RSA(EXT) 0045

Measurement of sound calibrator characteristics: NPL contribution to an EEC intercomparison

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January 1994

The National Physical Laboratory is an Executive Agency of the Department of Trade and Industry

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EEC CONTRACT NO. 3256/1/0/122/88/11-BCR-UK(30)

ABSTRACT

This report contains the results obtained by the National Physical Laboratory under contract to the Community Bureau of Reference (BCR) of the EEC, as part of an intercomparison of measurements of the characteristics of three different types of sound calibrator: a Brüel & Kjær pistonphone type 4220, a Brüel & Kjær calibrator type 4230, and a CEL calibrator type 177.

Each sound calibrator was coupled to seven different types/configurations of microphone and the sound pressure level, frequency and total harmonic distortion of the acoustical output were measured on five different days.

The effects of variation of atmospheric pressure, temperature and relative humidity on the characteristics of the sound calibrators were also investigated.

RSA(EXT) 0045

ISSN 0955-9655

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Approved on behalf of Chief Executive, NPL,
by Dr P Christmas, Acting Head, Division of Radiation Science and Acoustics.

CONTENTS

1 INTRODUCTION

Sound calibrators are portable devices which generate a known sound pressure level at a known frequency. These investigations covered three such devices which operate on different principles. The devices tested were:

1) a Brüel & Kjær pistonphone type 4220 - an electromechanical instrument producing a nominal sound pressure level of 124.0 dB (re 20 µPa) at a nominal frequency of 250 Hz, when operating into an effective load volume of 1.333 cm^3;

2) a Brüel & Kjær calibrator type 4230 - a piezoelectric instrument producing a nominal sound pressure level of 94.0 dB (re 20 µPa) at a nominal frequency of 1000 Hz;

3) a CEL calibrator type 177 - an electrodynamic instrument producing a nominal sound pressure level of 114.0 dB (re 20 µPa) at a nominal frequency of 1000 Hz, when coupled to specified types of microphone.

This investigation was to determine the characteristics of the three types of calibrator when coupled to seven different types/configurations of microphone and to investigate the effects of atmospheric pressure, temperature and relative humidity on the characteristics. It forms part of an international intercomparison under the auspices of EEC/BCR, the central laboratory for which is the Physikalisch-Technische Bundesanstalt (PTB) of FR Germany.

2 EQUIPMENT

One calibrator of each type was supplied by BCR and received from PTB, which, as the central laboratory, had already made initial measurements on them. PTB was also due to make further measurements on return of the equipment from NPL. The devices supplied were Brüel & Kjær pistonphone type 4220 serial no. 1297300, Brüel & Kjær calibrator type 4230 serial no. 1351806, and CEL calibrator type 177 serial no. 445097. All calibrators were supplied with adaptors to fit half-inch microphones. Half-inch microphones Brüel & Kjær type 4176 serial no. 1331576 and RFT type MK 221 serial no. 5957 were supplied, and from the recent BCR half-inch microphone intercomparison (Torr and Jarvis, 1988) Brüel & Kjær type 4134 M serial no. 982515 and Brüel & Kjær type 4134 serial no. 982394 were also used.

The intercomparison required seven different microphone types/configurations to be used for the measurements. Some were standard laboratory microphones and some non-standard microphones. In addition to those supplied by BCR, each participating laboratory had to supply its own Brüel & Kjær type 4160, and either a type 4144 or a type 4145 with protection grid and adaptor ring type DB 0111. NPL used a type 4144, both this and the type 4160 being one-inch microphones.

3 MEASUREMENTS AND CALCULATIONS

3.1 Microphone calibrations

Before making any measurements on the sound calibrators themselves it was necessary to measure the sensitivities of all the microphones at 250 Hz and 1000 Hz. The methods of calibration and associated uncertainties at an estimated confidence level of 95% for each type of microphone are shown in Table 1. All microphones were calibrated by the reciprocity method (IEC 327:1971), with the exception of the type 4176. The protective grid is not removable on this microphone so another method was devised for its calibration. A Brüel & Kjær type 4226 multi-function acoustic calibrator was calibrated using a type 4134 microphone which had itself been calibrated using the reciprocity technique. The calibrator was then immediately applied to the type 4176 microphone and, knowing the sound pressure level generated by the calibrator, the sensitivity of the type 4176 was calculated. The values calculated were -26.39 dB re 1V/Pa at 250 Hz and -26.56 dB re 1V/Pa at 1000 Hz for the microphone supplied. As an independent check, the sensitivity of the type 4176 was also measured at 250 Hz using the NPL laser pistonphone (Barham, 1990). For the other microphone supplied by BCR, the type MK 221, the sensitivities measured using reciprocity were -24.91 dB re 1V/Pa at 250 Hz and -25.00 dB re 1V/Pa at 1000 Hz.

In addition, whilst fitted with the adaptor rings necessary for reciprocity, the volume of the front cavity including the equivalent volume of the diaphragm was measured for each microphone (Delany and Bazley 1982), again with the exception of the type 4176. The total volumes measured are shown in Table 2.

Table 1   Methods of microphone calibration and uncertainties

Microphone type	Serial no.	Method of calibration	Uncertainty (dB) 250 Hz	1 kHz
4160	1292314	Reciprocity	± 0.03	± 0.03
4144	1233118	Reciprocity	± 0.05	± 0.05
4134 M	982515	Reciprocity	± 0.05	± 0.05
4134	982394	Reciprocity	± 0.05	± 0.05
4176	1331576	Calibrator type 4226	± 0.09	± 0.09
MK 221	5957	Reciprocity	± 0.05	± 0.05

Table 2   Total of front and equivalent volumes of microphones used

Microphone type	Total volume (mm^3)
4160	657.3
4144 with adaptor ring DB 0111	708.7
4134 M	41.2
4134 with adaptor ring UA 0825	41.0
MK 221 with adaptor type WA 0220/WA 0221	639.3

3.2 Calibrator calibrations

The sound pressure level, frequency and total harmonic distortion generated by each of the three sound calibrators when coupled to the seven different types/configurations of microphone were measured on five separate days. For these measurements the devices were stored and measured at a room temperature of 23 ± 1 °C, the relative humidity was adjusted to 50 ± 10%, and measurements were only made when the ambient pressure was 1013 ± 6 mbar. The temperature was measured using a calibrated mercury-in-glass thermometer, the pressure using a calibrated aneroid barometer and the humidity using a polymer thin film capacitor probe. A schematic diagram of the apparatus used is shown in Figure 1.

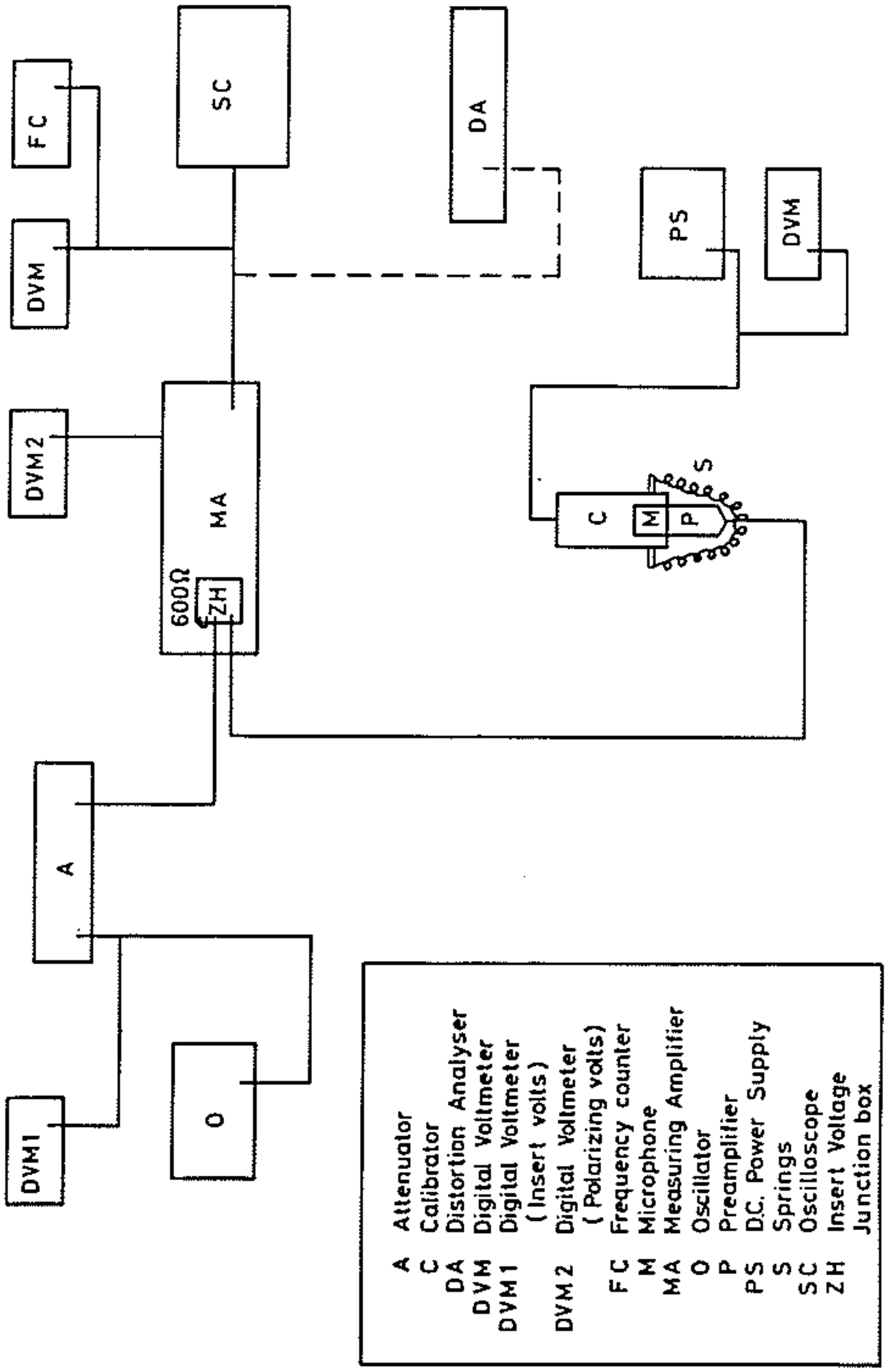

Figure 1 . Schematic diagram of apparatus

The three sound calibrators were all driven by a DC power supply, the devices having previously been modified by PTB to allow this. A voltage of 9.0 ± 0.1 V was used, the polarity depending on the device. All microphones were connected to their preamplifiers, under power, for at least twenty minutes prior to any measurements.

As required by the BCR contract, measurements were repeated on each sound calibrator, using each microphone type/configuration, on five different days. On a particular day, each set of measurements using a particular microphone type/configuration consisted of five measurements on a BCR sound calibrator interleaved with five measurements on a similar NPL device of known output, the latter acting as a check on the correct functioning of the measurement system; both sound pressure level and frequency were recorded. The first measurement of each set was made after the device had been coupled to the microphone for five minutes. For the other four measurements in the set the coupling time was much less. For all the measurements in a set values were recorded 60 s after switch-on in the case of the pistonphone, and 30 s after switch-on for the other two calibrators. As the measurements on the BCR device were interleaved with those on the NPL device it was obviously necessary to decouple the sound calibrator from the microphone between measurements. The total harmonic distortion (THD) was recorded three times in each set of measurements. All calibrators were coupled to the microphones by a spring arrangement.

3.3 Environmental effects

3.3.1 Atmospheric pressure

Measurements were made using the type 4160 microphone coupled to each of the sound calibrators over the pressure range 900 mbar to 1050 mbar, by using a pressure vessel. Measurements of sound pressure level, frequency and total harmonic distortion were made at 25 mbar intervals from 900 mbar up to 1050 mbar and down again, the measurements of sound pressure level and frequency being repeated on three separate days. The room temperature for these measurements was 23 ± 1 °C, and the room relative humidity was 50 ± 10%. Again values were recorded 60 s after switch-on for the pistonphone and 30 s after switch-on for the other two calibrators.

3.3.2 Temperature

Measurements were made using the type 4160 microphone coupled to each of the sound calibrators over the temperature range 5 °C to 35 °C. Measurements of sound pressure level, frequency and total harmonic distortion were made as nearly as possible at 5 °C intervals. For measurements in the range 15 °C to 30 °C the same room was used as for Section 3.2, where the temperature could easily be controlled to better than 1 °C, and the calibrators and microphone were left overnight to stabilize at each temperature. The relative humidity was adjusted to 50 ± 10%, but unfortunately due to ambient conditions it was necessary to apply a correction for deviations of atmospheric pressure from 1013 mbar, in the range 987 mbar to 1035 mbar. Above 30 °C and below 15 °C measurements were made in a small temperature chamber. The relative humidity could not be controlled, but the devices and microphone were again left overnight to stabilize. Temperatures in this small chamber were measured using a thermocouple attached to the calibrator.

Five measurements were obtained for each set of results - each time the first measurement was made after the microphone and calibrator had been coupled together for five minutes. Pistonphone values were recorded 60 s after switch-on and values for the other two calibrators 30 s after switch-on. Several measurements were repeated at the lower temperatures - it was particularly difficult to maintain the device temperature here, especially for the type 4230 calibrator, so a mean temperature had to be used. This was partly because the ambient noise within the small chamber was sufficiently high that the chamber had to be switched off during measurements and the temperature of the device then tended to rise, and partly due to the calibrator being decoupled from the microphone between each of the five measurements, necessitating handling. Further measurements were also made with the type 4230, leaving the microphone coupled to the calibrator and varying the temperature over a period of a few hours.

3.3.3 Relative humidity

Measurements were made using the type 4160 microphone coupled to each of the sound calibrators in the relative humidity range 30% to 80%. Measurements of sound pressure level, frequency and total harmonic distortion were made at nominal 10% intervals. For these measurements the temperature was controlled at 23 ± 1 °C and the devices were left to stabilize at each humidity for about seven hours. Due to ambient conditions a correction had to be applied for deviations of atmospheric pressure from 1013 mbar, in the range 984 mbar to 1031 mbar.

Five measurements were again obtained for each set of results - each time the first measurement was made after the microphone and calibrator had been coupled together for five minutes. Pistonphone values were recorded 60 s after switch-on and values for the other two calibrators 30 s after switch-on.

3.4 Final calibrator measurements

After the environmental tests were completed each calibrator was re-measured on five separate days using the type 4160 microphone, as described in Section 3.2. In this case, ambient conditions necessitated a correction for deviations of atmospheric pressure from 1013 mbar, in the range 1017 mbar to 1032 mbar.

3.5 Calculations

All values of sound pressure level (SPL) were calculated as follows:

$$SPL = 20 \log V_{insert} + 93.98 - A - M$$

where V_{insert} is the insert voltage,
A is the attenuator setting, and
M is the microphone sensitivity

It was not necessary to apply a correction for polarization voltage, which was controlled within 200.0 ± 0.1 V, and other corrections applied are described in the relevant parts of Section 4.

4 RESULTS AND DISCUSSION

4.1 Calibrator calibrations

Of the five measurements obtained for each set of results, only the first was made when the microphone and calibrator had been coupled together for five minutes - in the other four cases the coupling time was much less. However it was clear from the results that the coupling time had virtually no effect, the largest difference in sound pressure level observed between the first measurement and the mean of five being 0.02 dB, and this occurred on only three occasions.

Table 3 shows typical examples of measurements for each of the sound calibrators. It can be seen that within a given set there is a slightly higher standard deviation for the type 177 than the types 4220 and 4230. The measurements were repeated on five separate days. Tables 4, 5 and 6 show the mean values and standard deviations of the sound pressure levels, frequencies and total harmonic distortions, from each set of results for the sound calibrators when coupled to the seven different types/configurations of microphones, together with the final calibrator measurements following the environmental tests. Also shown are the ranges of ambient conditions at the time of the measurements; while the total ranges are shown, in all but one case the ambient temperatures were within 0.5° of 23 °C.

In the case of all three calibrators, there is a difference between the values obtained from the initial five sets of measurements and the final five sets of measurements with the type 4160 microphone. It amounts to 0.02 dB for the type 4220, 0.10 dB for the type 4230, and 0.10 dB for the type 177 and can largely be explained by the fact that the sensitivity of the microphone itself changed at some point during the initial measurements, by 0.06 dB at both 250 Hz and 1 kHz. In fact close inspection of the results shows that it probably changed after two of the five sets of initial measurements. However, the values have not been adjusted as it is impossible to be certain exactly when the change did occur, and the mean of the initial five sets is quoted in the Tables.

All the results are corrected to 101.3 kPa (1013 mbar), in the case of the pistonphone using the usual relationship of 20 log (p/p_o) where p is the ambient pressure and p_o is the reference pressure of 101.3 kPa, and

Table 3 Typical measurements for each sound calibrator, using a microphone type 4134

	Frequency Hz	SPL dB re 20µPa	THD %
Type 4220 Serial no. 1297300			
	247.9	124.02	0.52
	248.0	124.02	0.50
	248.0	124.02	0.49
	248.0	124.02	
	248.0	124.03	
Mean	248.0	124.02	0.50
S.D.	0.045	0.004	0.02
Type 4230 Serial no. 1351806			
	992.9	93.81	0.52
	992.9	93.81	0.51
	992.9	93.81	0.50
	992.9	93.82	
	992.9	93.82	
Mean	992.9	93.81	0.51
S.D.	0	0.005	0.01
Type 177 Serial no. 445097			
	1003.1	113.06	2.7
	1003.0	113.06	2.8
	1003.0	113.06	2.7
	1003.0	113.08	
	1003.0	113.07	
Mean	1003.0	113.07	2.7
S.D.	0.045	0.009	0.1

Table 4 Results for pistonphone type 4220 serial no. 1297300, corrected to 101.3 kPa

Microphone type	SPL dB re 20 µPa	S.D.	Freq. Hz	THD %	Pressure range kPa	Temp. range °C	RH range %
4160	124.35	0.026	248.1	0.40	100.7-101.7	22-24	44-62
4144 with adaptor type DB 0111	124.29	0.007	248.1	0.45	101.3-101.7	23-24	51-62
4144 with grid	124.07	0.009	248.1	0.42	101.3-101.8	22-24	48-53
4134 M	124.06	0.009	248.0	0.47	100.7-101.7	22-23	47-58
4134	124.01	0.005	248.2	0.51	100.5-101.9	22-24	44-55
4176	123.95	0.011	248.4	0.50	100.8-101.9	22-24	45-56
MK 221	123.95	0.008	248.4	0.48	100.8-101.9	22-24	48-56
4160	124.33	0.005	248.8	0.56	101.7-103.2	22-24	50-53

Table 5 Results for calibrator type 4230 serial no. 1351806, corrected to 101.3 kPa

Microphone type	SPL dB re 20 µPa	S.D.	Freq. Hz	THD %	Pressure range kPa	Temp. range °C	RH range %
4160	93.92	0.023	993.0	0.56	100.7-101.8	23-24	49-56
4144 with adaptor type DB 0111	93.87	0.029	993.0	0.57	101.1-101.8	23-24	45-64
4144 with grid	93.85	0.034	993.0	0.54	101.1-101.8	22-24	46-59
4134 M	93.81	0.013	992.9	0.54	100.7-101.6	22-24	44-55
4134	93.78	0.047	993.2	0.54	100.6-101.9	23-24	47-57
4176	93.76	0.024	993.6	0.54	100.7-101.9	23-24	44-50
MK 221	93.76	0.024	993.6	0.55	100.8-101.9	22-24	48-54
4160	93.82	0.035	994.5	0.57	101.8-103.2	23-24	48-52

Table 6 Results for calibrator type 177 serial no. 445097, corrected to 101.3 kPa

Microphone type	SPL dB re 20 μPa	S.D.	Freq. Hz	THD %	Pressure range kPa	Temp. range °C	RH range %
4160	113.72	0.023	1001.7	2.7	100.7-101.8	23-24	46-55
4144 with adaptor type DB 0111	113.55	0.013	1001.5	2.6	101.2-101.7	23-24	48-57
4144 with grid	112.69	0.024	1001.6	2.7	101.2-101.8	23-24	44-59
4134 M	113.30	0.032	1002.2	2.7	101.3-101.8	23-24	46-57
4134	113.08	0.016	1002.9	2.7	100.6-101.9	22-24	49-58
4176	112.92	0.016	1003.1	2.6	100.8-101.9	23-24	45-53
MK 221	112.95	0.022	1003.4	2.8	100.8-101.9	22-24	46-52
4160	113.62	0.011	1003.3	2.7	101.7-103.2	23-24	48-53

in the case of the types 4230 and 177 calibrators using the pressure coefficients measured in Section 3.3.1. In the case of the type 4230 these corrections were generally less than 0.01 dB. Corrections for pressure were also made to the standard microphones using a coefficient of -0.0016 dB/mbar for one-inch and -0.0007 dB/mbar for half-inch ie. excluding the type 4176 and the type MK 221. No corrections were made for temperature or relative humidity as all measurements apart from three were made within the specified limits.

For the type 4220, the cavity volume dependence and hence variation of sound pressure level with microphone type is clearly shown. The values are in good agreement with the manufacturer's data given for the Brüel & Kjær microphones, and from the results it appears that the sound pressure level for the microphone type MK 221 is very similar to that for the type 4176. Little variation in the frequency or total harmonic distortion generated is apparent for different microphones, as would be expected. The type 4230 shows itself to be not truly microphone-independent, with differences up to about 0.1 dB occurring in the sound pressure level measured by different microphones. Again the frequency and total harmonic distortion measured are very similar for all the types and configurations of microphone, but the frequency appears to have changed by about 1.5 Hz during the period of the measurements. The results for the type 177 show that the sound pressure level measured is very dependent on microphone type and configuration, with differences of the order of 1 dB. The total harmonic distortion is higher for this device, and it appears that the frequency of the device changed by nearly 2 Hz over the period of the measurements. Again the type MK 221 microphone gives a similar result to the type 4176.

The standard deviation of the sound pressure levels measured on the five different days was clearly greatest for the type 4230 and smallest for the type 4220, and this gives a measure of the relative stability of these two devices. The stability of the type 177 lies somewhere between the two.

4.2 Environmental effects

4.2.1 Atmospheric pressure

Figures 2, 3 and 4 show the variation of sound pressure level with atmospheric pressure for each of the three sound calibrators. The values of sound pressure level are each means of 6 measurements. Best straight lines were fitted in each case and gave the following coefficients, in all cases with correlation coefficients > 0.999:

Type 4220	8.99×10^{-3} dB/mbar
Type 4230	8.03×10^{-4} dB/mbar
Type 177	3.18×10^{-3} dB/mbar

In calculating these results it was necessary to correct the sensitivity of the type 4160 microphone for ambient pressure. A coefficient of -0.0016 dB/mbar was used, although as this coefficient has only been verified over the range of ambient pressures normally encountered it was necessary to assume linearity over the wider range used here.

The coefficient for the type 4220 was as expected, closely following the 20 log (p/p_o) relationship normally used. The type 4230 was virtually pressure independent, whereas the sound pressure level generated by the type 177 was definitely affected by the ambient pressure.

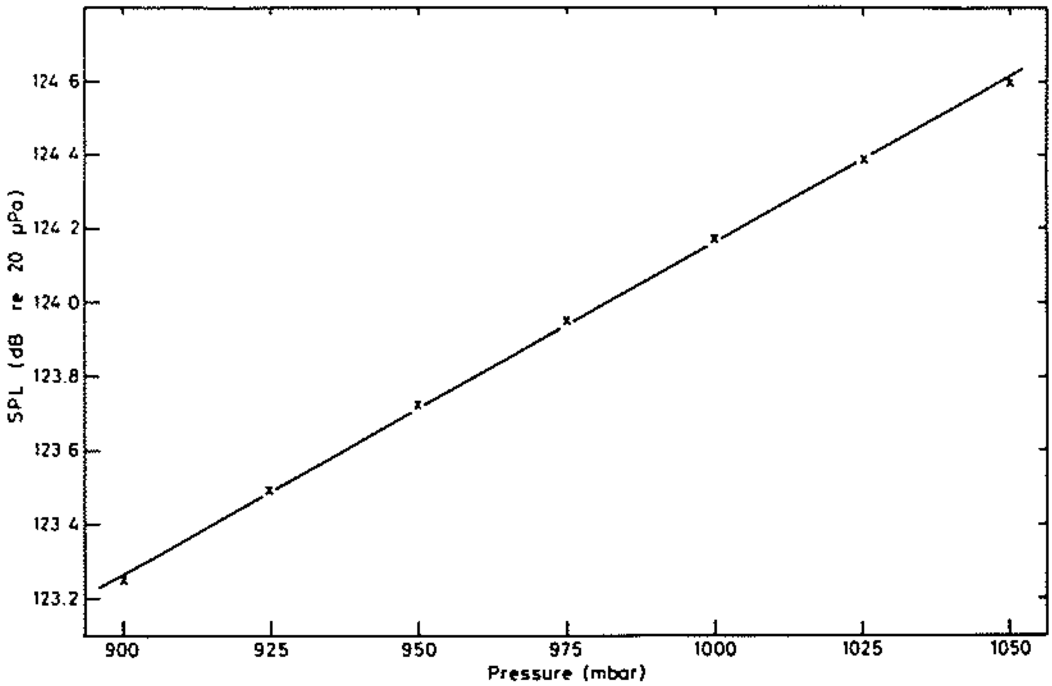

Figure 2 Variation of sound pressure level with atmospheric pressure for pistonphone type 4220, serial no. 1297300

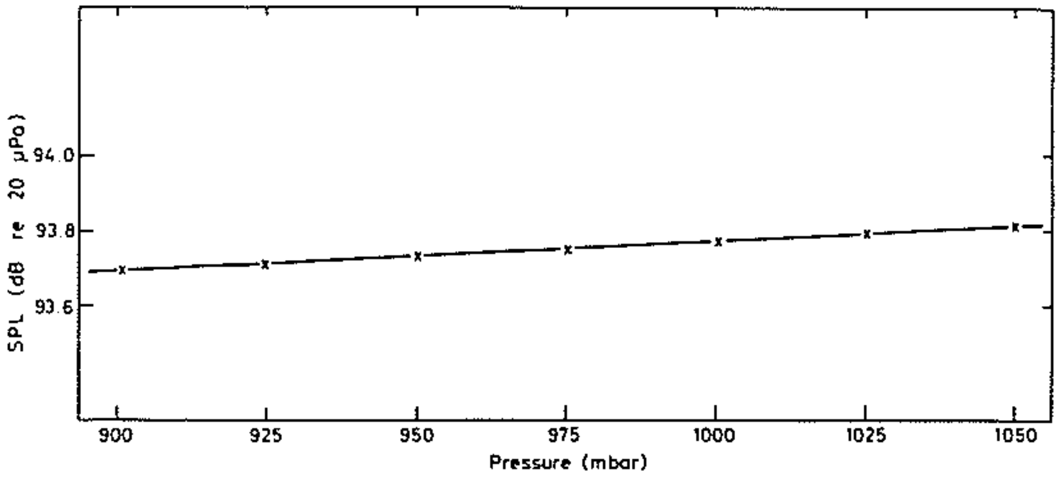

Figure 3 Variation of sound pressure level with atmospheric pressure for calibrator type 4230, serial no. 1351806

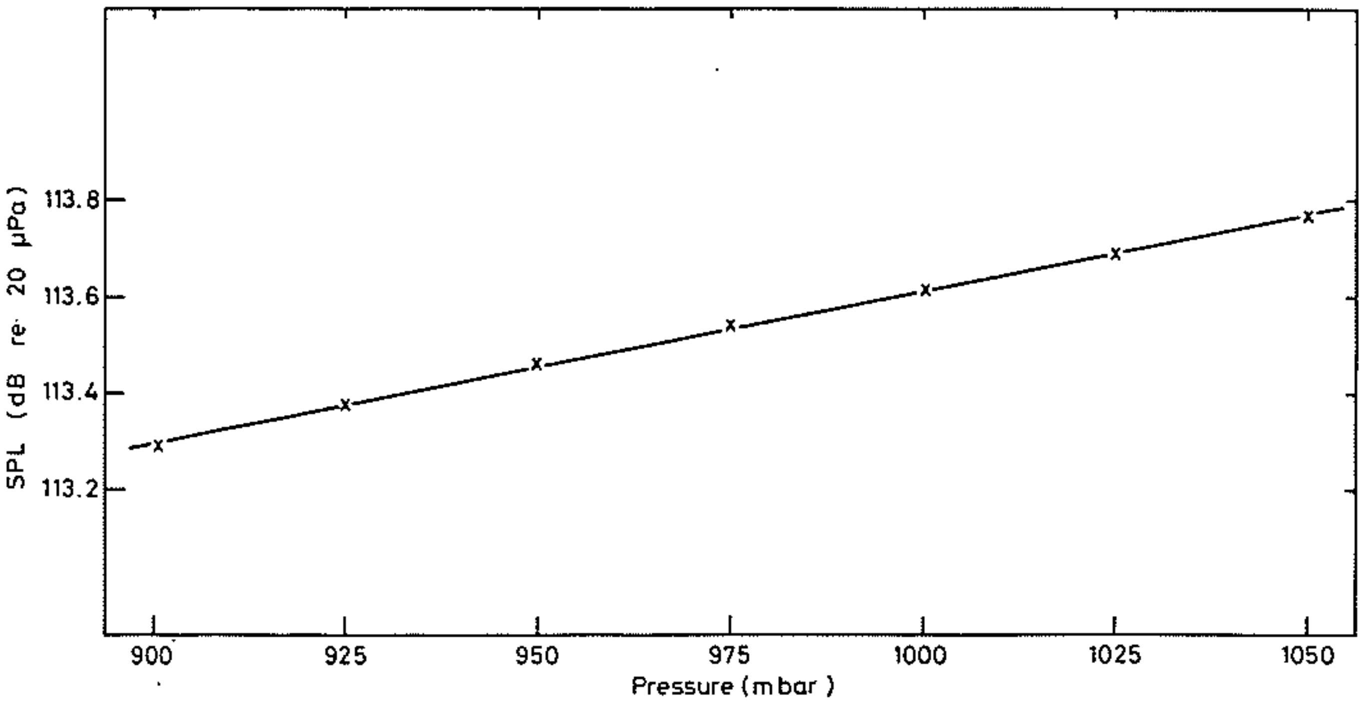

Figure 4 Variation of sound pressure level with atmospheric pressure for calibrator type 177, serial no. 445097

4.2.2 Temperature

Figures 5, 6 and 7 show the variation of sound pressure level with atmospheric temperature for each of the three sound calibrators. It was possible to fit a best straight line in the case of the type 4220

(Figure 5) and the type 177 (Figure 7) with the following coefficients:

Type 4220	-6.67×10^{-4}	dB/°C
Type 177	2.33×10^{-2}	dB/°C

For the type 4230 a second degree polynomial of the form $SPL = a + b_1 t + b_2 t^2$ was fitted with coefficients $a = 92.661$, $b_1 = 0.096$, $b_2 = -0.0019$ and a correlation of 0.886.
Results from varying the temperature of the device over a few hours were rather inconclusive, but showed a similar tendency.

In calculating the results it was necessary to correct the sensitivity of the type 4160 microphone for both pressure and temperature - coefficients of -0.0016 dB/mbar and -0.002 dB/°C were used. However since the temperature coefficient has only been verified over the range 15 °C to 25 °C, linearity outside these limits could only be assumed. A correction was also applied for the pressure dependence of the devices themselves. The correction for the types 4230 and 177 was as measured in Section 3.3.1 and the usual 20 log (p/p_o) correction was used for the type 4220.

The type 4220 was virtually temperature independent, as expected from its construction. The type 4230 showed a rather inexact dependence, the sound pressure level not repeating well for a particular temperature. The type 177 was also somewhat erratic, but demonstrated a clear temperature dependence.
The total harmonic distortion for the type 4230 increased at lower temperatures, but by less than 0.5%, and the frequency for the type 177 seemed to vary over about 6 Hz with no particular pattern.

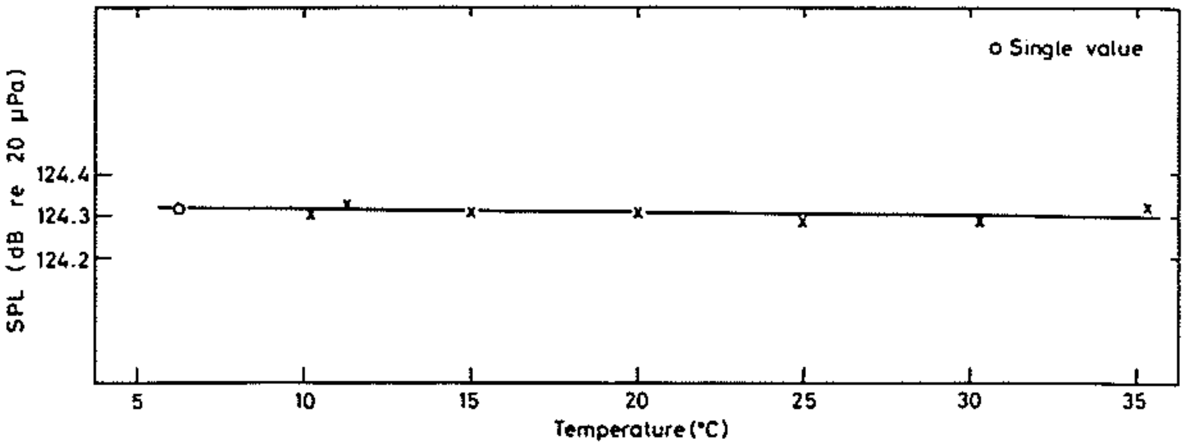

Figure 5 Variation of sound pressure level with atmospheric temperature for pistonphone type 4220, serial no. 1297300

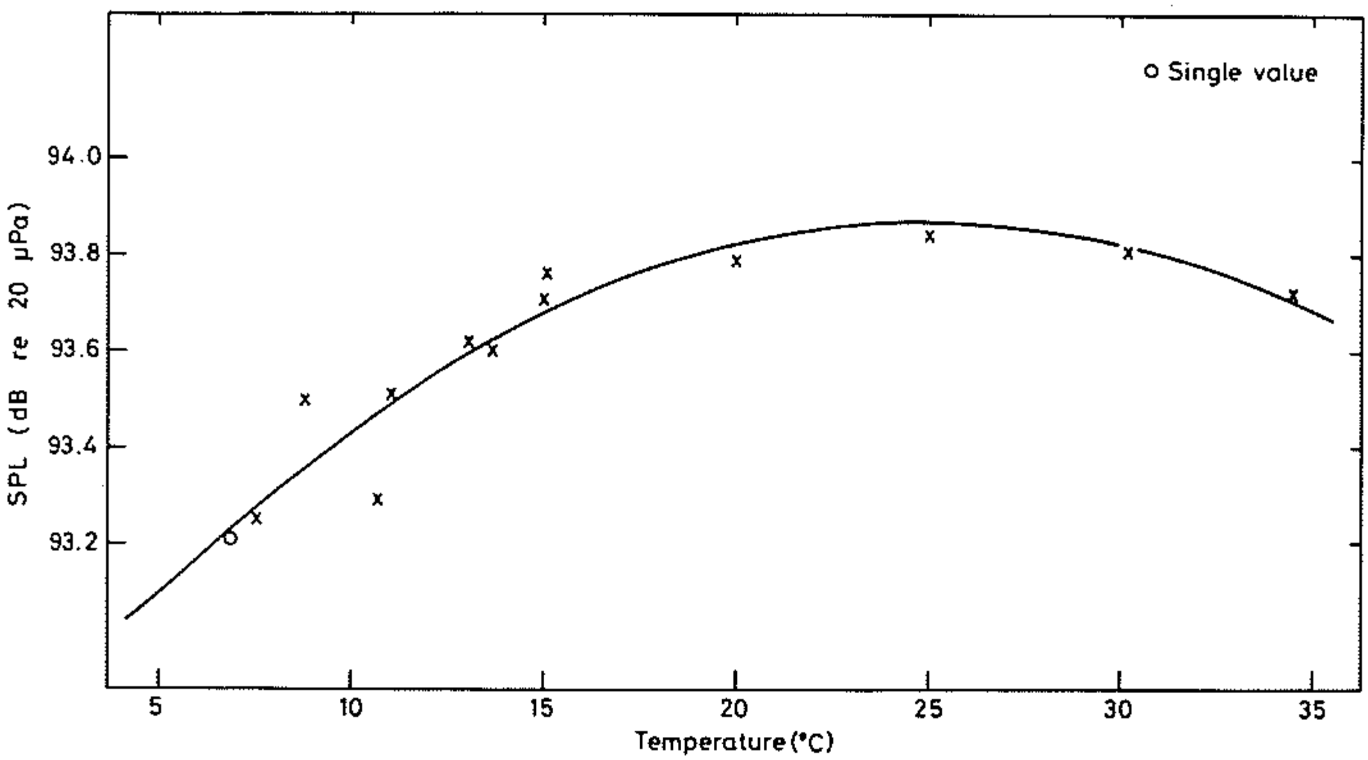

Figure 6 Variation of sound pressure level with atmospheric temperature for calibrator type 4230, serial no. 1351806

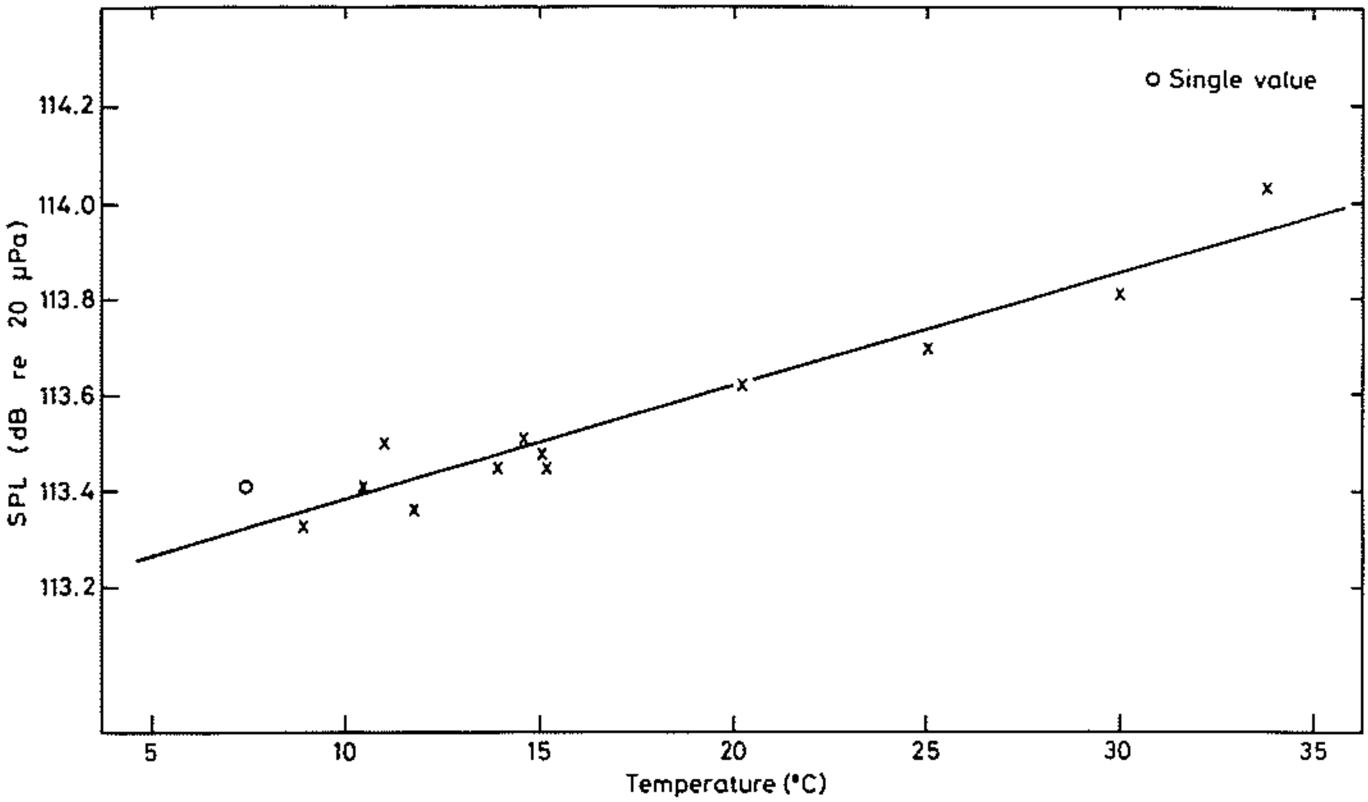

Figure 7 Variation of sound pressure level with atmospheric temperature for calibrator type 177, serial no. 445097

4.2.3 Relative humidity

Figures 8, 9 and 10 show the variation of sound pressure level with relative humidity for each of the three sound calibrators. Best straight lines were fitted with the following coefficients:

Type 4220	6.34×10^{-5}	dB/1%
Type 4230	4.35×10^{-3}	dB/1%
Type 177	-7.70×10^{-4}	dB/1%

In calculating these results it was necessary to correct the sensitivity of the type 4160 microphone for ambient pressure. A coefficient of -0.0016 dB/mbar was used. A correction was also applied for the pressure dependence of the devices themselves as in Section 4.2.2.

The types 4220 and 177 showed virtually no dependence on humidity, only the type 4230 showing any noticeable effect over the range of relative humidities normally encountered.

For the type 177 the frequency dropped by 7 Hz as the relative humidity was increased from 30% to 80%, the other devices showing no change. Total harmonic distortion on all three devices was essentially the same at all relative humidities.

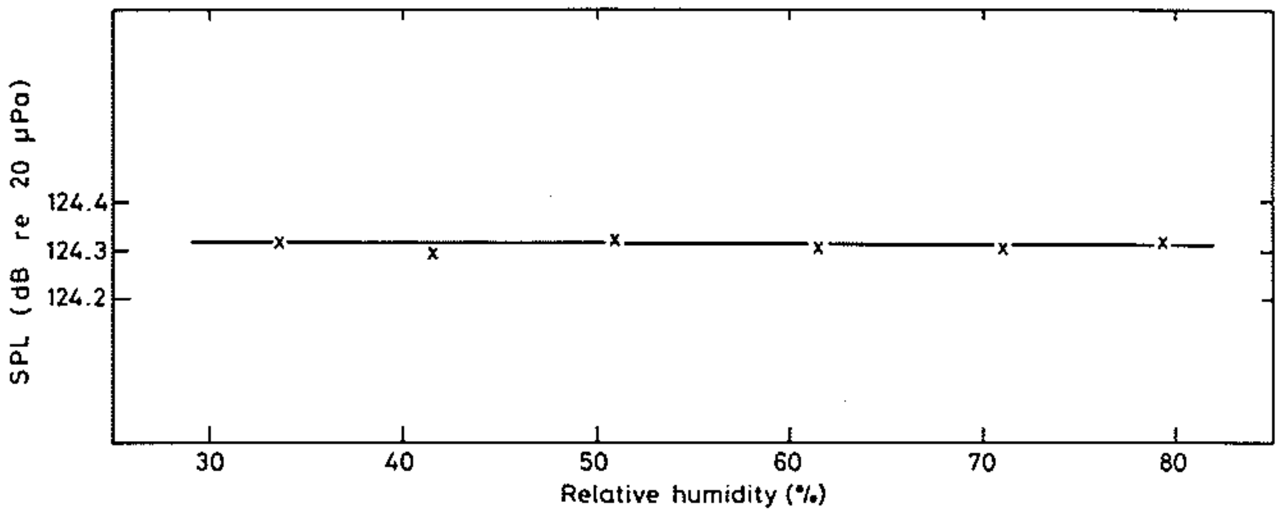

Figure 8 Variation of sound pressure level with relative humidity for pistonphone type 4220, serial no. 1297300

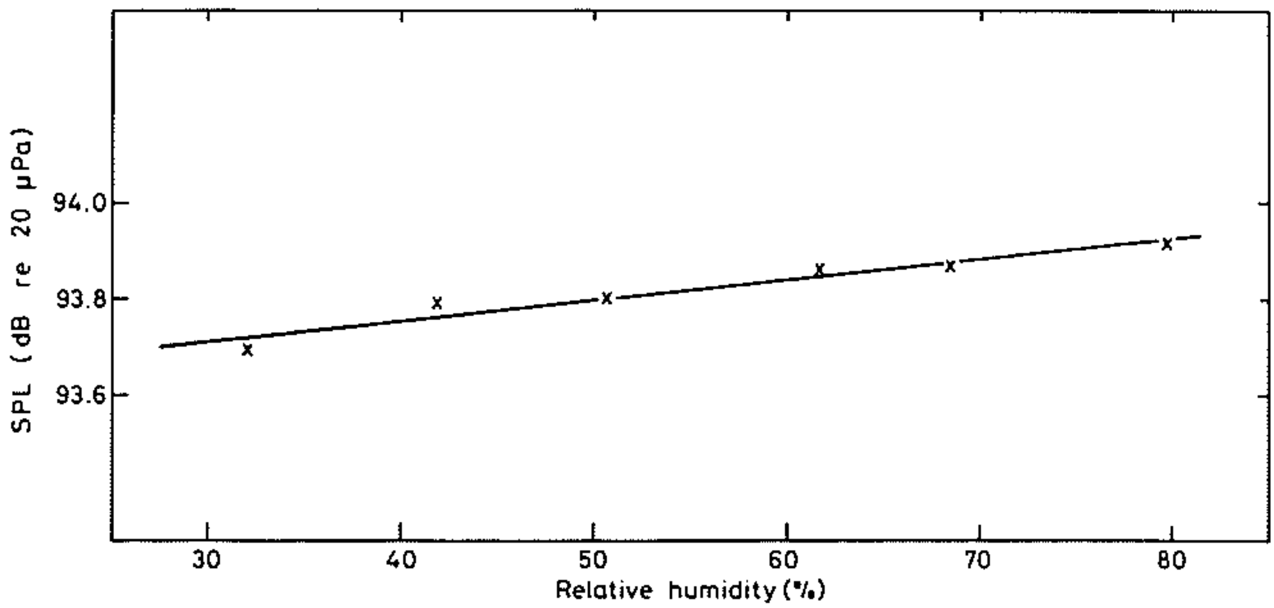

Figure 9 Variation of sound pressure level with relative humidity for calibrator type 4230, serial no. 1351806

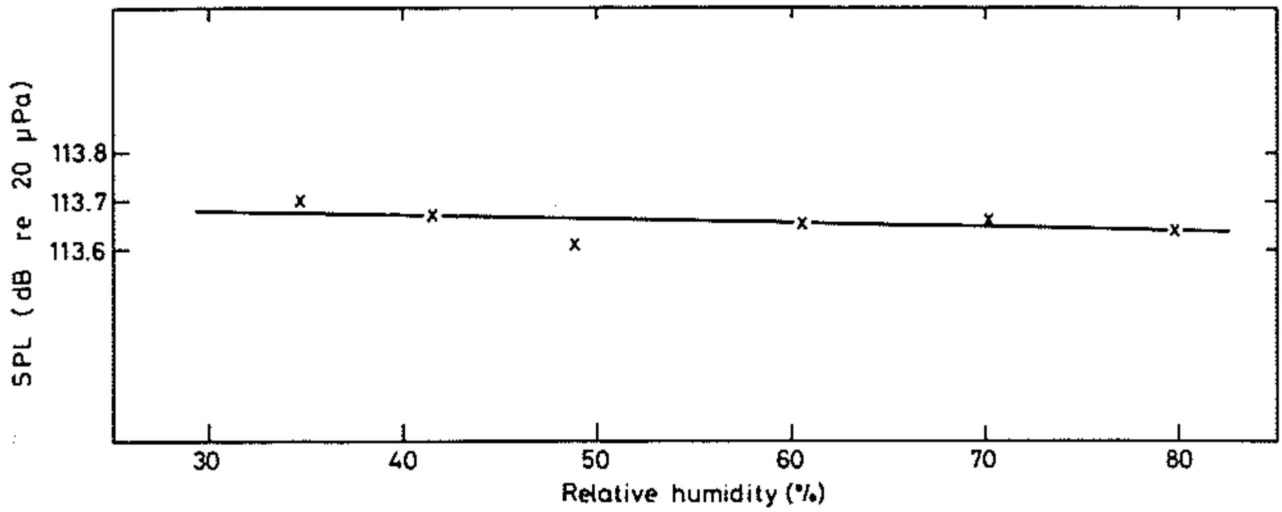

Figure 10 Variation of sound pressure level with relative humidity for calibrator type 177, serial no. 445097

5 UNCERTAINTIES

In each case, a number of systematic uncertainties from the measurements were first evaluated and combined to give a partial systematic uncertainty (U_s'). This was then combined with the appropriate uncertainty of the microphone calibration (U_s'', from Table 1) to give the total systematic uncertainty (U_s) at a 95% confidence level. This total systematic uncertainty was combined with the random uncertainty for the five sets of measurements (U_r) for each microphone, made on the five separate days, to obtain the total uncertainty (U_t). The components of systematic and random uncertainties were combined in accordance with the recommendations of NAMAS (1987) to give the total uncertainty at a confidence level of 95%.

5.1 Type 4220 pistonphone

The following systematic uncertainties are included:

	dB (semi-range)
Measurement of insert voltage to microphone	0.02
Accuracy of standard attenuator	0.03
Drive voltage to pistonphone	0.01
Polarizing voltage to microphone	0.025
Pressure coefficient of microphone	0.01
Correction for pistonphone pressure dependence	0.01
Front cavity plus equivalent volume of microphone	0.006
Rounding of final result	0.005

The combined uncertainties are shown in Table 7.

Table 7 Uncertainties for pistonphone type 4220 measurements

Microphone type	Uncertainties (dB)				
	U_s'	U_s''	U_s	U_r	U_t
4160	0.054	0.03	0.062	0.020	0.07
4144	0.054	0.05	0.074	0.010	0.08
4134 M	0.054	0.05	0.074	0.011	0.08
4134	0.054	0.05	0.074	0.007	0.08
4176	0.046	0.09	0.101	0.014	0.11
MK 221	0.054	0.05	0.074	0.010	0.08

5.2 Type 4230 calibrator

The following systematic uncertainties are included:

	dB (semi-range)
Measurement of insert voltage to microphone	0.02
Accuracy of standard attenuator	0.03
Drive voltage to calibrator	0.01
Polarizing voltage to microphone	0.025
Pressure coefficient of microphone	0.01
Correction for calibrator pressure dependence	0.005
Rounding of final result	0.005

The combined uncertainties are shown in Table 8.

Table 8 Uncertainties for calibrator type 4230 measurements

	Uncertainties (dB)				
Microphone type	U_s'	U_s''	U_s	U_r	U_t
4160	0.053	0.03	0.061	0.036	0.08
4144	0.053	0.05	0.073	0.039	0.09
4134 M	0.053	0.05	0.073	0.017	0.08
4134	0.053	0.05	0.073	0.059	0.10
4176	0.045	0.09	0.100	0.030	0.11
MK 221	0.053	0.05	0.073	0.030	0.08

5.3 Type 177 calibrator

The following systematic uncertainties are included:

	dB (semi-range)
Measurement of insert voltage to microphone	0.02
Accuracy of standard attenuator	0.03
Drive voltage to calibrator	0.01
Polarizing voltage to microphone	0.025
Pressure coefficient of microphone	0.01
Correction for calibrator pressure dependence	0.01
Front cavity plus equivalent volume of microphone	0.006
Rounding of final result	0.005

The combined uncertainties are shown in Table 9.

Table 9 Uncertainties for calibrator type 177 measurements

Microphone type	Uncertainties (dB) U_s'	U_s''	U_s	U_r	U_t
4160	0.054	0.03	0.062	0.022	0.07
4144	0.054	0.05	0.074	0.024	0.08
4134 M	0.054	0.05	0.074	0.039	0.09
4134	0.054	0.05	0.074	0.020	0.08
4176	0.046	0.09	0.101	0.020	0.11
MK 221	0.054	0.05	0.074	0.028	0.08

6 CONCLUSIONS

Measurements have been made of the characteristics of three types of sound calibrator coupled to seven different types/configurations of microphone. The effect of environmental conditions on the performance of the sound calibrators has also been investigated.

For the Brüel & Kjær type 4220 repeatability on a day-to-day basis was good, differences in the measured sound pressure levels generally being less than 0.03 dB. The Brüel & Kjær type 4230 however was noticeably less stable, with differences of up to 0.09 dB occurring, and the stability of the CEL type 177 lay somewhere between these two. For the type 4220 a variation in sound pressure level with microphone type was clearly shown and agreed well with the manufacturer's data for Brüel & Kjær microphones. The type 4230 showed itself to be not truly volume independent with differences of up to 0.1 dB in the sound pressure level occurring for different microphone types. The output from the type 177 was highly dependent on the type of microphone used with differences of the order of 1 dB being evident.

Environmental tests showed the type 4220 performance to be virtually independent of temperature and relative humidity, while the variation with atmospheric pressure closely followed the relationship normally used. The pressure coefficient for the type 177 was about one-third that of the type 4220, and again there was virtually no effect due to relative humidity. The effect of temperature was significant for this device, a change of temperature of 1 °C producing a change in sound pressure level of 0.02 dB. The type 4230 also showed a temperature dependence, but here a second degree polynomial was required to fit the curve. It was particularly difficult to make measurements on this device at the lower temperatures. The output of the type 4230 was virtually independent of atmospheric pressure, but this was the only calibrator tested to show a significant effect due to relative humidity over the range normally encountered - a change of 10% produced a change in sound pressure level of 0.04 dB.

The total uncertainties for the measurements of sound pressure level ranged from 0.07 dB to 0.11 dB at 95% confidence limits. The largest uncertainty was associated with the measurements using the type 4176 microphone, which could not be calibrated by the reciprocity method as its protective grid cannot be removed. Equally it was not possible to measure the front and equivalent volume of this microphone. Further work is necessary to develop techniques to calibrate these and other types of non-standard microphone more accurately.

7 ACKNOWLEDGEMENTS

The author wishes to thank R G Barham who made the reciprocity and laser pistonphone measurements, and N E Milton who assisted with the calibrator measurements.

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