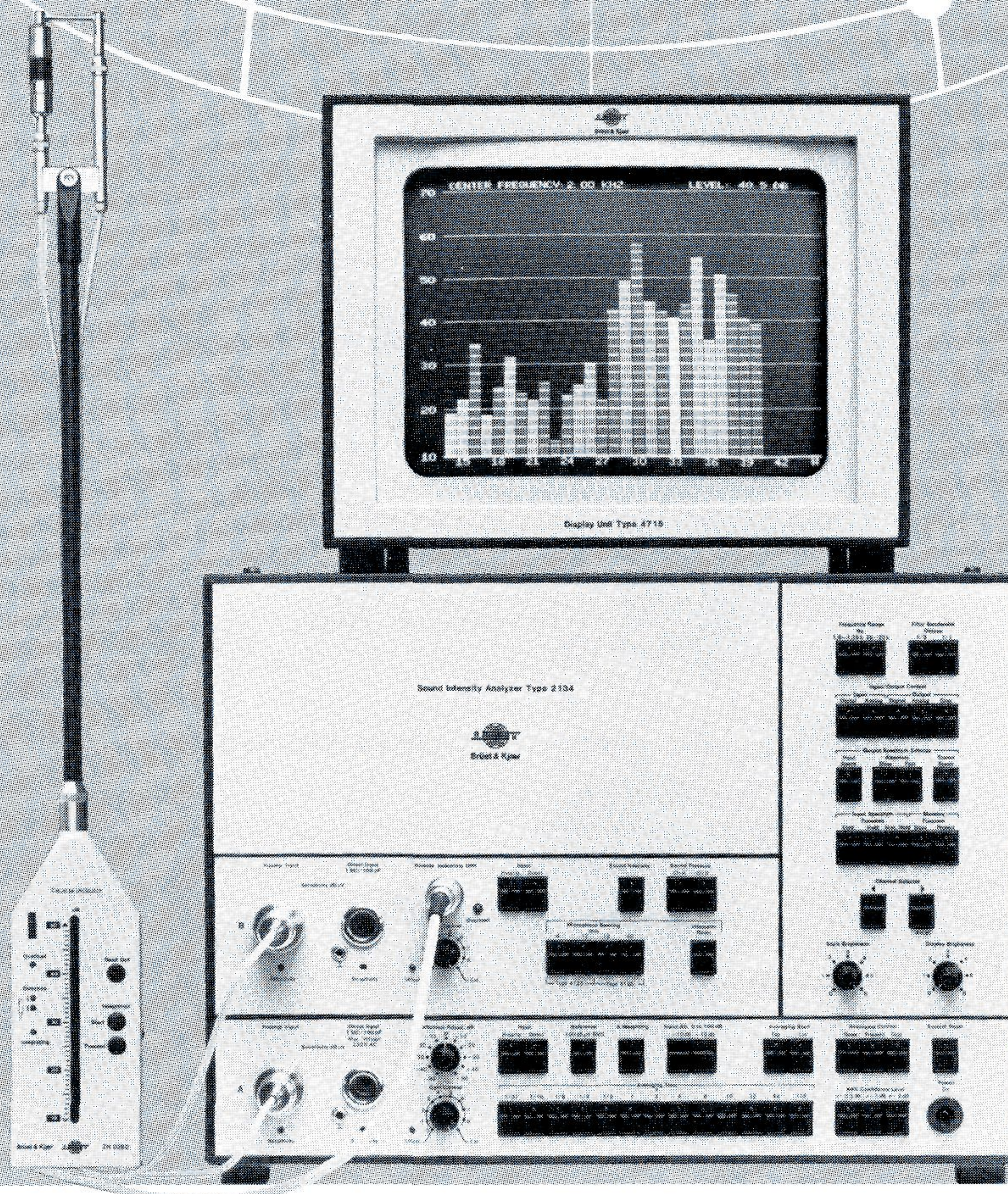




Sound power determinations from sound pressure and from sound intensity measurements in a semi-anechoic room



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Introduction

The aim of these measurements was to compare the sound power of an acoustic source as determined by:

- 1) sound pressure measurements
- 2) sound intensity measurements

In contrast to the multitude of standards describing sound power determinations based on sound pressure measurements, no such standards yet exist for determinations based on sound intensity measurements. However, the advantage of the sound intensity method, and the recent arrival on the market of sound intensity systems means that such standards will not be long in forthcoming.

The determination of sound power is the subject of ISO Standards 3740 to 3746 inclusive. These standards specify how the sound pressure produced by a source should be measured under various conditions to determine the sound power of the source to various degrees of accuracy i.e. survey, engineering and precision determinations. The measurements reported here were performed in accordance with the precision method described in ISO 3745.

Instrumentation

Both the pressure and the intensity measurements were performed with the Sound Intensity Analysing System Type 3360. This system is based on a two microphone technique (Fig.1) which imposes limitations on the useful frequency range for intensity measurement. However with careful phase matching of the two channels and suitably chosen spacers, sound intensity measurements can be performed over a wide frequency range (Fig.2). The test sound source used for these measurements was, for convenience, a B & K Reference Sound Source Type 4204. This source is known to be extremely stable with time.

Sound power from sound pressure measurements

The sound source under test was placed on a reflecting plane in an anechoic chamber as specified in ISO 3745 (i.e. a semi-anechoic room. Fig.3). Then the sound pressure levels produced by the source were measured by a microphone using linear averaging at ten standardised positions on a hypothetical hemisphere described about the source. The microphone positions as specified by ISO were distributed such that each microphone position was associated with the same proportion of the total surface area of the hemisphere and the measured sound pressure level was taken as the average of the sound pressure levels in each microphone position (Fig.4). The microphone signals were fed to the 3360 which was operating in the sound pressure mode, and were linearly averaged. All the ISO standards recommend the use of linear averaging rather than exponential or RC type averaging when measuring sound pressure levels.

The sound power of the source, L_W , was then calculated for each 1/3 octave band from the relationship:

$$L_W(p) = \sum L_p + 10 \log_{10} (S/S_0) - 10 \log_{10} N + C \text{ dB}$$

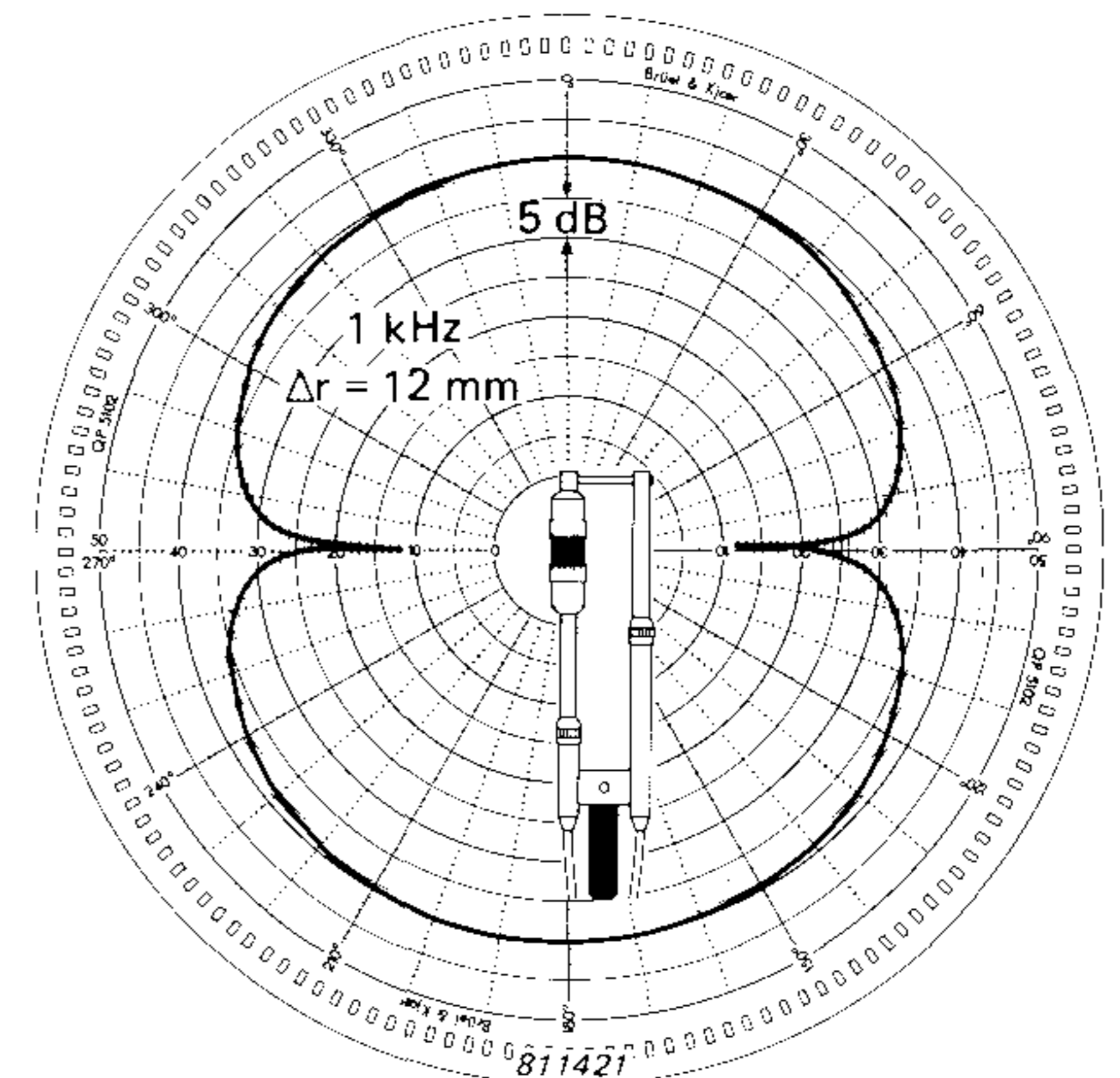


Fig. 1. Directivity characteristics of a sound intensity probe consisting of two 1/2" microphones separated by a spacer of 12 mm

where

$L_W(p)$ = sound power level of the source referenced to 1 pW determined from sound pressure measurements

$\sum L_p$ = sum of measured sound pressure levels referenced to 20 μ Pa

$S = 2\pi r^2$ the area of the test hemisphere

$S_0 = 1\text{m}^2$

N = number of linear averages i.e. number of measuring positions

C = correction term in dB for the influence of temperature and ambient pressure

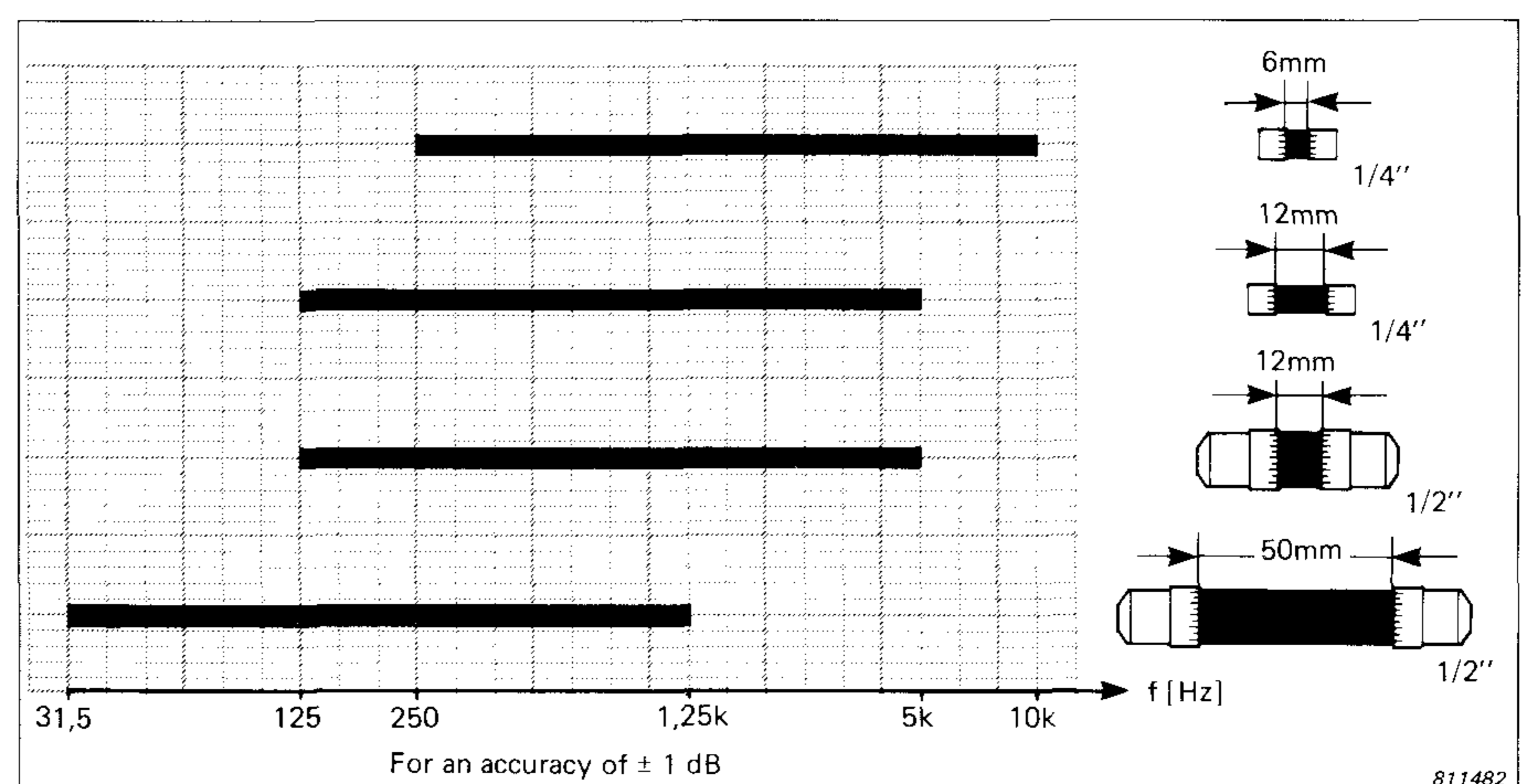


Fig. 2. Frequency ranges for various microphone and spacer combinations for an accuracy of ± 1 dB

The power spectrum of the Reference Sound Source Type 4204 as measured by this sound pressure method is shown in Fig.5.

Sound power from sound intensity measurements

The sound power of the 4204 was then determined from sound intensity measurements under the same conditions as those described in the previous section.

The 3360 was set in the sound intensity mode and the microphone was replaced by the Sound Intensity Probe Type 3519. The sound intensity was measured normally to each of the small areas of the hypothetical hemisphere using the same linear averaging time as with the sound pressure measurements. In practice, fine orientation of the probe is not necessary as the probe is rather insensitive to the angle of incidence of the sound intensity in the region of maximum sensitivity to sound intensity (see Fig.1). The expression above therefore becomes:

$$L_W(l) = \sum L_i + 10 \log_{10}(S/S_0) - 10 \log_{10}(N) + C \text{ dB}$$

where

$L_W(l)$ = sound power level of the source referenced to 1 pW determined from sound intensity measurements

$\sum L_i$ = sum of measured sound intensity levels referenced to 1 pW/m²

$S = 2\pi r^2$ the area of the test hemisphere

$S_0 = 1\text{m}^2$

N = number of linear averages i.e. number of measuring positions

C = correction term in dB for the influence of temperature and ambient pressure

The result from this method i.e. $L_W(l)$, is also shown in Fig.5. Fig.6 shows the difference, $L_W(p) - L_W(l)$, for each third octave band. When allowance is made for the roll-off at high frequency due to the bias error, the agreement is very good.

Advantage of sound intensity method

Where then is the advantage of the sound intensity method? The sound intensity method allows sound power determinations to be performed even in the presence of stationary

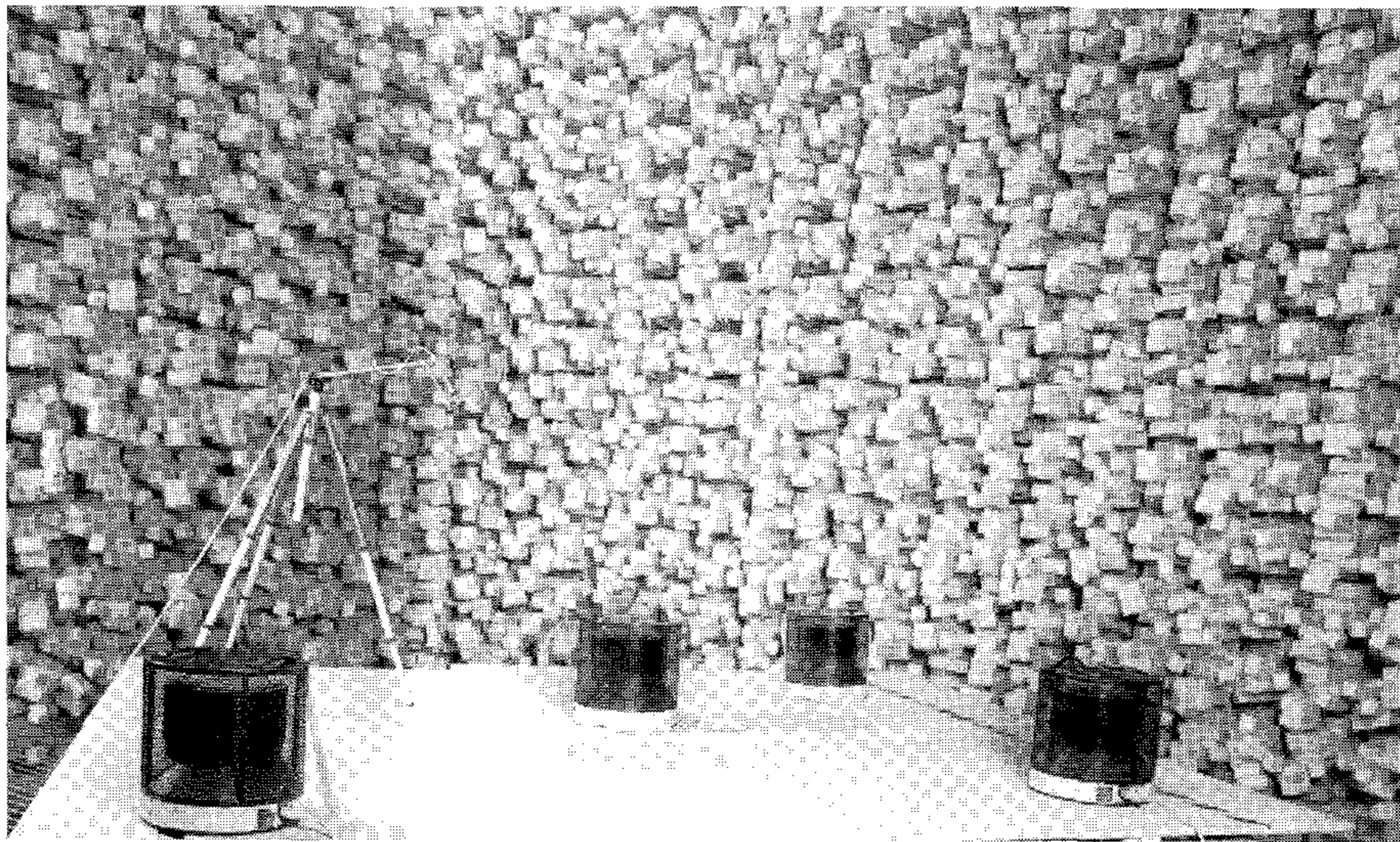


Fig. 3. Arrangement in a semi-anechoic room used to compare the sound power of a source (the source in the centre of the photograph) as determined by sound pressure and by sound intensity measurements. The probe can be seen directed towards the test source. Three other sources were used to provide noise when the sound intensity measurements were repeated in the presence of background noise

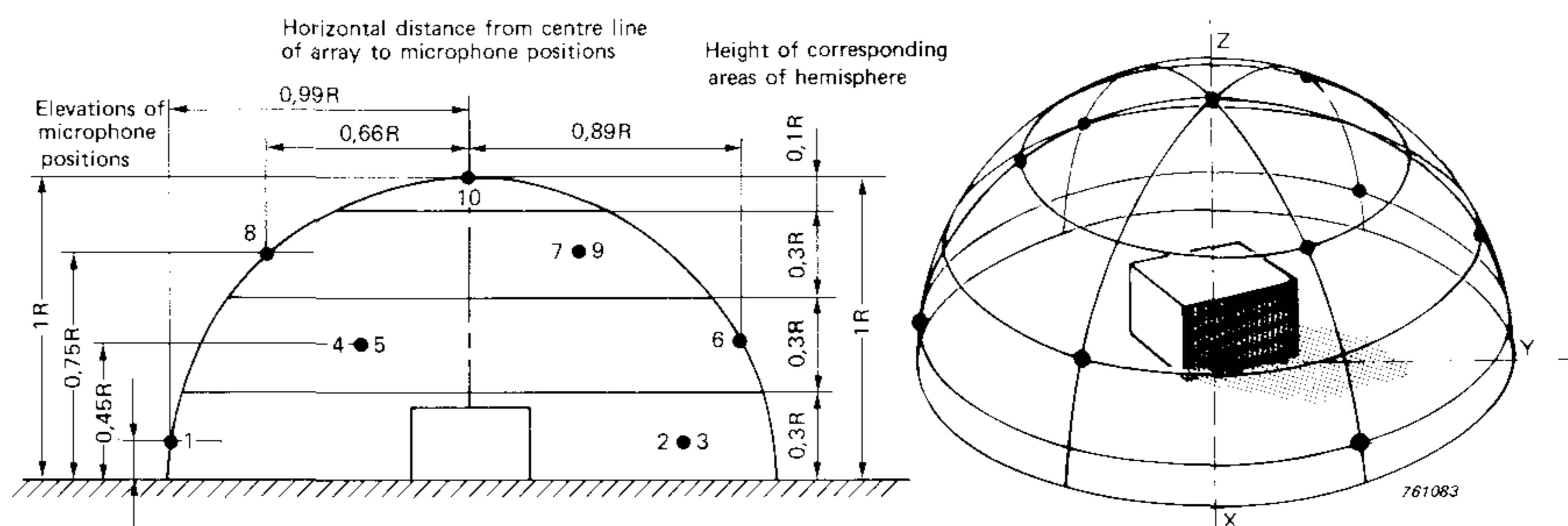


Fig. 4. Hemisphere enclosing the sound source showing the microphone positions recommended by ISO 3745

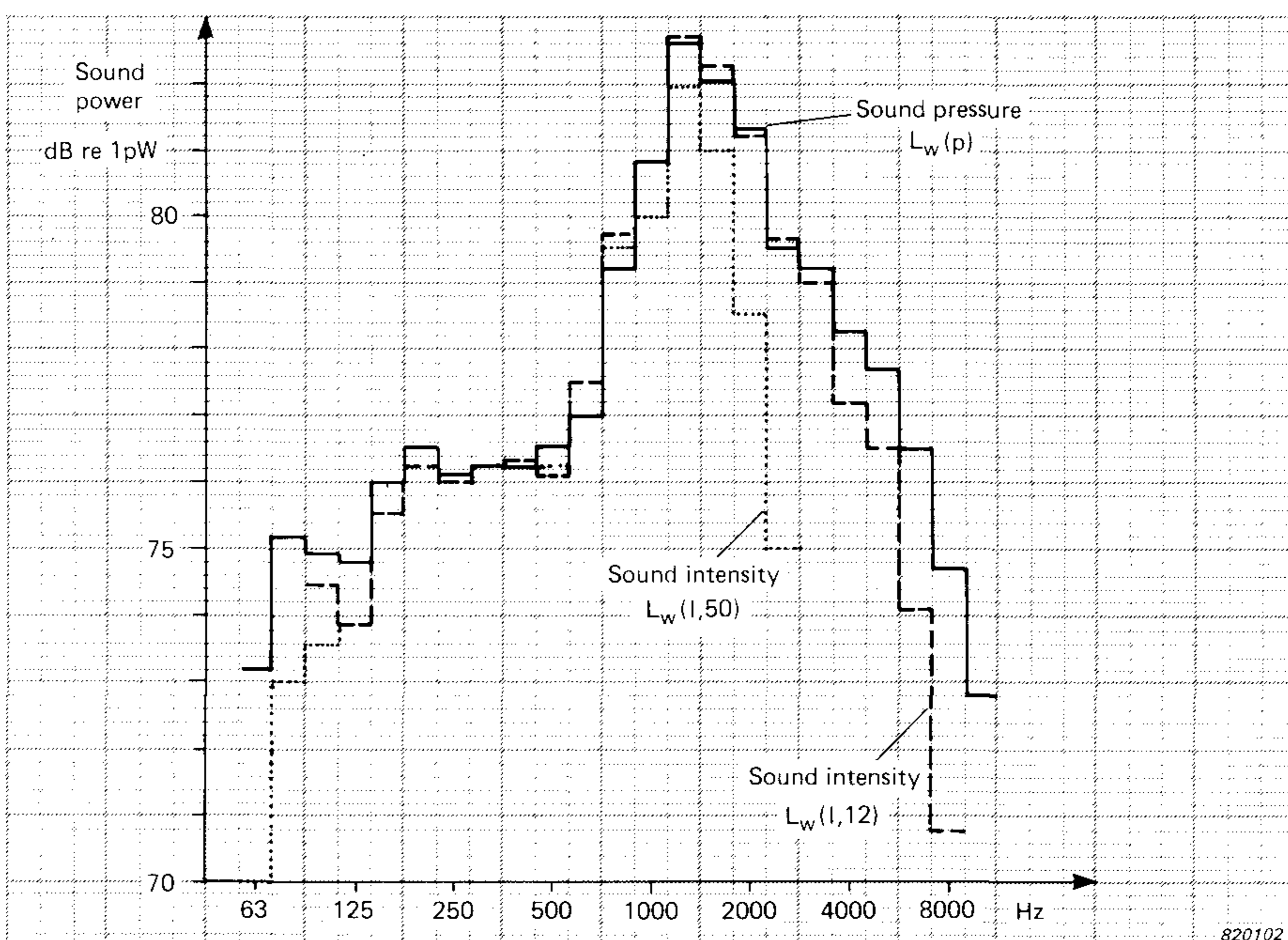


Fig. 5. Sound power spectrum of the test source as determined by:
 1) sound pressure measurements according to ISO 3745 (full line)
 2) sound intensity measurements using 12 mm spacer (dashed line)
 3) sound intensity measurements using 50 mm spacer (dotted line)

background noise! This is explained in Fig.7 & 8. In Fig.7, the total acoustic intensity, \bar{I} , leaving the surface which encloses the source multiplied by the area of the surface yields the sound power of the source, W . In Fig.8, where the source is placed outside the closed surface, the total intensity leaving the closed surface is zero. This is known as Gauss' Theorem. Mathematically:

$$W = \int_S \bar{I} \cdot d\bar{S}$$

When applying Gauss' Theorem in practice, one must ensure that there is no mean flow of the air, that there is no absorption within the closed surface and that noise from external sources is stationary during the measurements. To illustrate the utility of this theorem, three more 4204s were introduced into the anechoic chamber and placed about the test 4204. All sources were then set in operation and the sound pressure level of the background noise was approximately 5 dB above the sound pressure level produced by the test source. The sound intensity over the hypothetical hemisphere was again measured and the sound power of the test source calculated. The resulting sound power was denoted by $L_W(l,b)$ and the difference, $L_W(l) - L_W(l,b)$ is shown in Fig.9. The agreement is again very good.

Conclusions

The measurements show that precision sound power determinations by sound pressure and by sound intensity measurements yield the same results. However the advantages the sound intensity method are that:

- 1) No restrictions are imposed on the room where the sound intensity measurements are performed provided that the sound field is stationary.
- 2) Measurements may be performed in the near-field. Near-field measurements improve the signal to noise ratio and require less "free space" about the source under test.

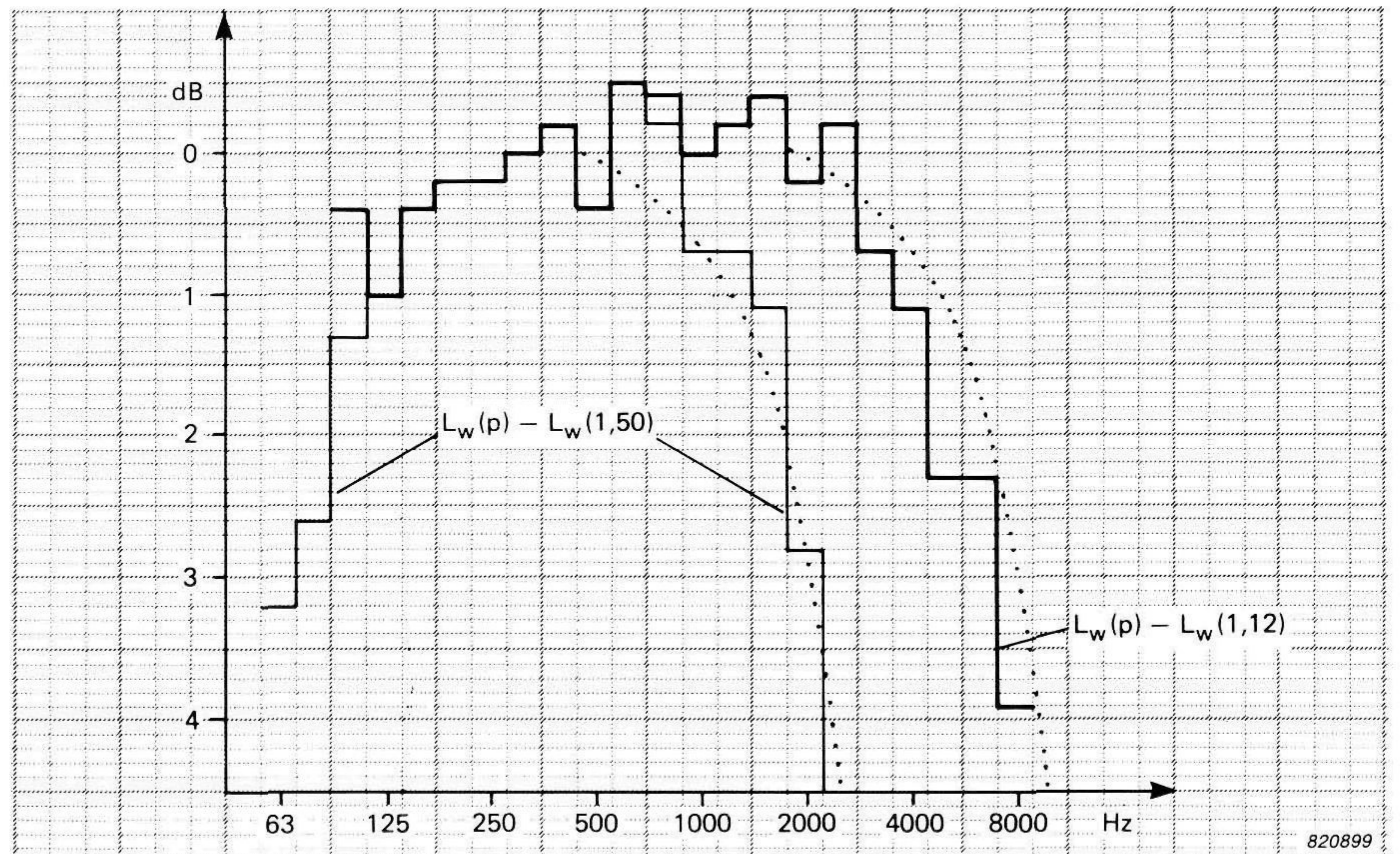


Fig. 6. Differences in sound power determinations from Fig.5.:
 1) $L_W(p) - L_W(l,12)$. Measured with 12mm spacer
 2) $L_W(p) - L_W(l,50)$. Measured with 50mm spacer
 The theoretical bias errors are indicated by the dotted curves.

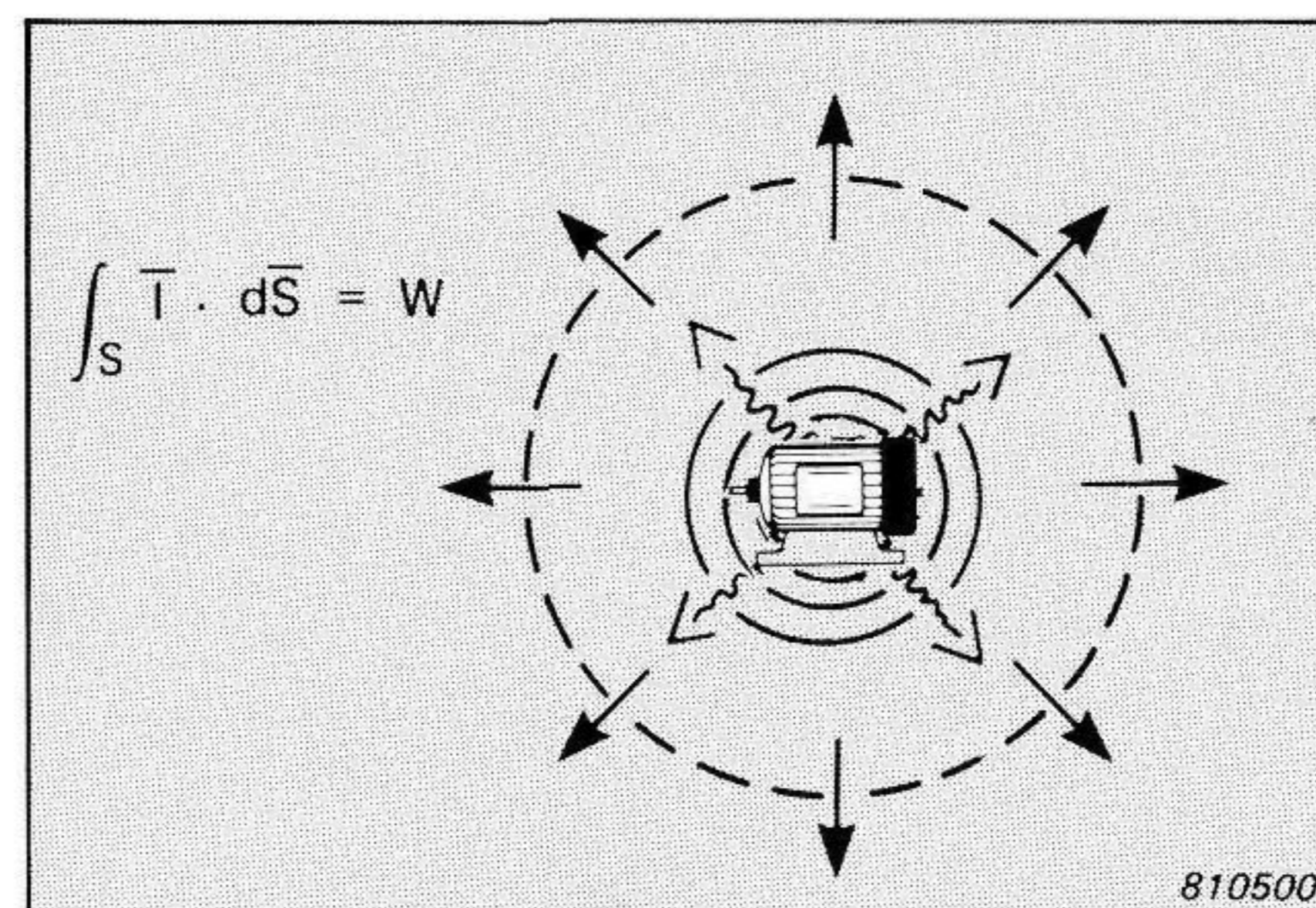


Fig. 7. Acoustic source situated within the enclosing surface. The black arrows indicate the direction of the intensity vectors which have to be taken into account. In practice this means that the probe must always be orientated normal to the measurement surface

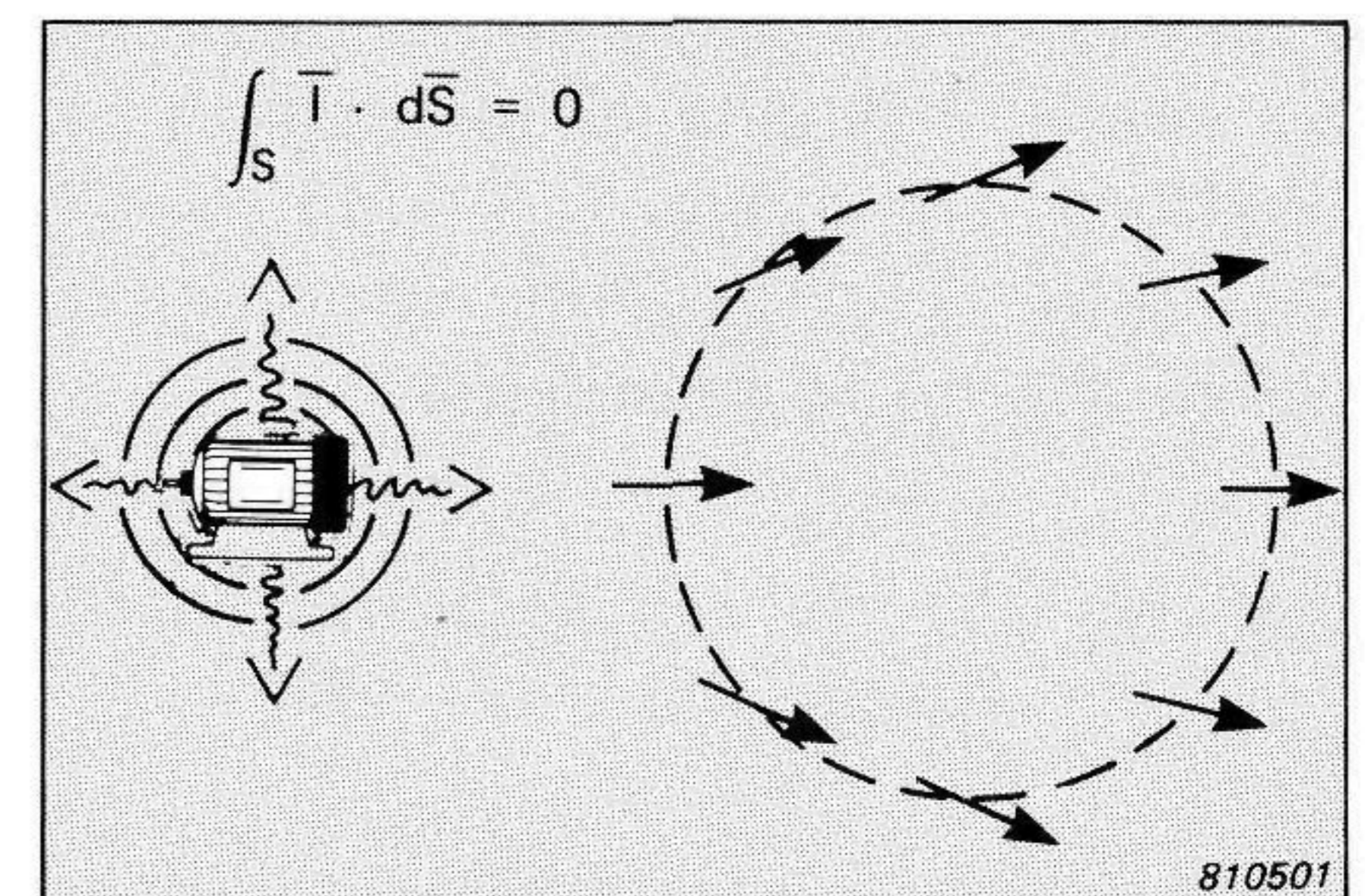


Fig. 8. Acoustic source not situated within the enclosing surface. This is Gauss' Theorem and is valid providing there is no flow and that there is no absorption within the enclosing surface

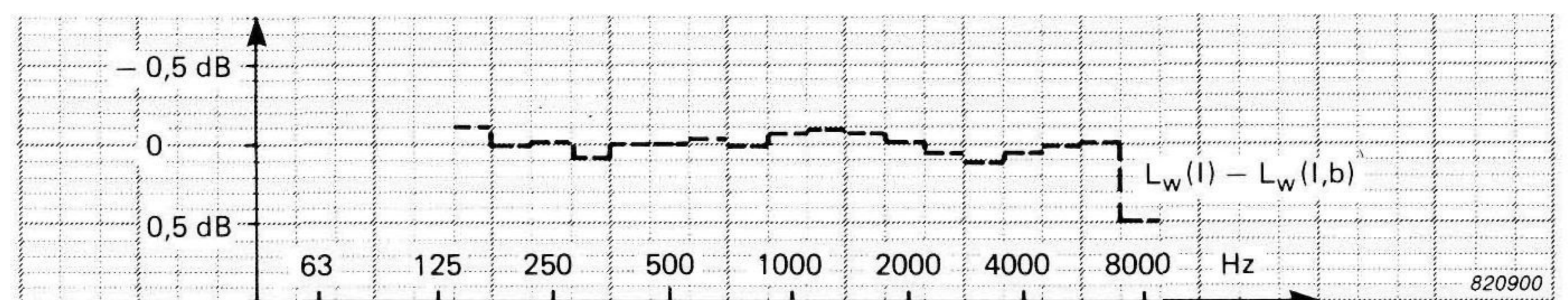


Fig. 9. $L_W(l) - L_W(l,b)$. Measured with and without background noise

- 3) No restrictions are imposed on the shape and size of the hypothetical measurement surface.
- 4) Measurements are not influenced by continuous background noise.
- 5) Sound intensity can be used to determine the sound power from various parts of machines.