87	88
	β	−0,18	−0,23	−0,22	−0,23	−0,23
I (Ns/m^2)	K_3	5760	5320	—	5900	6200
	γ	0,89	0,87	—	0,87	0,90
E (Joule/m^2)	K_4	$9,8 \cdot 10^4$	—	—	$11 \cdot 10^4$	$10,8 \cdot 10^4$
	δ	2,10	—	—	2,12	2,10

Table 3.

ever, when fitting the best line through the measured points emphasis should be placed on data obtained at small distances since inaccuracies occur in measured data at larger distances. The constants evaluated are given in Table 3, and are found to be in reasonably good agreement with those published by other authors.

Conclusion

It has been shown that Brüel & Kjær hydrophones, though not primarily intended for shock wave investigations, can be used for this purpose. The reproducibility of the experimental data was found to be satisfactory and in good agreement with results obtained by Cole, Bjørnø & Poche, (1), (5), (2).

By utilising an amplifier with high input impedance the effect of lower limiting frequency was eliminated. Deviation of measured results caused by transducer frequency response are easy to predict and may for instance be graphically removed.

The high sensitivity of hydrophones and capability to withstand relatively high pressures, permit use of the same transducer for measurements at distances from the explosion of 50 — 100 times the charge radius.

Further experiments are in progress to determine the influence of the orientation of the transducer and of explosive charge.

Acknowledgement

The author is indebted to Professor Leif Bjørnø (Danish Technical University) for valuable discussions during the work.

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A Comparison of ISO and OSHA Noise Dose Measurements

by

Leif S. Christensen

ABSTRACT

The equivalent continuous noise level L_{eq} represents an important step towards a unified measurement principle for occupational noise exposure. However, the Sound Level/exposure time exchange rate q is still in dispute, and the consequences for measurements in practice are evaluated.

SOMMAIRE

Le niveau de bruit équivalent L_{eq} représente un pas important vers un principe unique de mesure pour évaluer l'exposition au bruit pendant le travail. Cependant, le paramètre q, reliant le niveau sonore au temps d'exposition, est encore matière à discussion, et les consequences qui en résultent en pratique pour les mesures sont évaluées dans cet article.

ZUSAMMENFASSUNG

Der äquivalente Dauerschallpegel L_{eq} — bzw. die mit ihm über die Zeitdauer verwandte Lärmdosis — stellt einen wichtigen Schritt in Richtung auf ein einheitliches Meßprinzip für die Beurteilung der Lärmeinwirkung auf den Menschen hinsichtlich der Gefahr einer Gehörschädigung dar. Der Zahlenwert von L_{eq} bzw. der Lärmdosis hängt jedoch wesentlich von der Festlegung des sogenannten Halbierungsparameters q ab, der angibt, welche Pegelerhöhung in dB durch eine Halbierung der Einwirkdauer kompensiert wird. In ISO wird q = 3 angegeben, während OSHA q = 5 empfiehlt. Der Artikel zeigt den Einfluß der unterschiedlichen Halbierungsparameter auf den Wert L_{eq} anhand von Berechnungen und praktischen Messungen auf.

Introduction

Many workers in industry are exposed to harmful noise levels. 10 — 20% of the employees work in noise level above 85 — 90 dB(A) that is, their hearing may be permanently damaged after a certain period of time (1 & 2). The hearing impairment is often not detected in time to prevent it and may only be partially compensated for by hearing aids (3).

Therefore, it is important to be able to determine whether the noise levels at a given workplace are potentially harmful, and for this purpose the Equivalent Continuous Sound Level is used:

$$L_{eq} = \frac{q}{\log_{10}2} \cdot \log_{10}\left\{\frac{1}{T}\int_{0}^{T}\left[\frac{\overline{p(t)}}{p_o}\right]^{\frac{20\log_{10}2}{q}} dt\right\} \qquad (1)$$

where T is the measurement time,

$\overline{p(t)}$ represents the time-varying noise pressure,

q indicates the number of dB(A)'s corresponding to halving or doubling the measurement time (for a constant L_{eq}).

p_o is the reference sound pressure 20 μPa.

Noise Dose Meters for measurement of L_{eq} according to equation (1) are now commercially available and a typical block diagram is shown in Fig.1.

Referring to equation (1), the microphone registers p(t) while q corresponds to the combined effect of the squaring and exponent circuits.

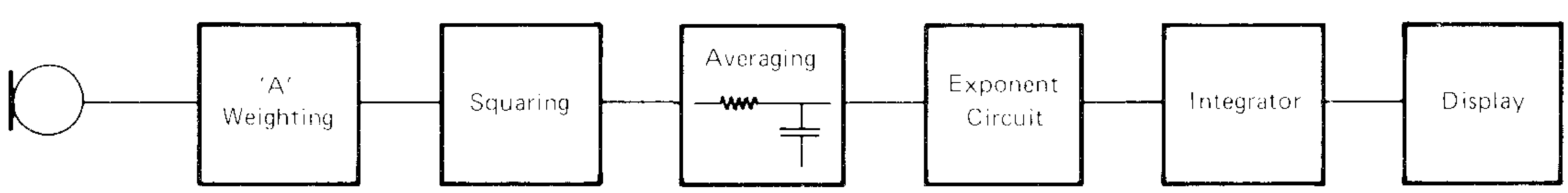

Fig. 1. Typical Noise Dose Meter Diagram

Standards for Noise Dose

Equation (1) allows for averaging a time-varying noise level, but does not establish a limit for acceptable noise exposure. The circles in Fig.2 show how the limit in most countries is set at L_{eq} = 90 dB(A) for an 8 hour workday (40 hour week). Only in Sweden, Austria and South Africa is the limit 85 dB(A).

Besides the L_{eq} limit, a choice of q must be made, and the Atlantic here divides the proponents of q = 3 (ISO Recommendation, (4)) and q = 5 (OSHA, (5)). In Fig.2, q determines the slope of the line through the 8 hour circle. Levels below 90 dB(A) are presently ignored according to OSHA as indicated by the horizontal line at 90 dB(A).

Lowering this cut-off to 85 dB(A) has been proposed by NIOSH (6). In the ISO countries, the cut-off is generally 10 dB below the 8 hour level.

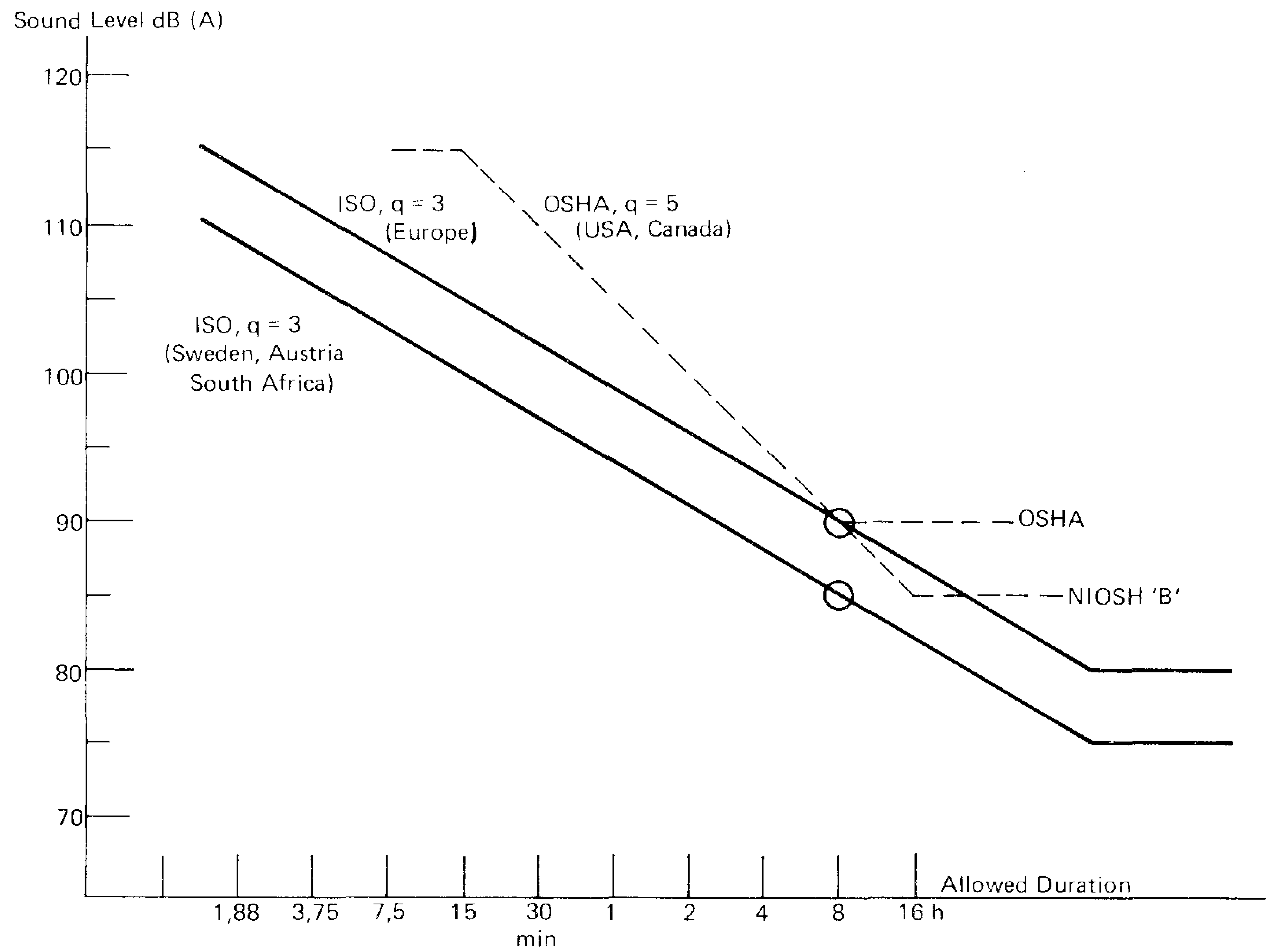

Fig.2. Noise Dose limits in various countries

The effect of q on Noise Dose

Since a person's ears must be assumed to be equally susceptible to damage no matter where he lives, it would be of interest to see what differences, if any, are found when measuring noise dose using the two different values of q. Noise doses are therefore evaluated using the OSHA curve and the upper ISO curve of Fig.2 for various types of noise. The effect of various parameters of the noise are also considered.

a) Constant Level Noise

For a given duration, Fig.2 gives the permitted level. At points above the ISO/OSHA intersection, the permitted level is greater for $q = 5$ with a maximum difference of 10 dB(A).

b) Two alternating levels

This is the simplest model of level variation. Fig.3 shows the difference in calculated L_{eq} as a function of level difference and duty cycle.

It can be seen that $q = 5$ gives lower L_{eq} and that the maximum difference depends on the Level Ratio. At 20 dB level ratio the maximum difference is about 4 dB.

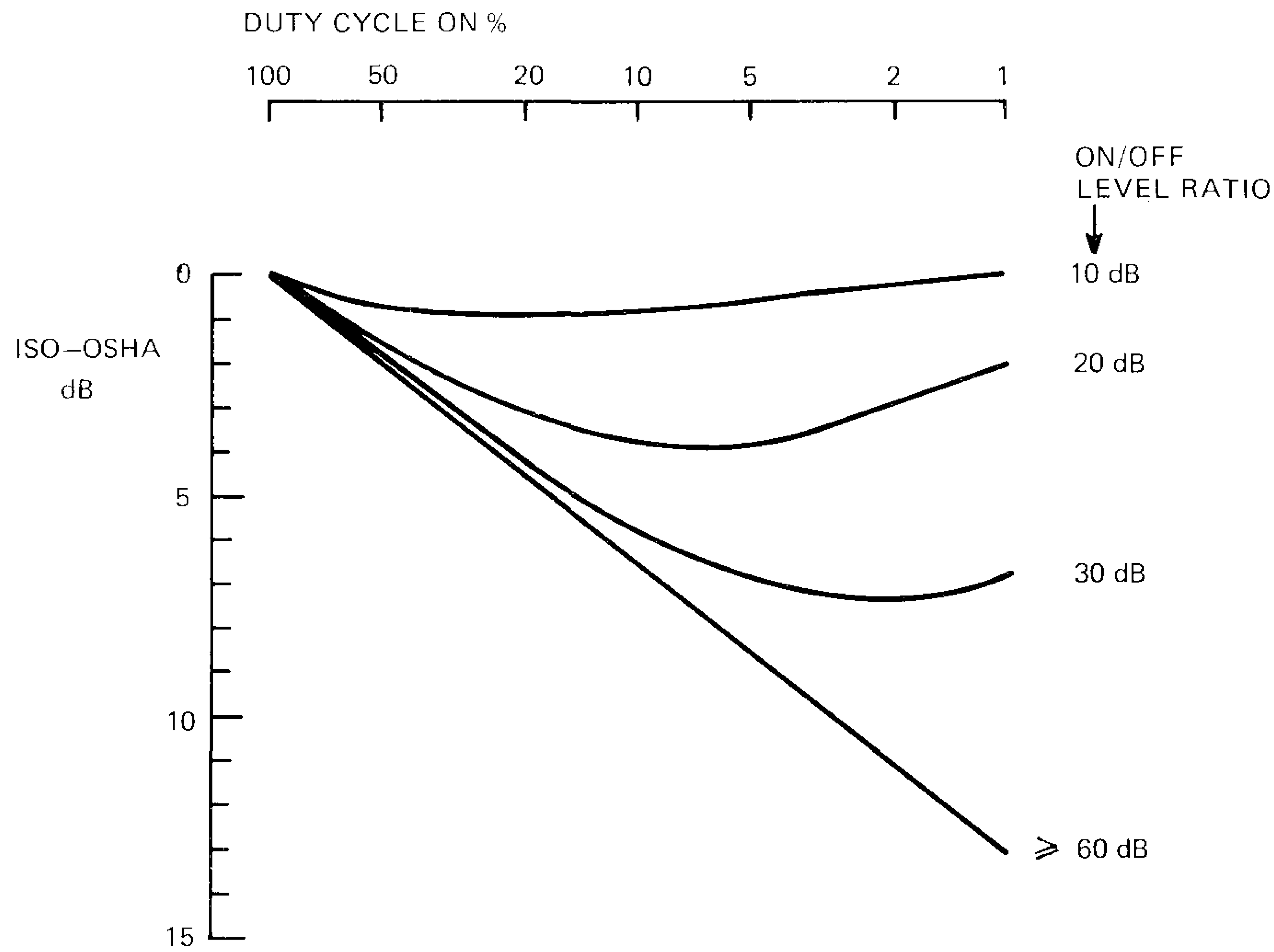

Fig. 3. L_{eq} *difference for two alternating levels as a function of level ratio and duty cycle. ("On" corresponds to the higher of the two levels)*

c) Gaussian level distribution

Using an expression given by Hesselmann (7),

$$L_{eq} = L_m + 0{,}0863 \times (2\sigma)^2/q \qquad (2)$$

where L_m is the mean value and
σ is the standard deviation.

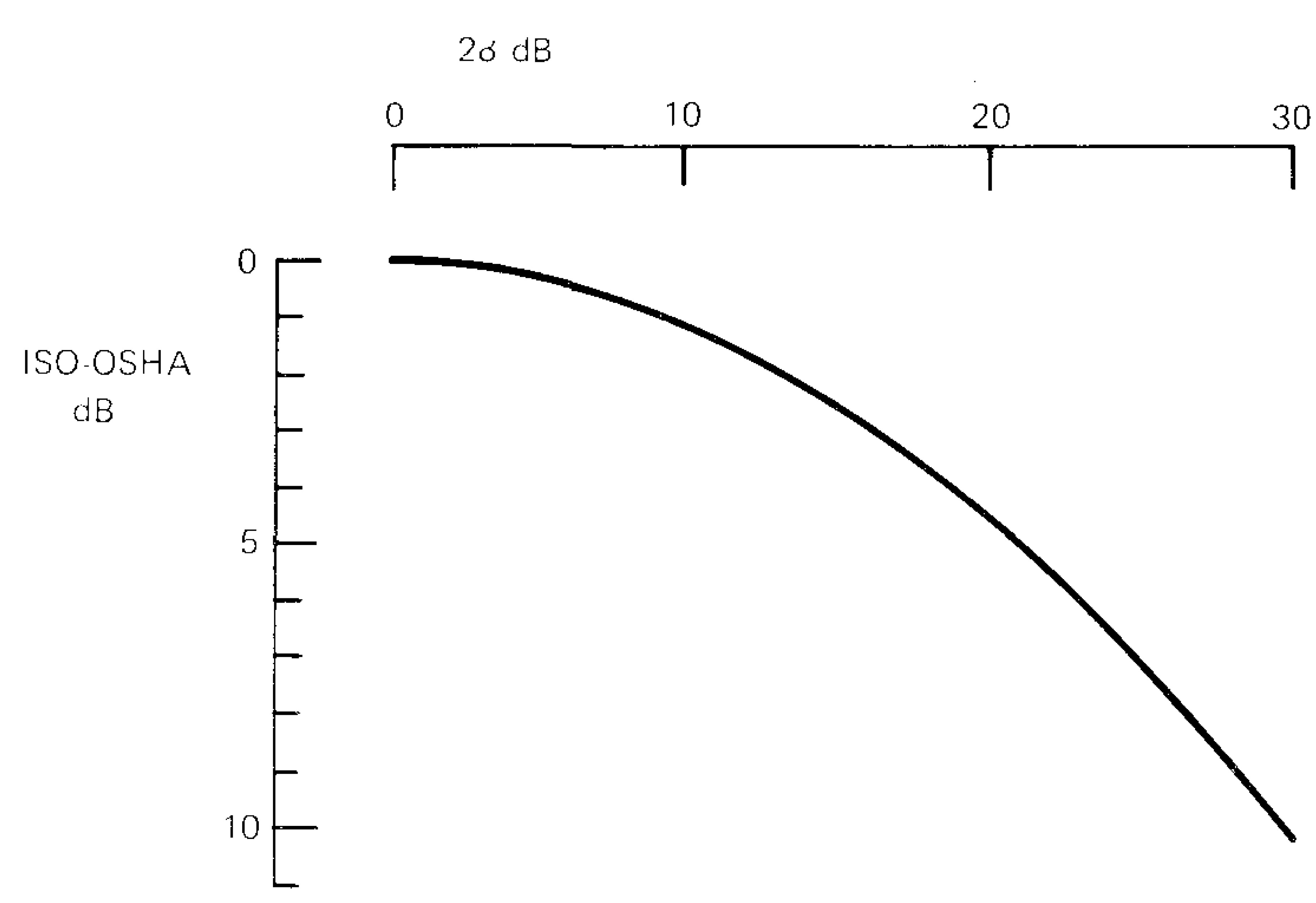

Fig. 4. L_{eq} *difference for Gaussian Level distribution*

Fig.4 shows the calculated difference in L_{eq}. For q = 5 we again get the lower value; for example, at 2σ = 20 dB the difference is about 4 dB.

d) Fast level changes

Up to now, we have disregarded the influence of the RC averaging circuit in Fig.1. In the case of q = 3 it can be shown to be of no influence on the measured noise dose (8). For q = 5 this is not so. If the level variations become fast enough to let the RC circuit reduce them, the ISO/OSHA difference will also be reduced. To demonstrate this dependence, two Brüel & Kjær Noise Dose Meters of identical design apart from q value (Types 4424 and 4425) were exposed to simulated reverberation decay signals. The pulse repetition period (PRP) and exponen-

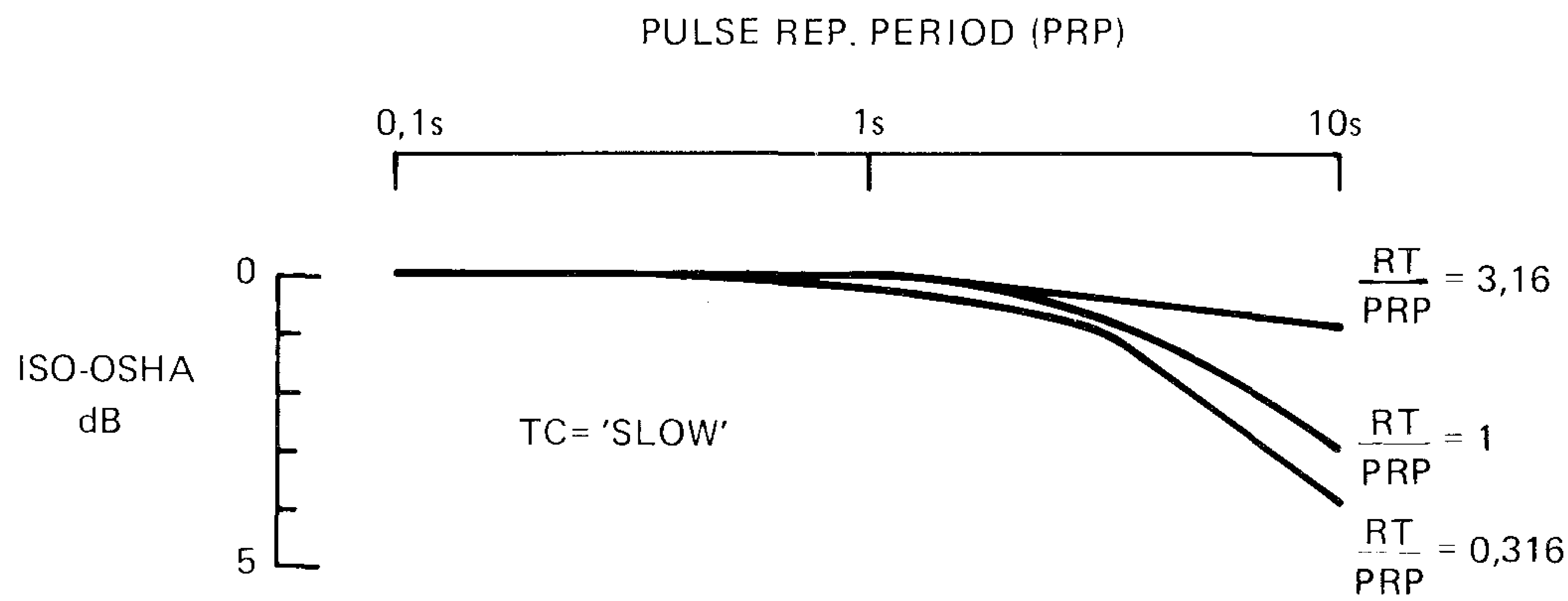

Fig.5. L_{eq} difference for rapid level variations with "Slow" meter time constant

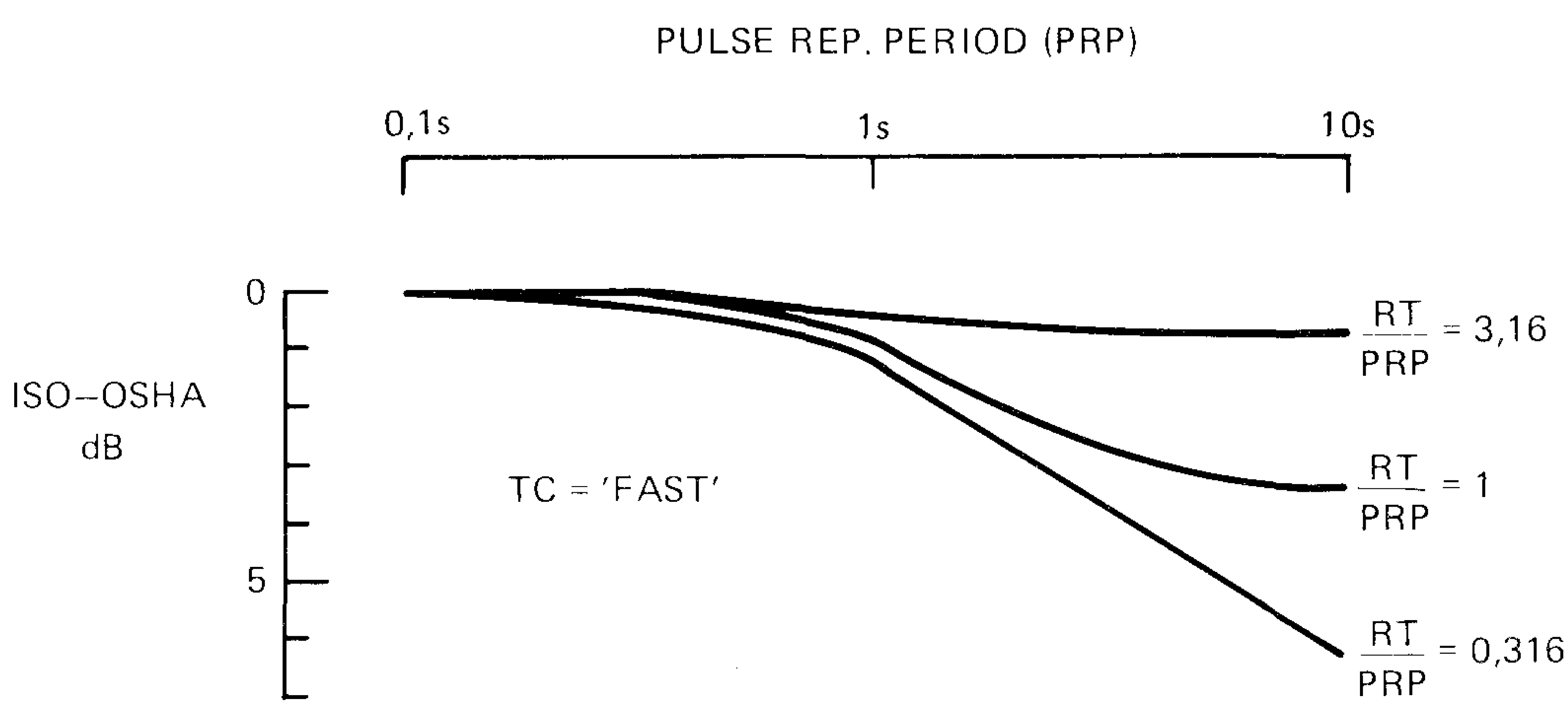

Fig.6. L_{eq} difference for rapid level variations with "Fast" meter time constant

tial decay time (Reverberation Time RT) were variable. Keeping the ratio of RT/PRP constant at 3,16, 1 and 0,316, the difference between the ISO and OSHA criteria were measured for different values of PRP.

Figs.5 and 6 show the result: when the pulse repetition period is reduced, the L_{eq} difference disappears. Going towards greater values of PRP, we approach a difference of about 4 dB for the case where PRP = RT. These two figures which are obtained for "Slow" and "Fast" meter time constants respectively, show at which PRP the difference becomes significant.

Fig.7 shows similar curves for tone burst signals.

As the PRP increases, the two curves approach a level difference of about 2 and 7 dB, corresponding to two points (50% and 10% duty cycle) on the ≥ 60 dB line in Fig.3.

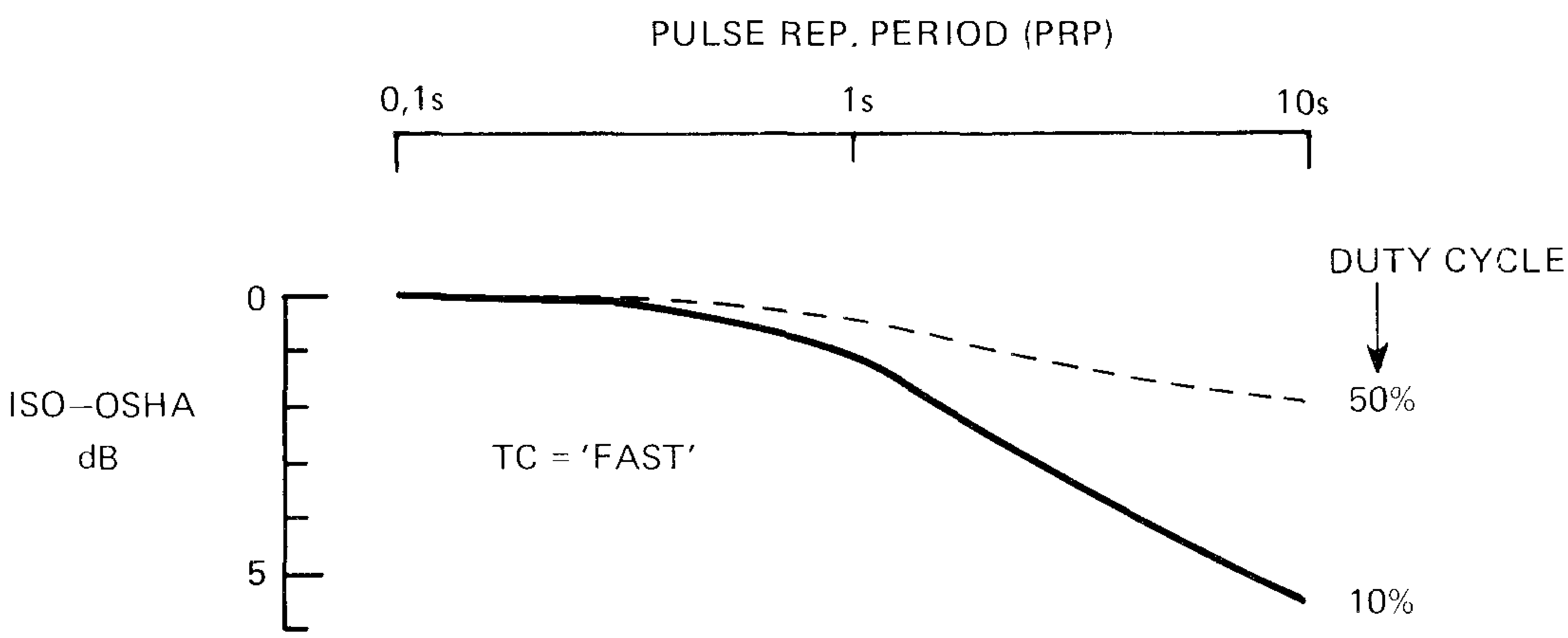

Fig.7. L_{eq} difference for tone burst signals

e) Measurements of industrial noise

Finally, a series of measurements were performed of noise in industry, using the two Noise Dose Meters and their readings were compared. A variety of noise signatures were covered, and typical sample level recordings are shown in figures 8, 9, 10 and 11. From the results the following remarks can be concluded: when measuring fairly constant noise levels, (i.e. slowly varying levels within a few dB) or rapidly repeated noise bursts (PRP less than 1 s) ISO and OSHA measurements show little differences, as illustrated in Figs.8 and 9. Noise bursts repeated at greater intervals exhibit a noticeably lower reading for the

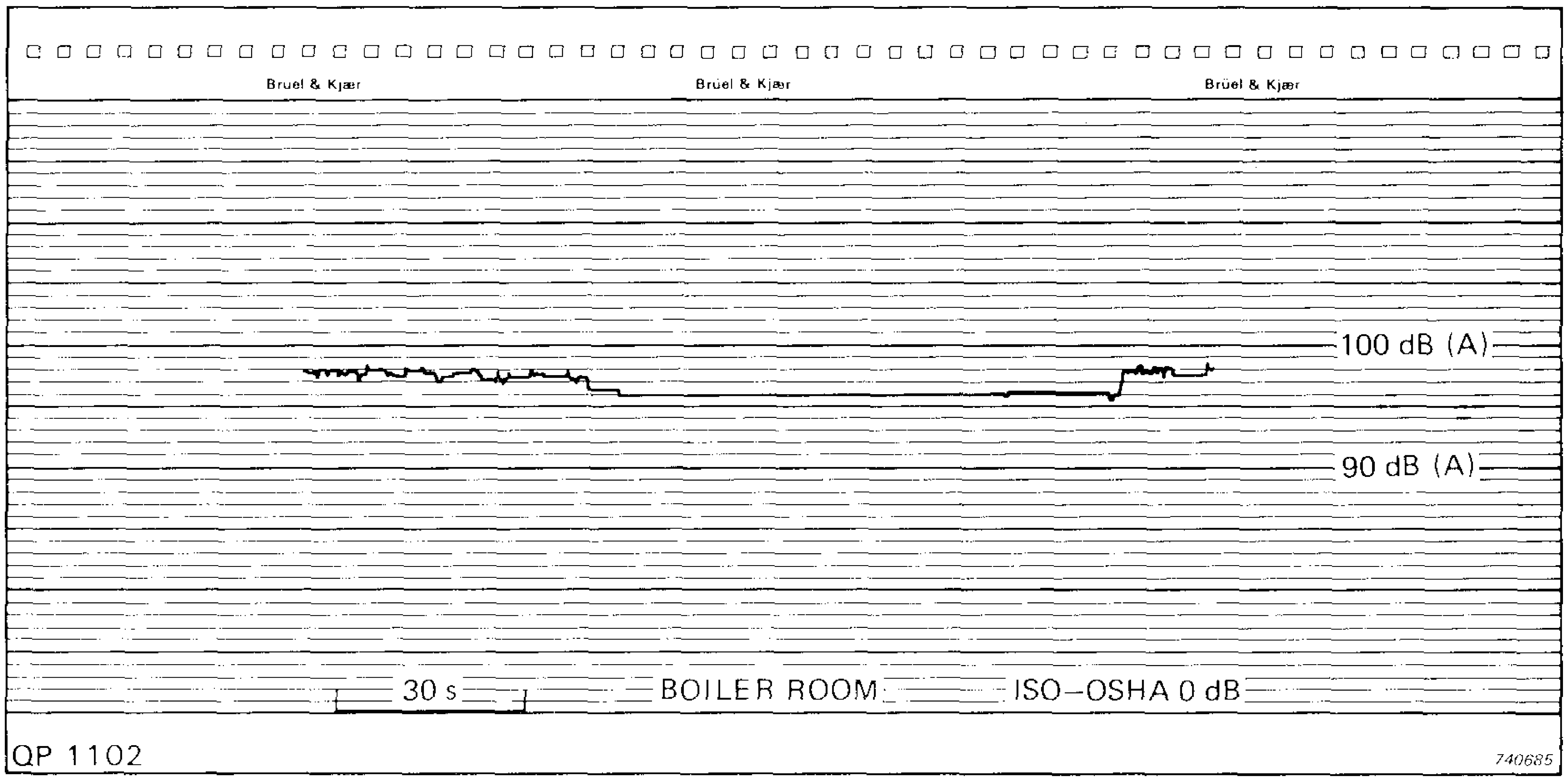

Fig.8. Noise from a boiler room

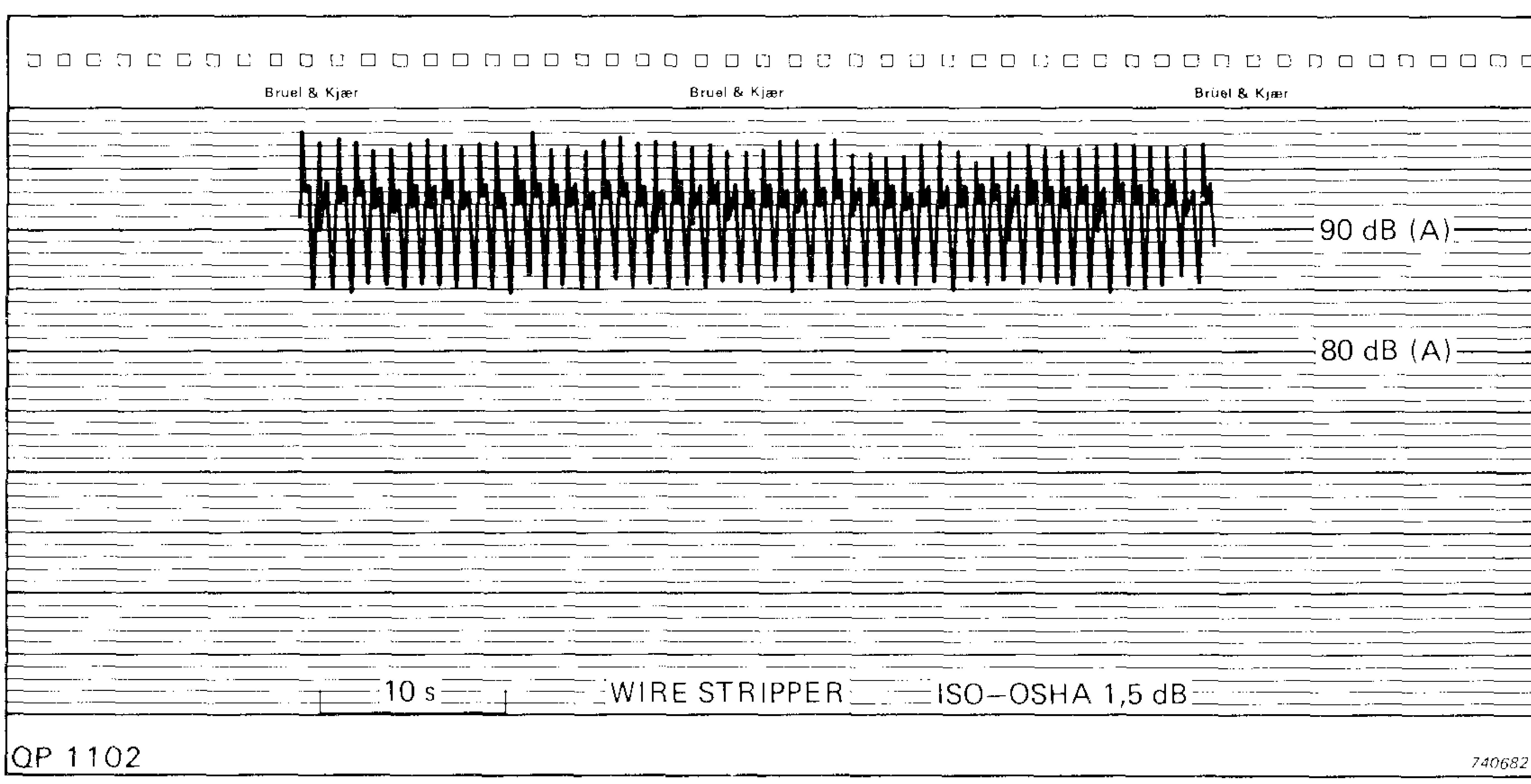

Fig.9. Noise from a wire stripper

OSHA Dose Meter (3 dB in Fig.10), while large burst intervals combined with great level variations give a still lower OSHA reading (6,5 dB in Fig.11). These results are comparable to those obtained by other authors (9).

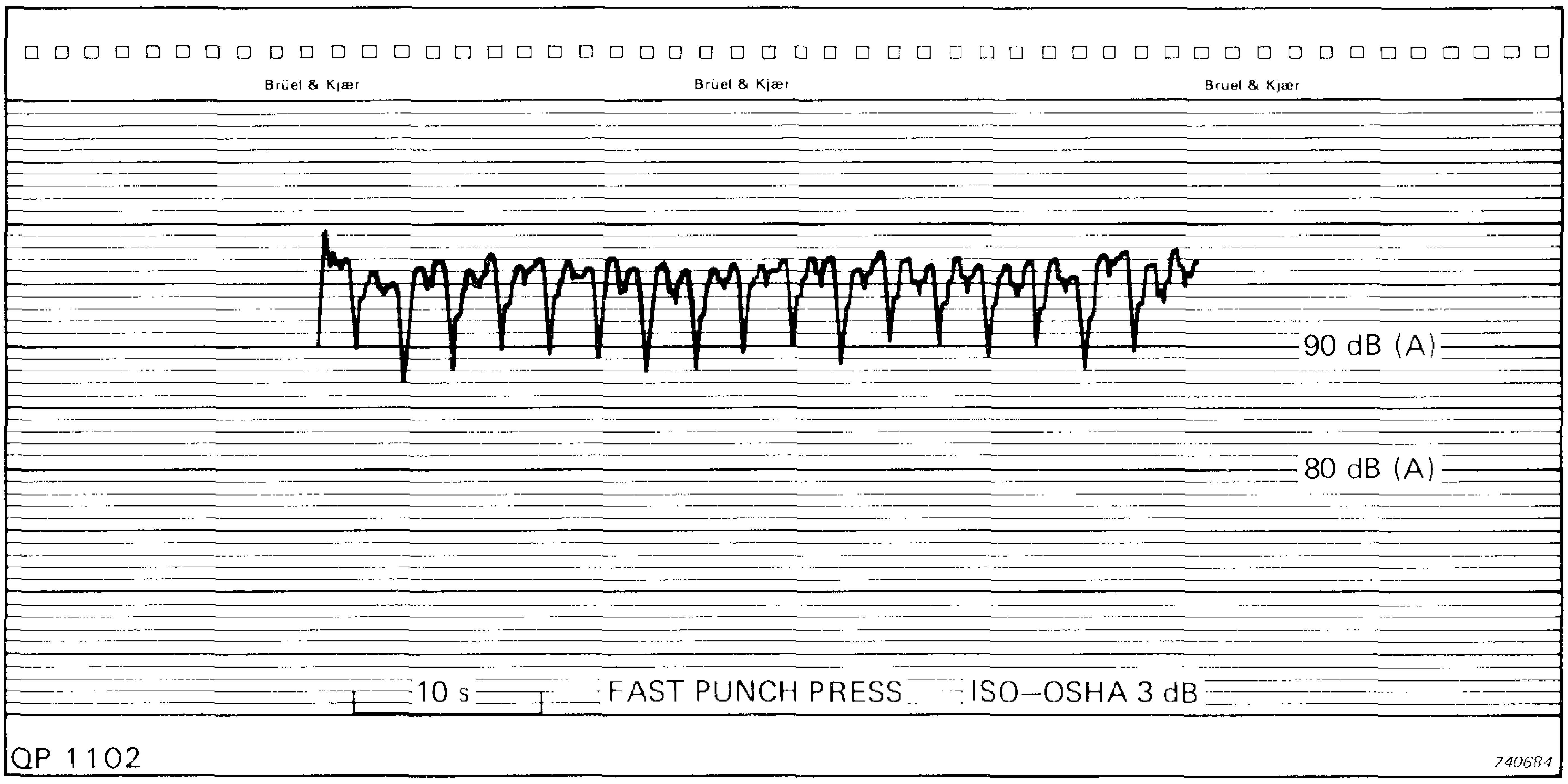

Fig.10. Noise from a fast punch press

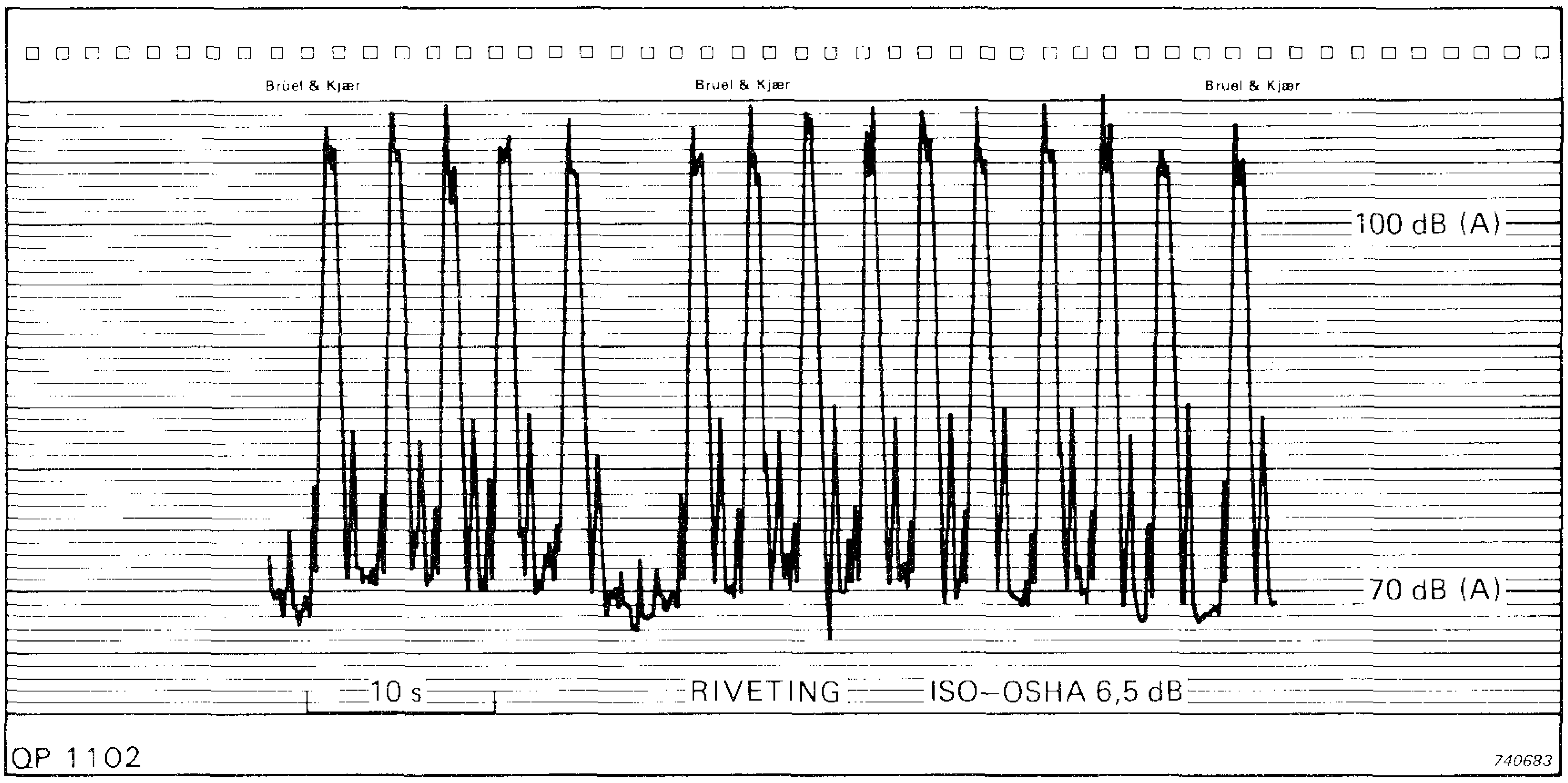

Fig.11. Noise from a riveting process

Conclusion

It would have been desirable that the various standards for noise dose measurements would lead to similar results in practice. However, measurements according to OSHA may give an L_{eq} 5 — 10 dB lower than those according to ISO, and there may for a given exposure time be up to 10 dB difference in permitted level.

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Sound Radiation from Loudspeaker System with the Symmetry of the Platonic Solids

by

Viggo Tarnow

ABSTRACT

Isotropic radiation from a sound source is often achieved by mounting small loudspeakers on the surface of a regular solid. In this article the theoretical limit for isotropic range of some loudspeaker systems has been calculated. In the case of the dodecahedron the theoretical intensity is compared with experimental results for various directions.

SOMMAIRE

La radiation isotrope d'une source sonore s'obtient souvent en montant de petits haut-parleurs sur la surface d'un solide régulier. Dans cet article, on calcule la limite théorique de la gamme isotrope de certains systèmes de haut-parleurs. Dans le cas d'un dodécaèdre, l'intensité théorique est comparée aux résultats expérimentaux dans différentes directions.

ZUSAMMENFASSUNG

Eine ungerichtete (kugelförmige) Schallabstrahlung wird häufig durch die Montage kleiner Lautsprecher an der Oberfläche eines regelmäßigen Polyeders erreicht. In diesem Artikel wird die theoretische Grenze für die kugelförmige Charakteristik einiger Lautsprecheranordnungen berechnet. Für den Fall des Dodekaeders wird der berechnete Schalldruck mit experimentell gewonnenen Resultaten für verschiedene Richtungen verglichen.

Introduction

Sound sources may be build in many ways by combining a number of loudspeaker units. However, equal radiation of sound in all directions can only be obtained at low frequencies. The precise meaning of "low frequencies" depends on the size and shape of the loudspeaker system. In general small systems have a high upper limit for isotropic radiation but often there is a practical lower limit for the size of the system, determined by the required power handling capacity. Also a physically small system would not be able to radiate low frequency sound.

To obtain isotropic radiation loudspeaker units are often placed in a symmetrical way on a regular solid.

In this article the limit of the isotropic range for some loudspeaker systems has been calculated. The wave equation for the sound pressure is solved by the usual expansion in spherical harmonics. This is simplified by the use of group representation theory. Only small deviations from isotropy was considered, because the idealizations used for the computation are only valid for this case. The idealizations are:

1) The vibration pattern of the loudspeaker membranes do not violate symmetry.

2) The solids are replaced by spheres.

A less necessary assumption is that the loudspeaker units are regarded as point sources. This may give a little too high a value of the deviation from isotropy if a large fraction of the solids is covered by the membranes of the loudspeakers.

The computed values of the sound intensity have been compared with some experimental data for the dodecahedron. The agreement is within a few decibels.

Theory

The wave equation

The sound pressure outside the source is given by the formula:

$$p(r,\Theta,\varphi,k) = i\rho c \frac{1}{4\pi} \sum_{l=0}^{\infty} h_l(k\,r) \sum_{m=-l}^{l} u_{lm} Y_{lm}(\Theta,\varphi)$$

This formula may be found in the book by Morse and Ingard (1). ρ is the density of air, c the velocity of sound, h_l is the spherical Hankel function. u_{lm} are constants depending on frequency. Y_{lm} are the usual spherical harmonics.

The value of u_{lm} is found from the boundary condition, which expresses the continuity of the velocity normal to the surface of the source.

$$u = \frac{1}{ik\rho c} \cdot \frac{\partial p}{\partial n}$$

Symmetry

Any sound source of finite extension has symmetric properties belonging to one of the finite subgroups of the 3-dimensional orthogonal group.

If subgroups with a principal axis of rotation are neglected, only 3 groups remain, the groups of the tetrahedron, the octahedron and the icosahedron. The cube belongs to the octahedron group while the dodecahedron to the icosahedron group.

The symmetry of the source determines in part the values of the coefficients of the spherical harmonics, u_{lm}. For a given value of l it may happen that all constants are zero i. e. $u_{lm} = 0$, or a particular linear relationship may exist between them.

Another way to look at this is to find the independent invariant harmonics for a given l. The number of invariant harmonics is given by the characters of group representation theory, see Appendix A.

The invariant harmonics are given in the paper by Bell (3) for the tetrahedron and the octahedron. The lowest order nontrivial function for the icosahedron group has been computed for this paper. It is given in Appendix B.

The Sound Intensity

The sound pressure formula (1) may be rewritten as

$$p \quad = \quad i\rho c \frac{1}{4\pi} \sum_{l=0} h_l(k\,r)\; v_l \; Z_l(\Theta, \varphi)$$

with new constants, v_l, and the invariant harmonics Z_l. There is only one harmonic for each l, for the values of l actually used for the numerical calculations.

In order to determine the coefficient v_l it is assumed that the sound source is a sphere of which a part is vibrating. The coefficient v_l may now be found in the usual way by using the orthogonality of the harmonics and the boundary value on the sphere.

$$v_l \quad = \quad \frac{1}{h_l'(k\,a)} \int u(\Theta, \varphi)\; Z_l(\Theta, \varphi)\; d\Omega$$

In the far field the sound pressure is given by the formula

$$p \quad = \quad i\rho c \frac{e^{ikr}}{ikr \cdot 4\pi} \sum_{l=0} i^{-l} v_l \; Z_l(\Theta, \varphi)$$

From this formula the variation of the intensity with direction may be found for all the solids and is shown in Fig.1. The loudspeakers were assumed to be point sources and positioned on the surface of the sol-

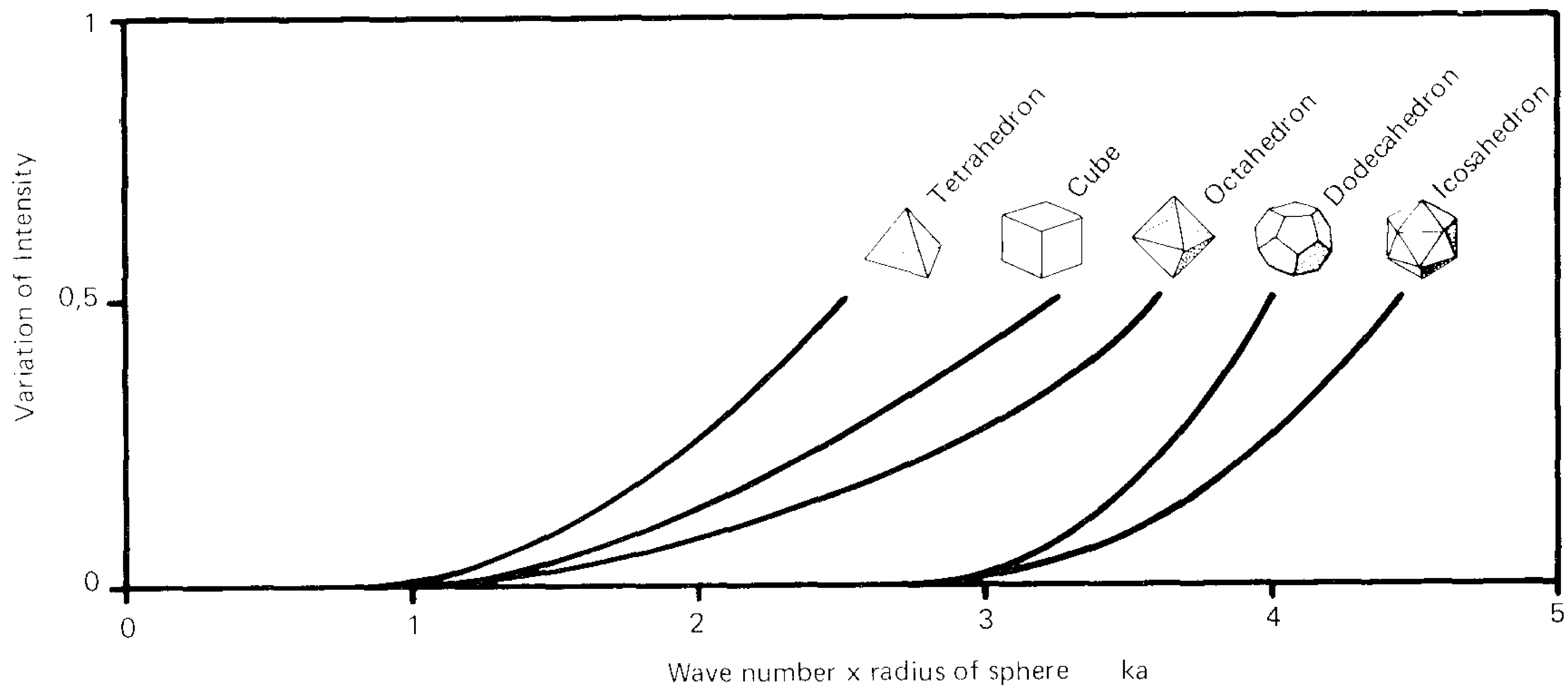


Fig. 1. The curves indicate the deviation from isotropic radiation. The loudspeakers are placed on the faces of the solids

ids. The ordinate is the root mean square of the intensity over all directions divided by the mean intensity and represents the deviation from isotropic radiation. The abscissa is equal to the wave number k, (i.e. $2\pi f/c$) times the radius of the sphere "a". The figure shows how the intensity varies as the frequency is increased for a fixed radius of the solid. It can also be seen that for regular solids with greater number of surfaces the variation in intensity gets significant at higher frequencies than for solids with less number of surfaces.

Measurement Results

To check the theoretical results with practical measurements, the intensity of the dodecahedron was studied in more detail. The theoretical var-

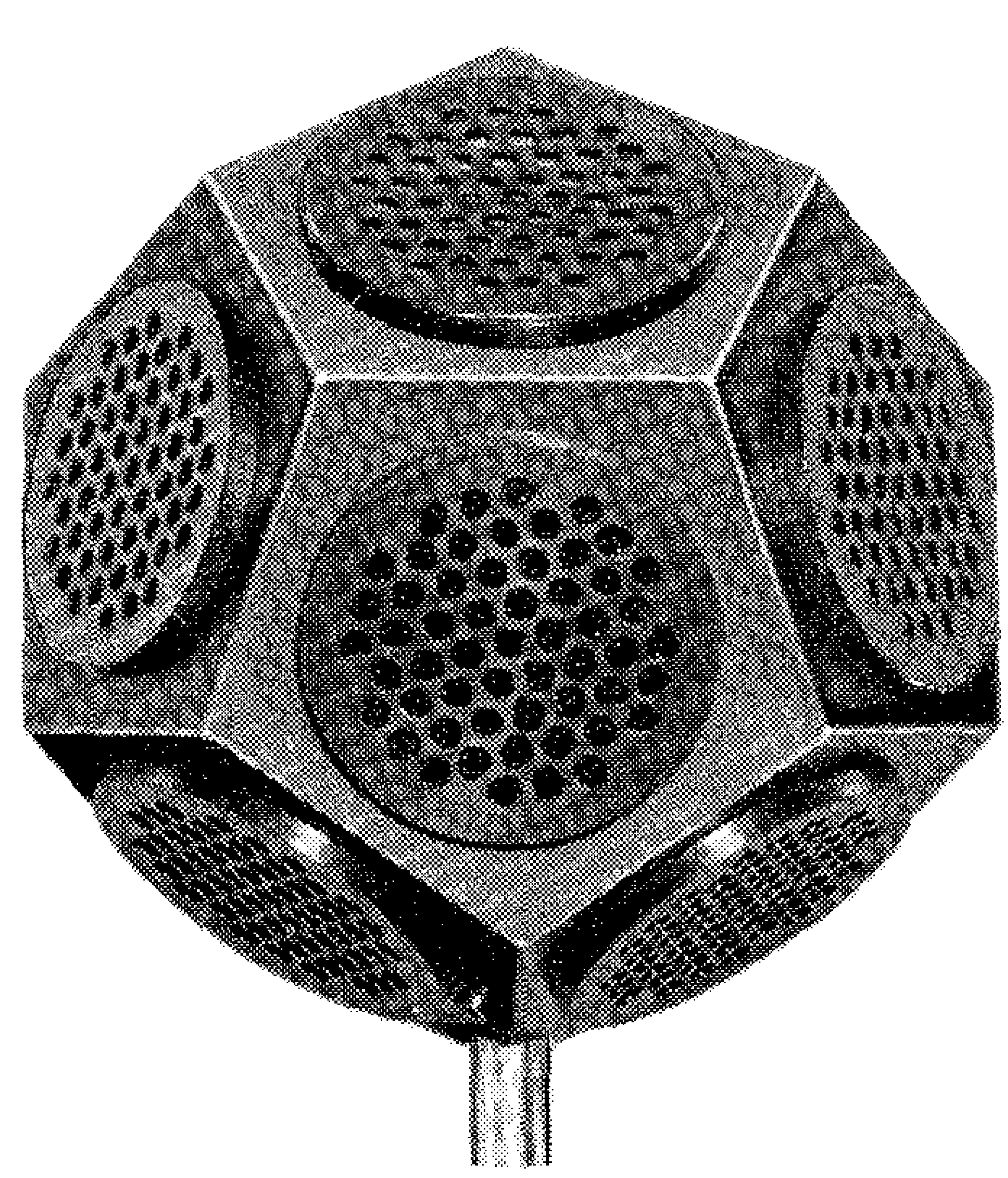


Fig. 2. Dodecahedral Sound Source

iation of intensity around different latitudes was calculated and compared with experimental results obtained from measurements around a dodecahedral sound source shown in Fig.2. In Fig.3 a three fold symmetry axis of the dodecahedron is used as the polar axis while the longitude is calculated from one of the three edges at the north pole. (An n-fold symmetry axis is defined as the axis around which the body maps into itself n times per revolution i.e. the rotated body is indistinguishable from the unrotated after 1/n th of a revolution.)

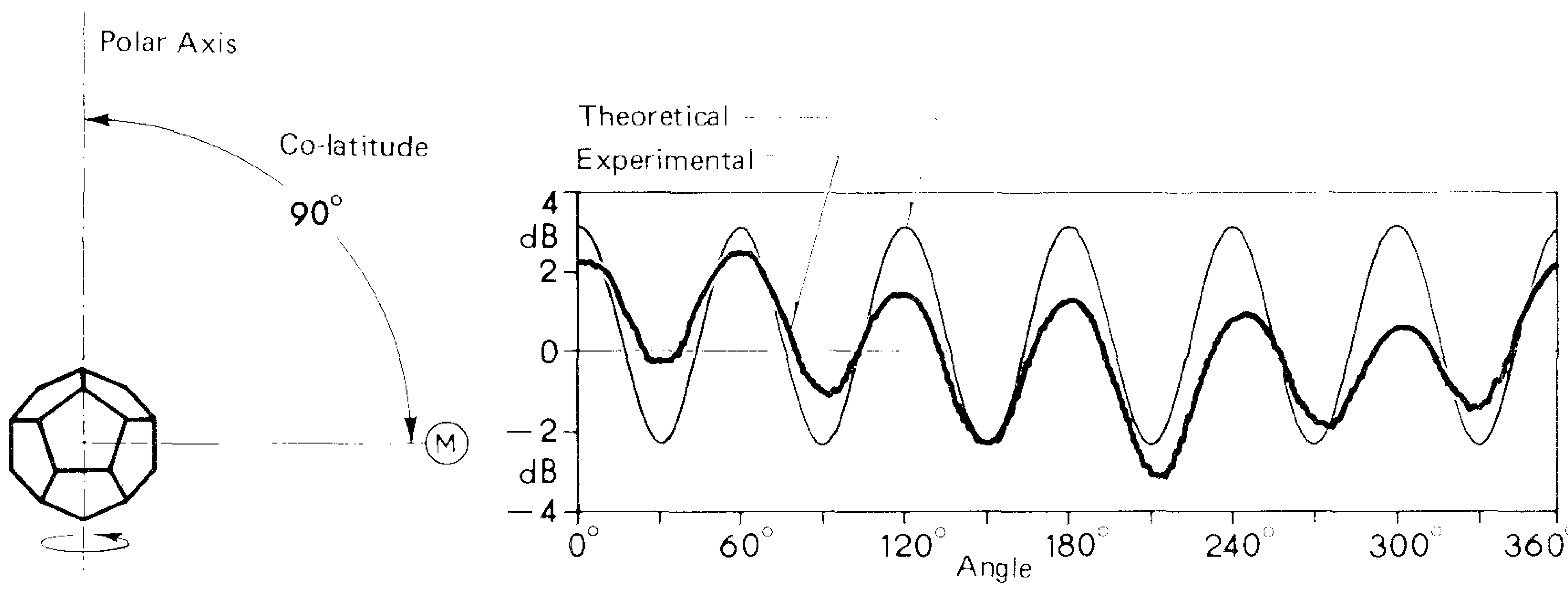


Fig.3. Theoretical and experimentally measured intensity at different angles around the equatorial plane for a dodecahedron. Co-latitude 90°

The curve shows variation of intensity in the equatorial latitude plane (co-latitude of 90°). The theoretical as well as practical results were obtained for the condition ka = 4. The mean radius of the dodecahedral sound source, 11,5 cms was used for the value of "a" to calculate the theoretical curve. For the experimental results the frequency of excitation of the sound source was calculated from

$$\frac{2\pi fa}{c} = 4 \text{ where } \frac{2\pi f}{c} = k \text{ wave number}$$

and was found to be 1930 Hz. It is obvious that the experimental intensity does not have exactly the six-fold symmetry expected. The six-fold symmetry is a consequence of the symmetry of the dodecahedron, if the vibration pattern of the loudspeakers does not violate the symmetry. Consequently the deviations are caused by the differences in the loudspeakers.

In Figs.4 and 5 variation of intensity in other latitude planes (co-latitudes 60° & 30° respectively) is shown. In all the three figures ka = 4 (wavenumber times radius of sphere).

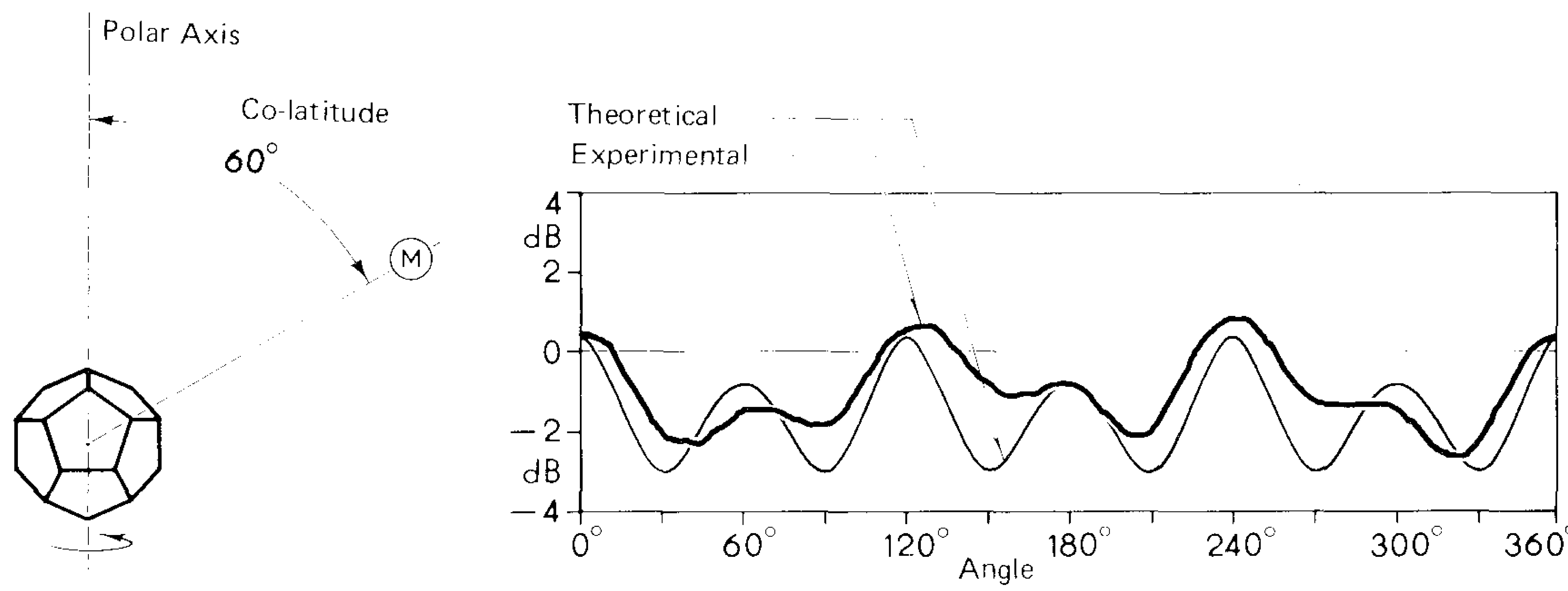


Fig.4. Theoretical and experimentally measured intensity at different angles around a latitude plane. Co-latitude 60°

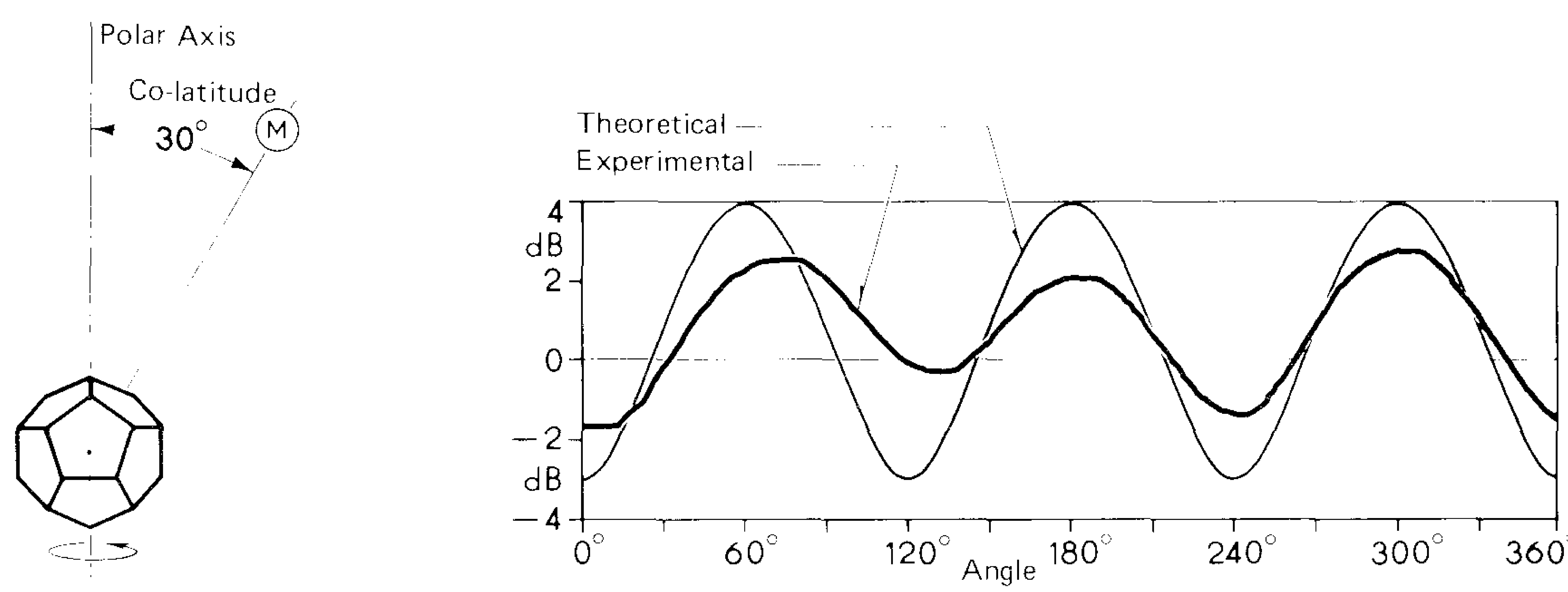


Fig.5. Theoretical and experimentally measured intensity at different angles around a latitude plane. Co-latitude 30°

In order to give a view of the intensity distribution over the direction sphere, Fig.6 has been sketched. It shows a pictorial view of the theoretical intensity at the frequency corresponding to ka = 4. The fivefold axes are directions of maxima, and the three-fold of minima. The two-fold axes are directions of saddle-points. The values of the relative intensity of the corresponding points are 8,8 dB, 0 dB & 1,9 dB respectively.

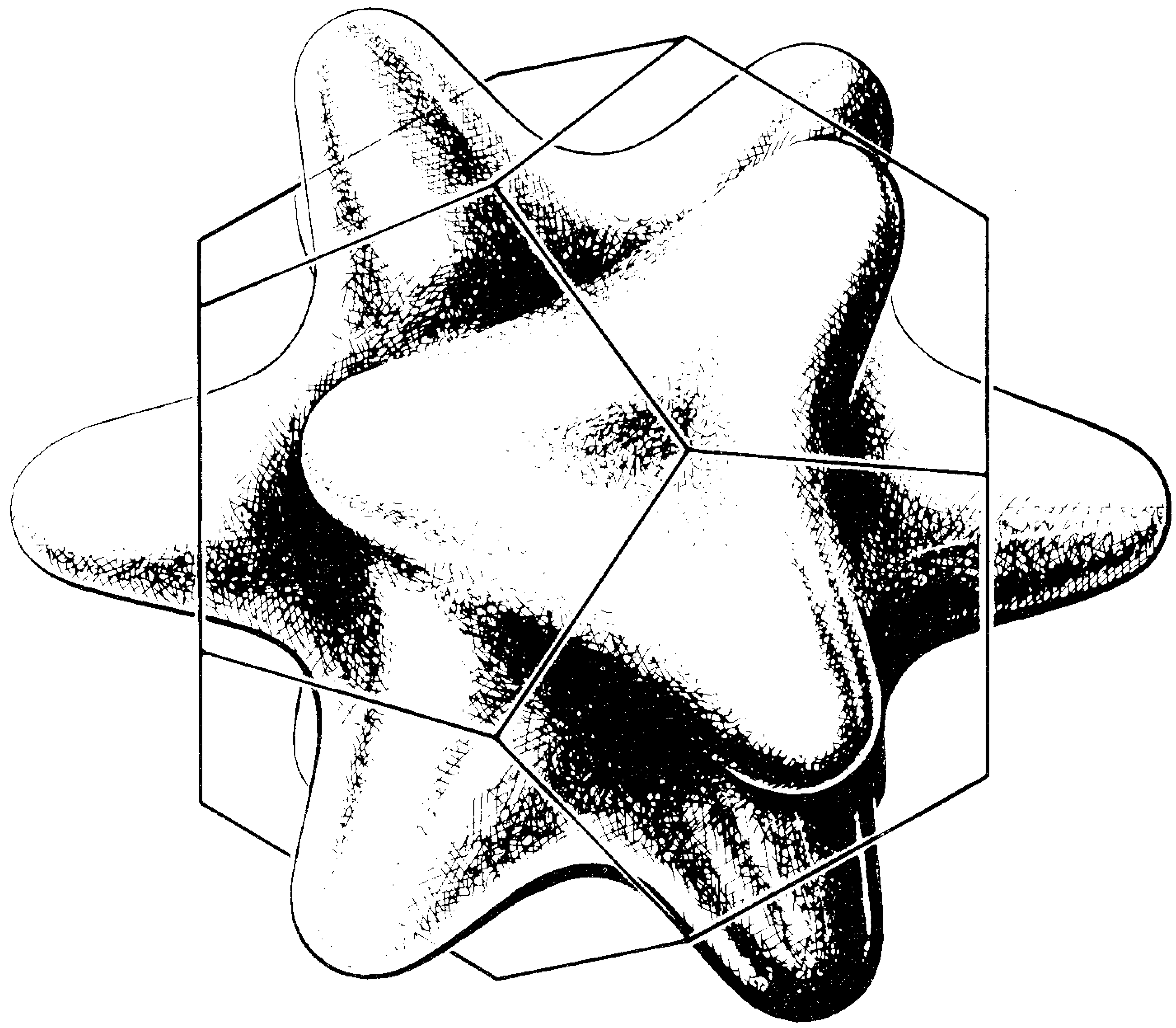


Fig.6. Drawing of a 3-dimensional surface, describing the theoretical intensity of sound waves from the dodecahedron

References

1. P. M. MORSE and K. V. INGARD: Theoretical Acoustics, Mc Graw-Hill, 1968.

2. M. TINKHAM: Group Theory and Quantum Mechanics, Mc Graw-Hill, 1964.

3. DOROTHY G. BELL: Rev. Mod. Phys. (1954) Vol. 26, 311.

Appendix A

The number of invariant harmonics

The symmetry group may be represented by the spherical harmonics. The character of this representation is easily found. In Table A 1 is given the mean value of the character over the symmetry group. This is equal to the number of invariant spherical harmonics. The mirror plane of the tetrahedron, and the inversion centre of the two other groups have been considered.

1	0	1	2	3	4	5	6	7	8	9	10
Tetrahedron	1	0	0	1	1	0	1	1	1	1	1
Octahedron, Cube	1	0	0	0	1	0	1	0	1	0	1
Icosahedron, Dodecahedron	1	0	0	0	0	0	1	0	0	0	1

Table A 1

This means that $u_{2m} = 0$ in all cases. More details on group representation is given in the book by Tinkham (2).

Appendix B

The invariant harmonic of the dodecahedron and icosahedron

The lowest order nontrivial harmonic of the icosahedron group is given by

$$\frac{\sqrt{13 \cdot 11}}{5 \cdot 16}\left[231z^6 - 315z^4 + 105z^2 - 5 - 42z(5x^4y - 10x^2y^3 + y^5)\right]$$

The harmonic is normalized to 4π on the sphere. x, y, z are directional cosines ($x = x/r$ etc.). The z-axis is here a five-fold axis of the dodecahedron, and the x-axis is a two-fold axis. The choice of the coordinates is shown in Fig.B1.

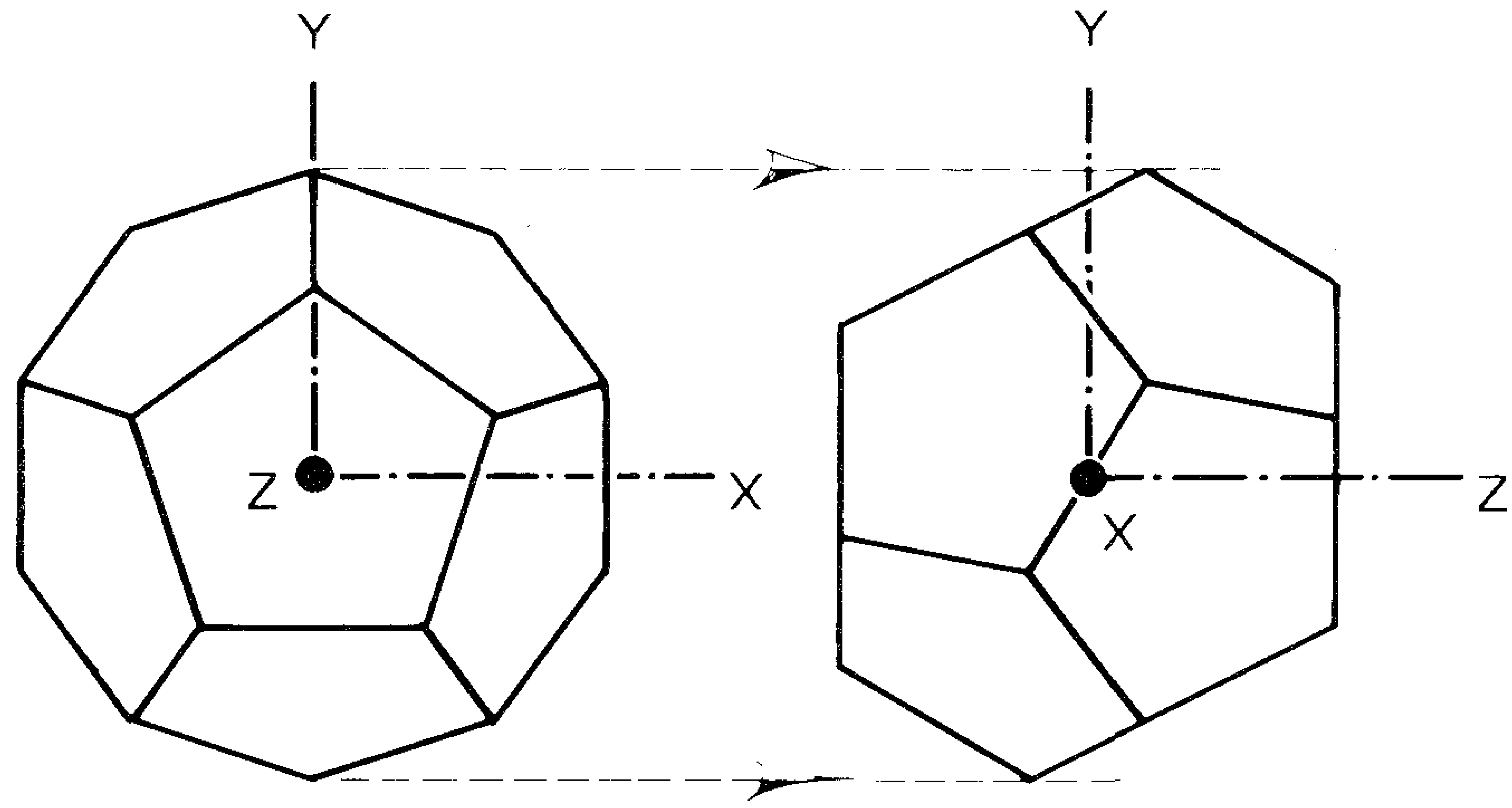


Fig.B1. The axes of the coordinate system for the harmonic

The harmonic may be written as a linear combination of the usual spherical harmonics. The sum will only contain the harmonics Y_{60}, Y_{65}, Y_{6-5}, because a five-fold axis is used as polar axis. These harmonics are computed with the usual formula for Legendre functions. The directional cosine is substituted in the formula instead of the angles.

It is seen that only one value is not immediately found. This is the ratio between the coefficient of Y_{60} and $Y_{65} + Y_{6-5}$. The ratio may be found from the requirement that the harmonic should be invariant, if any symmetry transformation is performed. A suitable transformation is a rotation about the x-axis, which makes the top pentagon-plane cover the nearest pentagon plane, followed by a rotation of π about an axis normal to this plane. The resulting rotation is expressed in a transformation of the directional cosine, and this is substituted in the expression for the spherical harmonic. The coefficient of y_6 has to be 0. This condition determines the required number. It should be noted that the variable x should be eliminated from the formula, because the variables must be independent. The rest is obtained by the normalization of the harmonic on the sphere.

News from the Factory

Personal Noise Dose Meter Types 4424 & 4425

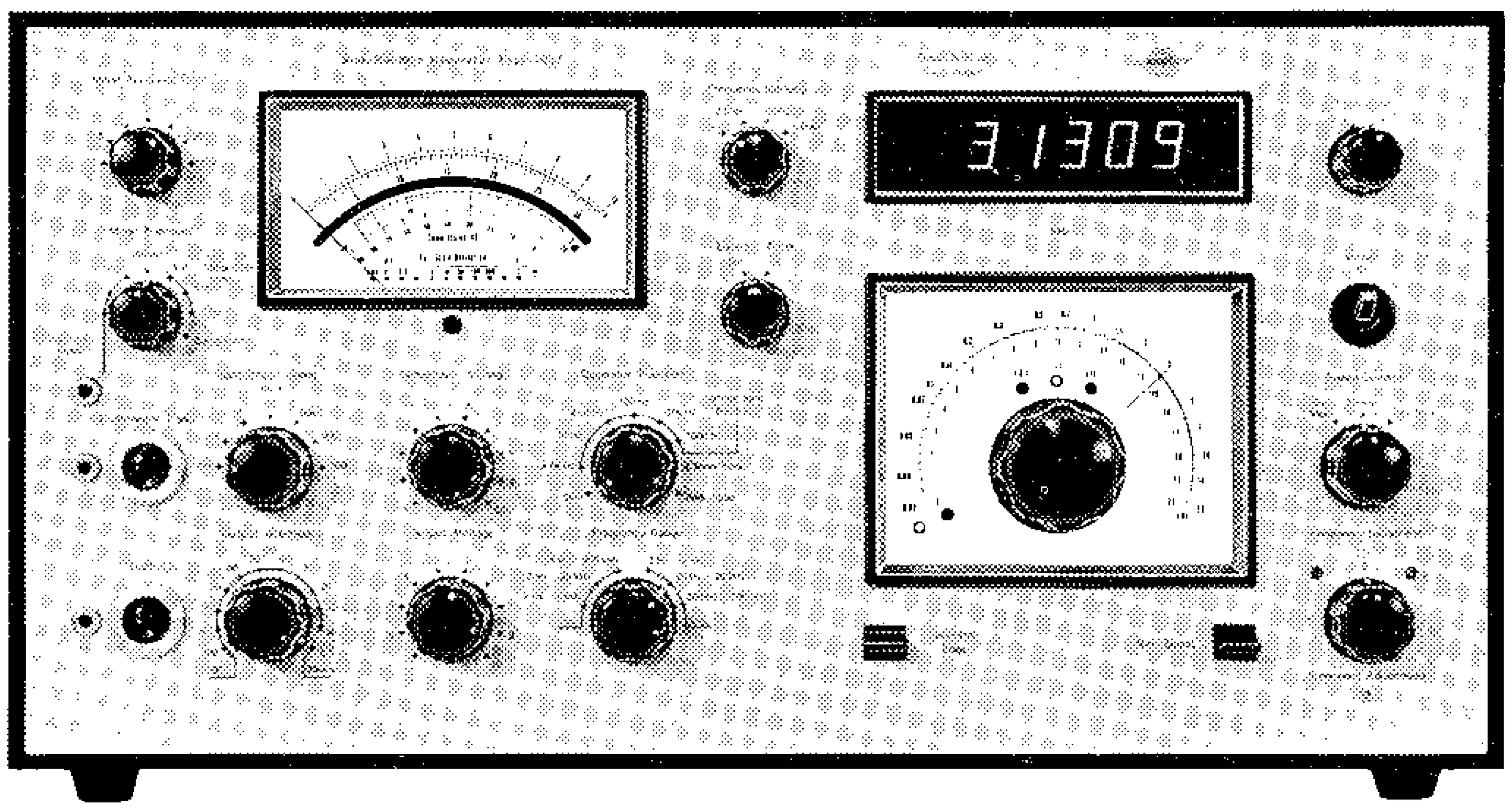
The personal Noise Dose Meters Types 4424 and 4425 are completely self-contained pocket-size units which measure the true accumulated noise exposure according to ISO Recommendation R 1999 and OSHA requirements respectively. A digital display gives continuous reading of the percentage of the allowable noise exposure to which the wearer has been subjected.

As standard a half inch microphone Type 4125 is mounted directly on the Noise Dose Meters, but as an option it can be mounted on a Microphone Preamplifier ZE 0132 for clip-mounting near the wearer's ear. Low level detectors are incorporated to inhibit measurements below 80 dB(A) for Type 4424 and 89 dB(A) for Type 4425. High level detectors indicate exceedance of 115 dB(A) required by OSHA standard. The upper measurement limits are 120 dB(A) for Type 4424 and 115 dB(A) for Type 4425 while instantaneous levels in excess of 130 dB(A) and 125 dB(A) can be handled by Types 4424 and 4425 respectively.

With the "accelerated measurement mode" providing more than 100 times faster indication, measurement of less than 5 minutes noise duration can be made. A conversion table is supplied to ease the derivation of L_{eq} for measurement periods of 5 min, 15 min, 1 h, 2 h, 4 h and 8 h.

Finally, a very simple and accurate calibration can be performed using the Sound Level Calibrator Type 4230.

Sine Random Generator Type 1027



The Sine Random Generator Type 1027 is a high accuracy, high stability signal source covering a frequency range of 2 Hz and 200 kHz. The four types of output waveforms available for various applications are:

1) Sinusoidal
2) Narrow band random noise
3) White noise (wide band random noise)
4) Pink noise (wide band random noise —3 dB/octave)

Six bandwidths of 3,16 Hz, 10 Hz, 31,6 Hz, 100 Hz, 316 Hz and 1000 Hz are available, the centre frequency of which can be varied over the whole frequency range. The frequency of the generator can be selected within a fraction of a Hz with the aid of the built-in frequency counter and a 6 digit frequency display. Linear or logarithmic frequency sweeps can be carried out either manually or remotely by a mechanical drive or electrical signal.

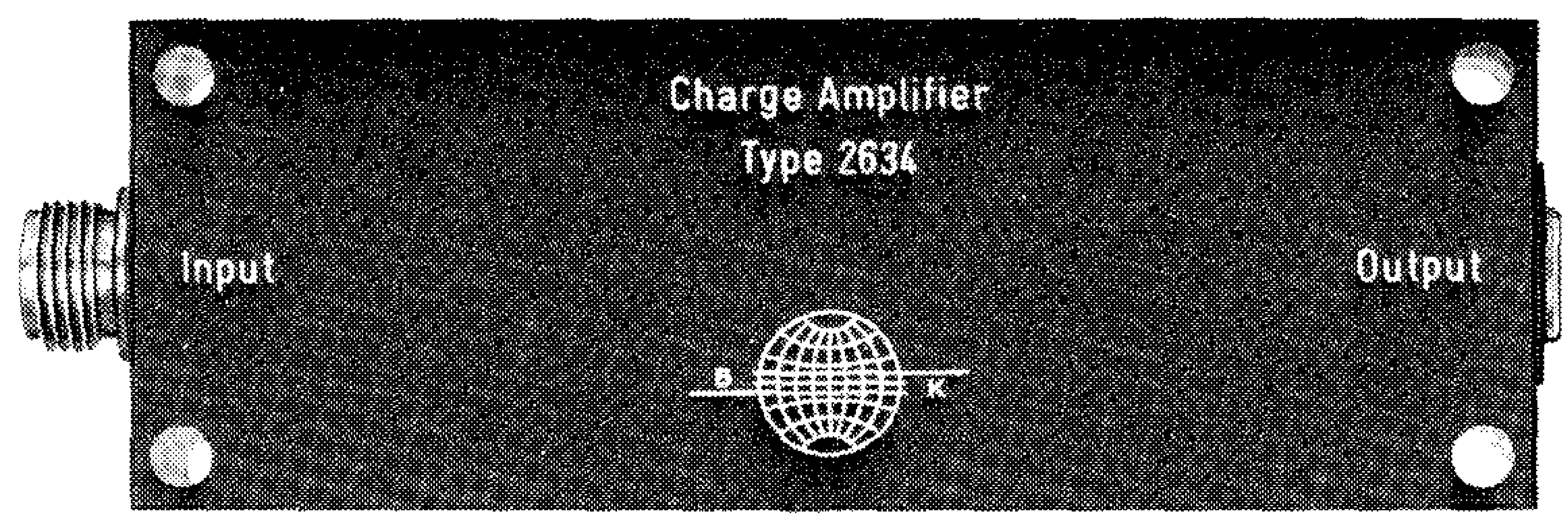
The wide band random noise has a true symmetrical Gaussian amplitude distribution up to 4,5 σ. With the appropriate selection of high and low pass filters of slopes 18 dB/octave, wide band random noise or pink noise may be generated in the five ranges 2 Hz — 2 kHz; 2 Hz — 20 kHz; 2 Hz — 200 kHz; 20 Hz — 20 kHz and 200 Hz — 200 kHz.

A built-in compressor facility works in all modes with a dynamic range up to 90 dB (for sinusoidal mode) and 0 dB static error for maintaining a constant output level, for example on a loudspeaker or a vibration exciter.

Either the output voltage, compressor input voltage or the amount of compression can be monitored on a built-in, electronic voltmeter which has 7 averaging times from 0,1 to 100 s. Facilities for connection to external filters (e. g. 1/3 octave or 1/1 octave filter sets) is available as well as tuning signals for Brüel & Kjær Heterodyne Slave Filters.

This universal precision generator is well suited (as can be seen from the facilities) for accurate measurements in the fields of acoustics, electroacoustics, mechanical dynamics and electronic research.

Charge Amplifier Type 2634



Charge Amplifier Type 2634 is a compact two stage amplifier primarily intended for measurements in industrial environments. On account of its rugged construction it can be mounted in conditions alien to normal electronic instrumentation. It is therefore ideal for use in conditions where the preamplifier must be mounted close to the accelerometer to avoid noise pick-ups in long transducer cables due to electro-magnetic noise and tribo-electric noise.

The lower limiting frequency of the amplifier is 1 Hz while the fall-off slope between 1 Hz and 0,1 Hz is 12 dB/octave to eliminate the influence of pyroelectric effects of some transducers. The amplification of the amplifier can be adjusted between 0 — 20 dB by means of a 10 turn potentiometer. The back plate of the amplifier, which is removable for access to this potentiometer, is fitted with a rubber seal to prevent ingress of dirt, oil etc.

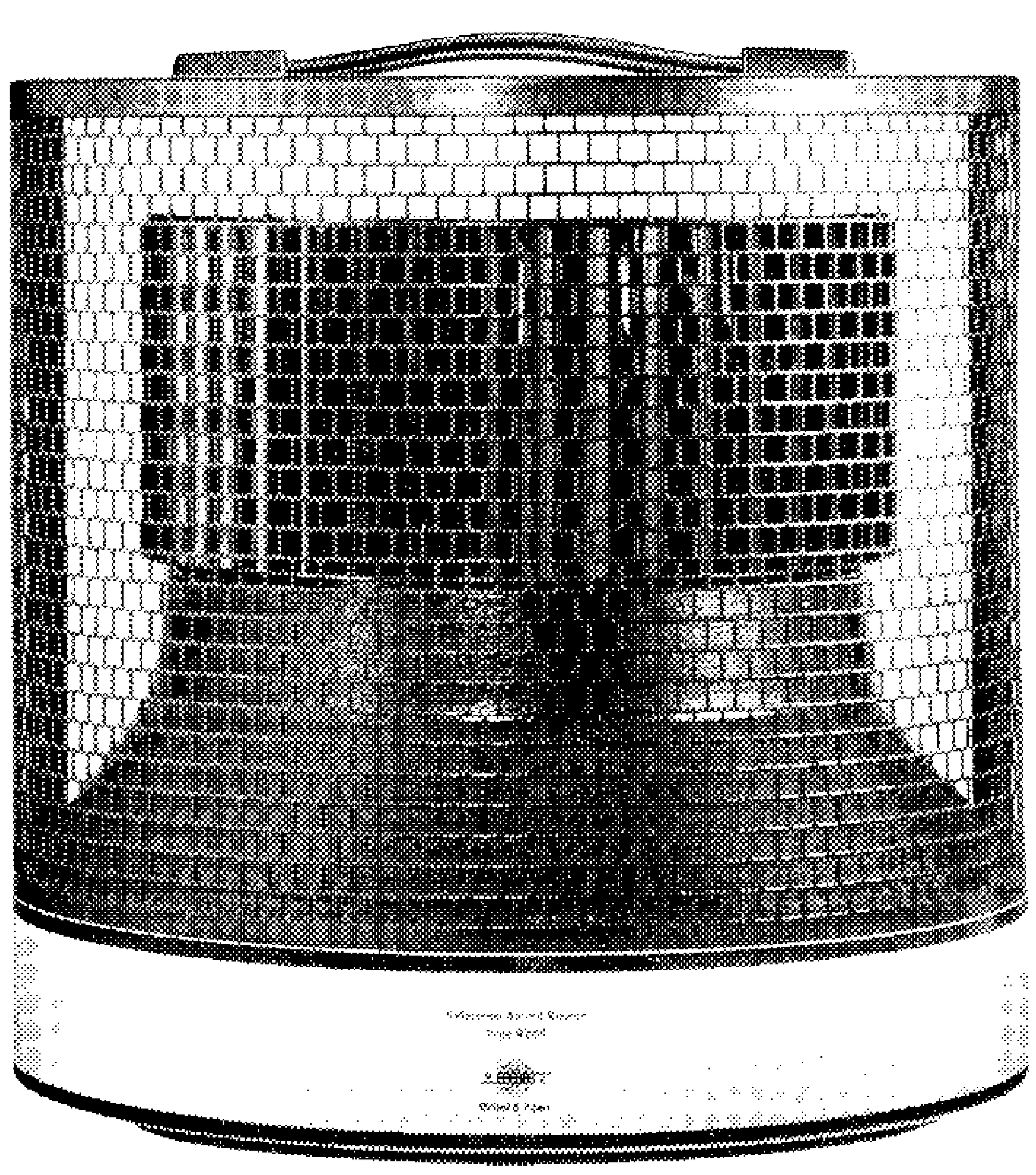
The amplifier can be powered by single polarity supply between + 12 V and + 28 V or dual polarity supply between ± 6 V and ± 24 V.

Reference Sound Source Type 4204

For determination of sound power output of equipment by the substitution method a calibrated reference sound source is required. Such a sound source has been developed by Brüel & Kjær that fulfils the requirements stated in ISO Draft 2880 Annex B and ASHRAE Standard 36-62 section 3 except for the directivity index values in the frequency range 3 kHz — 10 kHz.

The Sound Source consists essentially of a centrifugal fan driven by a powerful synchronous motor. On account of the high moment of inertia of the rotor, a very stable speed of rotation is achieved. The motor is mounted on a cast aluminium base, shaped to minimize reflections, and the whole assembly (motor and fan) are covered with a cylindrical safety grid fitted with carrying handles.

The frequency range of the Reference Source is from 100 Hz to 10 kHz and the acoustic power output is greater than 70 dB (re. 10^{-12} W) in any 1/3 octave band. The A weighted power output is typically 92 dB and 96 dB for 50 Hz and 60 Hz line frequencies respectively.



In 1/3 octave bands, the directional characteristics of the sound source varies less than 6 dB and ± 0,2 dB in the vertical and horizontal planes respectively.

Each sound source is individually calibrated and a calibration chart is supplied.

PREVIOUSLY ISSUED NUMBERS OF BRÜEL & KJÆR TECHNICAL REVIEW

(Continued from cover page 2)

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- Mechanical Vibration and Shock Measurements (English, German)
- Acoustic Noise Measurements (English), 2. edition
- Architectural Acoustics (English)
- Power Spectral Density Measurements and Frequency Analysis (English)
- Standards, formulae and charts (English)
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