B.

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PISTONPHONE
TYPE 4220

Applicable to instruments from serial
No. 501 397

Revision November 1980

CONTENTS

type 4220

Pistonphone for Acoustic Calibration

FEATURES:

- Well defined sound source
- Few, highly stable parameters determine SPL
- High calibration level, 124 dB SPL at microphone diaphragm
- Accurate calibration within ± 0,15 dB
- Transistorized frequency control
- Individually calibrated
- Battery operated
- Fits 1", 1/2", 1/4" and 1/8" microphones

USES:

- Direct calibration of sound measurement equipment
- Field and laboratory use
- Laboratory standard

The Pistonphone Type 4220 is a small, battery operated, high level precision sound source, which provides quick and accurate direct calibration of sound measuring equipment, tape recordings of sound etc. with an error of less than ±0,15dB. It is always ready for use and can be utilized in the field under severe environmental conditions while still maintaining high accuracy. It is also extremely useful as a laboratory standard sound pressure level. The Pistonphone fulfils the recommendations of the IEC on the calibration of precision sound level meters. The calibration frequency, which is 250 Hz with the self-contained batteries, is controlled within ± 1% by means of a transistor circuit. The piston arrangement, an original B & K design, consists of two pistons moving in opposite direction and ensures maximum stability and low non-linear distortion (see Fig.1).

The operation procedure is simple: Fit the microphone into the coupler of the Pistonphone and push the control switch to the "On" position and the Pistonphone will now produce a constant sound pressure level on the diaphragm of the microphone. The Pistonphone can be held in one hand in any position, while with the free hand the sensitivity of the sound measuring equipment is adjusted until a reading corresponding to the sound pressure level produced is obtained.

The Pistonphone fits the B & K 1", 1/2", 1/4" and 1/8" microphones and microphones having the same standard diameter, such as the types WE 640 AA, MR 103, etc. Fig.2 shows its use with 1" and 1/2" microphones. The Pistonphone can also be adapted to other types of microphones by means of special

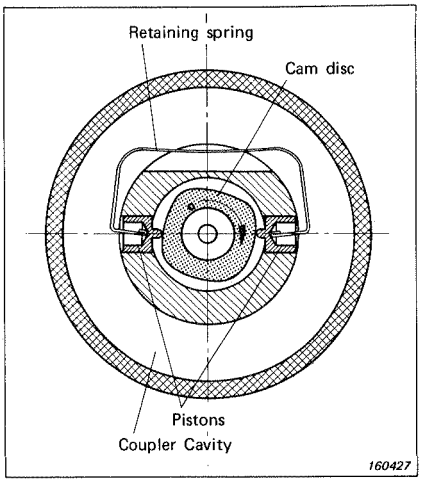

Fig.1. Cross sectional view showing the principle of operation

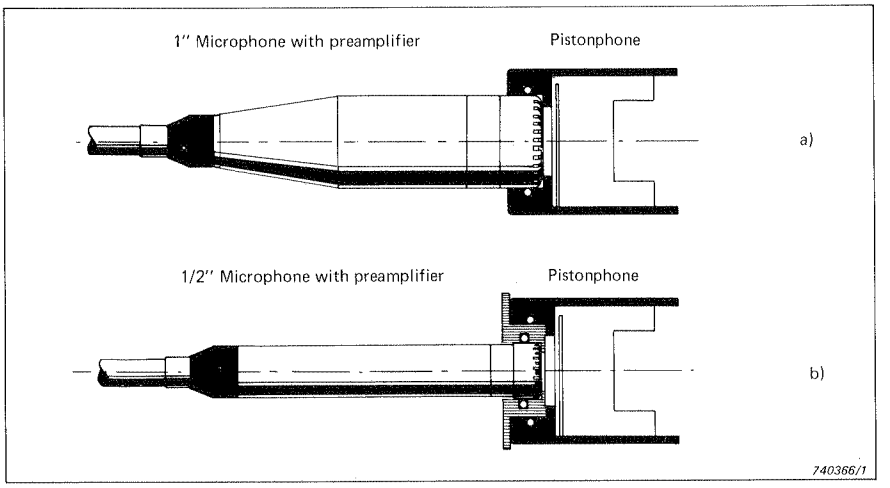

Fig.2. Mounting B & K microphones on the Pistonphone
a) 1" microphone
b) 1/2" microphone. The total volume of the cavity is the same in both cases

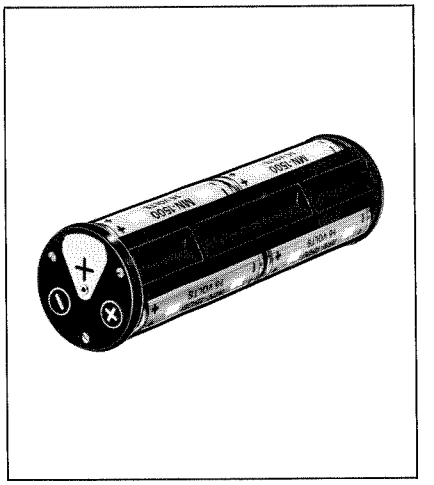

Fig.3. Battery container DH 0236 fitted with 6 batteries

adaptors. The sound level produced by the Pistonphone, when fitted to a B & K microphone is 124 ± 0,2 dB re 2 x 10^{-5} Pa. This high level allows correct calibration to be made even in very noisy surroundings. Each pistonphone is individually calibrated at normal atmospheric pressure. A barometer supplied with the Pistonphone gives the ambient pressure correction in dB, in the range 790 to 1040 mbar.

The Pistonphone is delivered with alkaline batteries, IEC LR 6 (QB 0013), mounted in a battery container DH 0236 (Fig.3), which enables very easy battery replacement. Fitted with alkaline batteries, the 4220 operates in the temperature range —10 to + 55°C (14 to 131°F). The batteries can be checked by pushing the control switch of the Pistonphone to the "Batt." position where the frequency should be higher than in the "On" position (approximately 320 Hz with new batteries).

The operating frequency of the Pistonphone can be varied from less than 30 Hz to maximum 320 Hz by using an appropriate external DC power supply. (In the range 30 Hz to 320 Hz the sound level is independent of the frequency).

Specifications 4220

Sound Pressure Level: (Individually calibrated)
124 dB (re 2 × 10^{-5} Pa) ± 0,2 dB at
Ambient Pressure: 1013 mbar
Ambient Temp.: 23°C
Ambient Humidity: 50% RH
Effective Load Volume: 1,333 cm^3

Calibration Accuracy:
± 0,15 dB

Frequency:
Pos. "On": 250 Hz ± 1% (+ 5°C to + 45°); ± 2% (—10°C to + 55°C)
Pos. "Batt.": approx. 320 Hz with new batteries

Nominal Effective Coupler Volume:
19,733 cm^3 (at 250 Hz) including Nominal Effective Load Volume 1,333 cm^3

Distortion:
< 3% at 250 Hz

Temperature Range:
With batteries: —10°C to + 55°C
With external Power Supply: —30°C to + 70°C

Influence of:
Ambient Pressure: SPL is proportional to the ambient pressure. (Correction Barometer supplied)
Ambient Temperature: < 0,001 dB/°C from —10°C to + 55°C
Ambient Humidity: —12 × 10^{-5} dB per % Relative Humidity
Effective Load Volume: See Manual

Batteries:
6 batteries IEC LR 6
If frequency (speed of motor) increases when switching from "On" to "Batt." position, then battery voltage is sufficient

Dimensions:
Length: 224 mm (8,7 in.)
Diameter: 36 mm (1,4 in.)

Weight:
Pistonphone with batteries: 0,7 kg (1,5 lb)
Total weight of case containing pistonphone, adaptors and correction barometer: 1,6 kg. (3,5 lb)

Correction Barometer Specifications:
Pressure Range: 790 to 1040 mbar
Accuracy (1 year): better than ± 0,1 dB at 23°C; ± 0,2 dB from —10°C to + 50°C

Accessories included:

6 alkaline batteries IEC LR 6, size AA	QB 0013
1 battery container	DH 0236
1 adaptor for 1/2" microphones	DB 0311
1 adaptor for 1/4" microphones	DB 0310
1 adaptor for 1/8" microphones	DB 0352
1 Correction Barometer	UZ 0003

2. OPERATION

2.1. GENERAL

After the sound measuring equipment under test has been warmed up and made ready for use in the 120 — 130 dB range and with "linear" or "C" weighted frequency response, operation of the Pistonphone is as follows:

1. Fit the required microphone adaptor to the Pistonphone.

2. Turn on the Pistonphone and check the batteries by pushing the switch backwards and forwards between the positions "On" and "Batt.". As long as a clear frequency difference can be heard, the batteries are in good condition and the Pistonphone will operate within specifications.

3. Turn off the Pistonphone.

4. Fit the microphone to the microphone adaptor. The Pistonphone can be held in one hand in any orientation*, provided that the microphone is properly seated in the adaptor so that errors due to inaccurate coupler volume are eliminated.

5. Turn on the Pistonphone, setting the switch "On".

6. Adjust the sensitivity of the sound measuring equipment until the indication coincides with the SPL (RMS Sound Pressure Level) given by the calibration card supplied with the Pistonphone plus the dB correction for ambient pressure as indicated by the Barometer UZ 0003, or Fig.2.2. Use of the Barometer is explained in section 2.3.

7. Turn off the Pistonphone as soon as the calibration has taken place in order to preserve the batteries.

The output level of the Pistonphone as stated on its calibration chart is valid for the following test conditions.

1. An effective loading volume of 1,333 cm^3.

2. An ambient atmospheric pressure (P_0) of 1013 mbar.

3. A relative humidity of 50%.

4. An ambient temperature of 23°C.

If conditions at the time of use vary significantly from these values, small corrections to the calibration level may be required as described in the following sections 2.2 to 2.5.

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* A slight variation in the noise produced by the motor can be noticed when holding the Pistonphone in different positions. This has no relation to the frequency and the SPL produced

2.2. CORRECTION FOR CAVITY VOLUME

The factory calibration is valid for an effective loading volume of 1,333 cm^3. An important correction to the sound pressure output of the Pistonphone is required if the total volume of the coupler cavity differs from the standard case of a B & K microphone with standard protection grid. The adaptors supplied with the Pistonphone convert the smaller B & K microphones fitted with their normal protection grids to the correct coupler volume so that no additional volume correction is required. Other microphones require a correction as follows.

From equation (3.3) (section 3.1), the volume correction can be derived as:

$$\Delta P = 20 \log_{10} \frac{V}{V + \Delta V} \text{ dB}$$

where ΔP is the correction, in dB, to be added to the calibration value.

V is the nominal effective coupler volume (19,733 cm^3)* including the nominal effective load volume (1,333 cm^3).

ΔV is the actual effective load volume minus the nominal effective load volume.

The nominal effective load volume (1,333 cm^3) corresponds to the load imposed by a one-inch microphone with normal protecting grid or by the smaller B & K microphones and their respective adaptors.

The effect of changing the coupler volume is best illustrated by an example. Take the case of a Pistonphone calibrated to 123,9 dB with the standard coupler volume of 19,733 cm^3. The barometric pressure is such that a correction of —0,2 dB and the Pistonphone is used to calibrate a one-inch B & K Condenser Microphone Type 4160. The 4160 is a specially developed pressure microphone intended for coupler measurements such as reciprocity calibration and as a laboratory standard. The 4160 features the normalized front cavity for coupler measurements, and without the protecting grid the sum of the front volume and microphone equivalent volume is 0,670 cm^3 (nominal). The total coupler volume of the pistonphone is therefore 19,07 cm^3. The sound pressure level (SPL) produced in the coupler will be:

$$\text{SPL} = 123{,}9 - 0{,}2 + 20 \log_{10} \frac{19{,}733}{19{,}07} = 123{,}9 - 0{,}2 + 0{,}3 = 124 \text{ dB re } 20\ \mu\text{Pa}$$

The calculated correction values for 1" microphones are:

Type	Without protection grid	With protection grid
4160 (WE 640 AA, MR 103)	+ 0,3 dB	+ 0,42 dB
4144, 4145	+ 0,3 dB (with coupler adaptor ring DB 0111)	0

800727

* The nominal effective coupler volume is composed of the geometric coupler volume (18,24 cm^3) plus an additional volume to account for heat conduction (0,16 cm^3 at 250 Hz), and the nominal effective load volume (1,333 cm^3)

2.3. BAROMETER UZ 0003 FOR AMBIENT PRESSURE CORRECTIONS

The sound pressure output given on the calibration chart supplied with the 4220 is given for normal atmospheric pressure conditions (P_0 = 1013 mbar). For large changes in ambient pressure (due to altitude changes, for example) a correction must be made.

The exact formula for the SPL correction can be derived as:

$$\Delta \text{SPL} = 20 \log_{10}\left(\frac{P_a}{P_o}\right)$$

where P_a is the actual atmospheric pressure in mbar

and P_0 is the reference atmospheric pressure (1013 mbar)

A barometer (part number UZ 0003) graduated both in dB of correction and millibar, is supplied with the 4220 for this purpose. The barometer range is from 790 to 1040 mbar. See Fig.2.1.

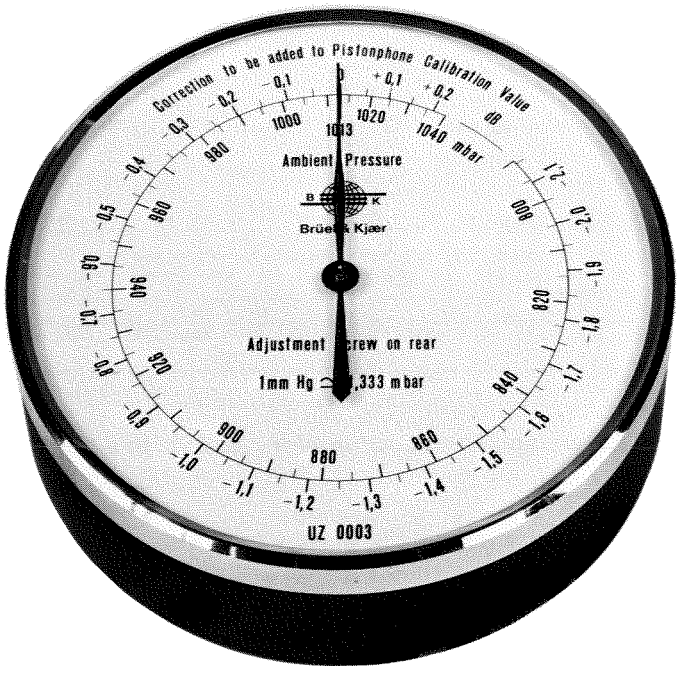

Fig.2.1. Barometer UZ 0003

Over this pressure range the accuracy of the barometer is better than 0,1 dB at an ambient temperature of 23°C and better than 0,2 dB over the temperature range —10°C to 50°C, for at least one year after calibration.

For variation of the ambient pressure above 2000 m and up to 18000 m i.e. down to 80 mbar, the correction curve given in Fig.2.2 can be used.

A conversion chart giving the equivalence between the pressure expressed in different units is shown in Fig.2.3.

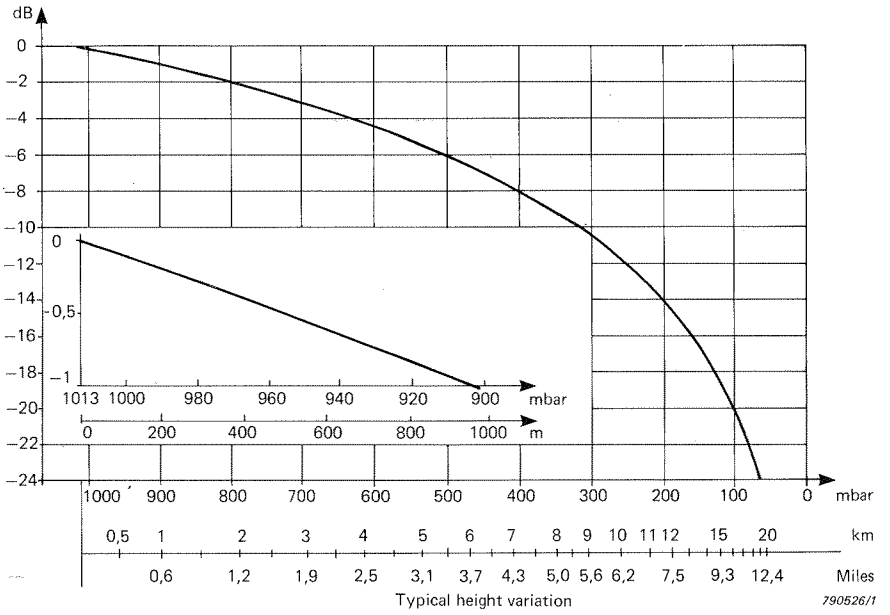

Fig.2.2. Correction curve for operation at low pressures or high altitudes

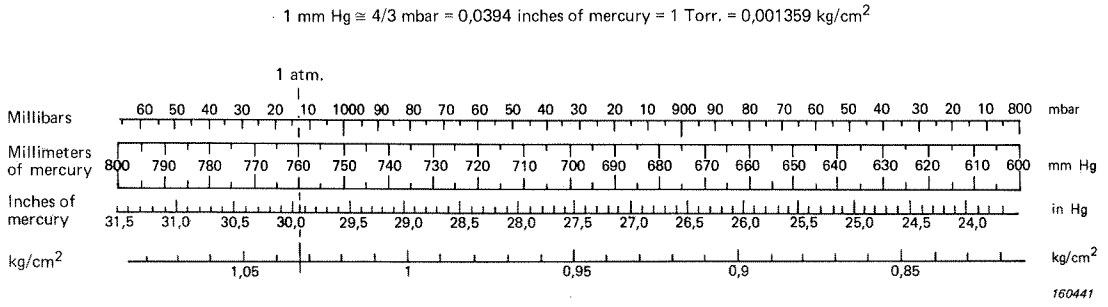

Fig.2.3. Conversion chart of barometer readings in different units

From time to time, and especially after transportation or a large change in altitude, it is recommended that the calibration of the barometer be checked. The pointer of the barometer can be adjusted by means of a screw at the rear of the barometer. Suitable references are provided by a laboratory mercury barometer, or by a local meteorological station or airport.

2.4. INFLUENCE OF HUMIDITY

The influence of humidity is generally not of significance unless the instrument is in use as a laboratory standard where extreme accuracy is required. Corrections are normally not greater than 0,01 dB over the ranges of relative humidity and temperature normally encountered in use. See Fig.2.4.

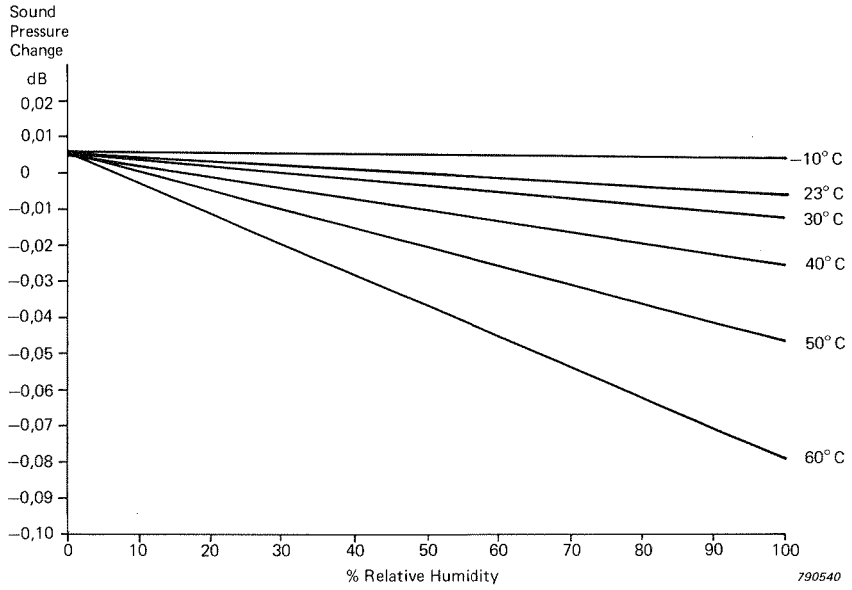

Fig.2.4. The influence of humidity on the sound pressure produced by the Pistonphone Type 4220. The reference value as stated on the calibration chart for the instrument is valid for an ambient pressure of 1013 mbar, a temperature of 23°C and a relative humidity of 50%

2.5. INFLUENCE OF TEMPERATURE

The influence of temperature on the calibration level is negligible. Change in volume of the cavity caused by thermal expansion of the material of which the instrument is made leads to a sound pressure level change of less than + 0,001 dB per °C rise in temperature.

2.6. USE OF AN EXTERNAL POWER SUPPLY

The 4220 is normally used at its controlled frequency of 250 Hz. However, in certain instances, it may be used to check the frequency response of a sound measuring system between 30 Hz and 320 Hz. At 30 Hz, the sound pressure level in the coupler is less than 0,5 dB below the level at 250 Hz.

The frequency can be varied from 320 Hz to 30 Hz, using an external variable voltage power supply. The speed of rotation is stabilized to give 320 Hz or 250 Hz, for a power supply of between 9 and 6 V DC, for the switch positions "Batt." and "On" respectively.

The battery compartment must be removed and the external supply connected as in Fig.2.5.

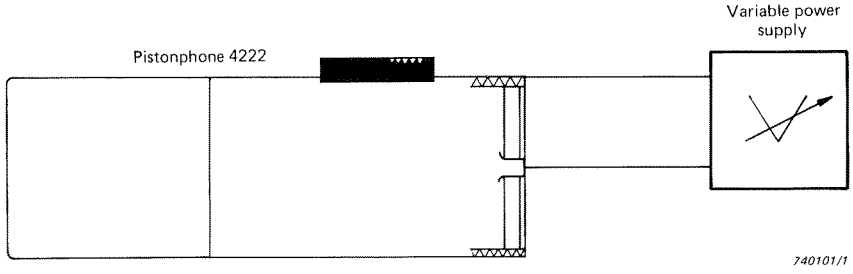

Fig.2.5. Connection of an external variable power supply

Care should be taken when using a symmetrical power supply to ensure that no short circuit can occur between the 4220 and the rest of the sound measurement system, where generally the negative pole (ground) is connected to the housings and to the microphone body.

When the control switch is set to "Batt.", the upper limit of the motor's rotational speed is obtained with a voltage of 6 V DC (and up to 9 V) giving a frequency of 320 Hz. A 2 V supply will give a frequency of about 30 Hz, and the voltage/frequency relationship is given by Fig.2.5. The initial voltage applied to start the Pistonphone should never be less than 6 V, which should be gradually reduced until the required frequency is obtained.

The lower frequency limit is imposed by the leakage time constant of the coupler cavity, and is less than —0,5 dB at 30 Hz even if no special precautions are taken to improve the fit. Between the limits of 30 Hz and 320 Hz the SPL produced by the 4220 is constant and independent of frequency.

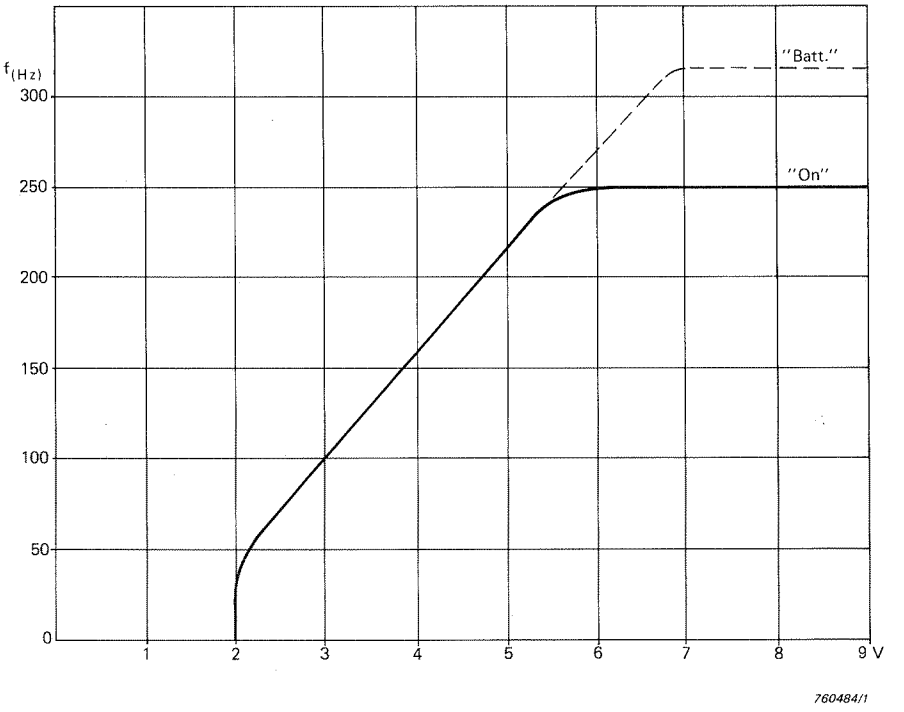

Fig.2.6. Voltage-to-frequency relationship with an external variable power supply

3. CHARACTERISTICS

3.1. PRINCIPLE OF OPERATION

The principle of operation of the Pistonphone Type 4220 is shown in Figs.3.1 and 3.2. The two pistons are symmetrically driven by means of a cam disc, mounted on the shaft of a miniature electric motor. The cam, which is made of tempered steel, is machined to a high degree of accuracy. The theoretical equation to be followed, illustrated in Fig.3.2, is:

$$r = a + b \sin 4\alpha \qquad (3.1)$$

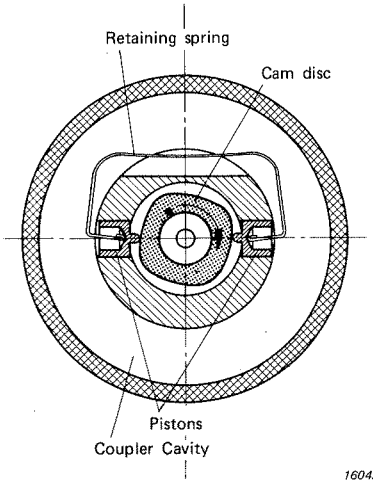

Fig.3.1. Cross-section showing the principle of operation

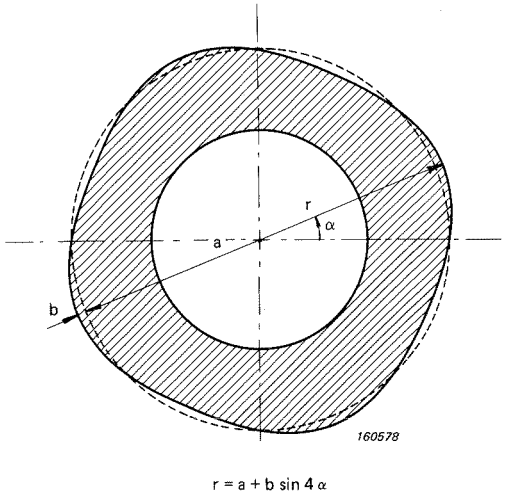

Fig.3.2. Sketch of a sinusoidal-shaped cam

However, equation (3.1) assumes that the piston tip is always in point contact with the cam. This is not the case in practice, as illustrated in Fig.3.3.

The contact point between the piston and the cam varies relative to the piston axis. This would result in second harmonic distortion. Therefore the equation (3.1) has been corrected to compensate for this distortion.-

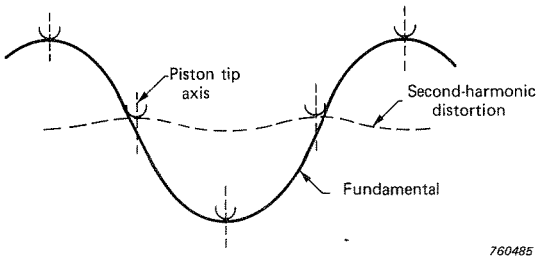

Fig.3.3. Second-harmonic distortion when cam shape follows Eqn.3.1

$$r = a + b \sin 4\alpha + c \sin 8\alpha \qquad (3.2)$$

When rotating, the cam will give the pistons a sinusoidal movement at a frequency equal to four times the speed of rotation. Consequently the cavity volume is varied sinusoidally and the RMS sound pressure produced will be:

$$P = \gamma P_o \frac{2 A_p S}{V\sqrt{2}} \qquad (3.3)$$

where:

γ = C_p/C_v = ratio of specific heats for the gas in the cavity (γ = 1,402 for air at 20°C and 1 atm.)

P_o = atmospheric pressure, expressed in Pa

A_p = area of one of the pistons (m^2)

S = peak amplitude of motion of one piston from the mean position (m)

V = volume of cavity with the pistons in mean position + the equivalent volume of the microphone (m^3)

The sound pressure level in dB is consequently:

$$SPL = 20 \log_{10} \frac{P}{P_t}$$

where $P_t = 20\,\mu Pa$ (threshold of hearing).

It is assumed in the above equation that $A_p \times S << V$, and that compression is adiabatic. These conditions are satisfied entirely in the case of the Pistonphone Type 4220, where $A_p \times S/V \cong 0{,}0002$, and where the heat conduction correction would be approximately 0,24 dB at 30 Hz, and approximately 0,08 dB at 250 Hz.

It is possible to define with great precision the different quantities involved in equation (3.3). The piston stroke S is one quarter of the difference between the maximum and the minimum diameters of the cam. Accurate measurement of this difference, though relatively small, presents no problem when using a precision micrometer. In addition, as the pistons are symmetrically located with respect to the cam, any mechanical deviation due to the mounting or to a wobbling of the motor is compensated in the total movement of the pistons, and has no influence of the SPL produced.

The frontal surface A_p of the pistons and the volume V of the cavity are also easy to measure accurately, and as the diameter of the pistons is large relative to the stroke, the influence of the space between the pistons and the walls is negligible. (The tightness of the pistons is satisfactory, without any lubricating material, down to about 30 Hz.) Finally a possible error in the ambient pressure P_o is far below the required limit, as ten degrees on the scale of Barometer (UZ 0003) correspond to 0,07 dB. These features make it possible to calculate the SPL produced by the Pistophone Type 4220 at the standard frequency of 250 Hz to within less than ± 0,2 dB (± 2%).

3.2. PISTONS, NON-LINEAR DISTORTION

The design of the piston drive in the Pistonphone 4220 provides very low distortion. Distortion is produced, not by imperfection of the specially shaped cam, which can be considered as a rather perfect sinusoidal shape, but by the wear of the piston tips sliding on the cam. If no special care has been taken, the tips can become worn on one side, and in due course this slightly distorts the movement of the pistons. The distortion is mainly at the second harmonic frequency.

The pistons are made of a special synthetic material, presenting a particularly low friction coefficient with steel. The cam and pistons are lubricated with high quality oil on assembly. The tension of the retaining spring is also carefully adjusted to maintain even contact of the piston tips on the cam, but without excessive pressure. These precautions maintain the distortion of the Pistonphone below 3% at 250 Hz. The frequency spectrum of the signal produced by the Pistonphone is shown in Fig.3.4.

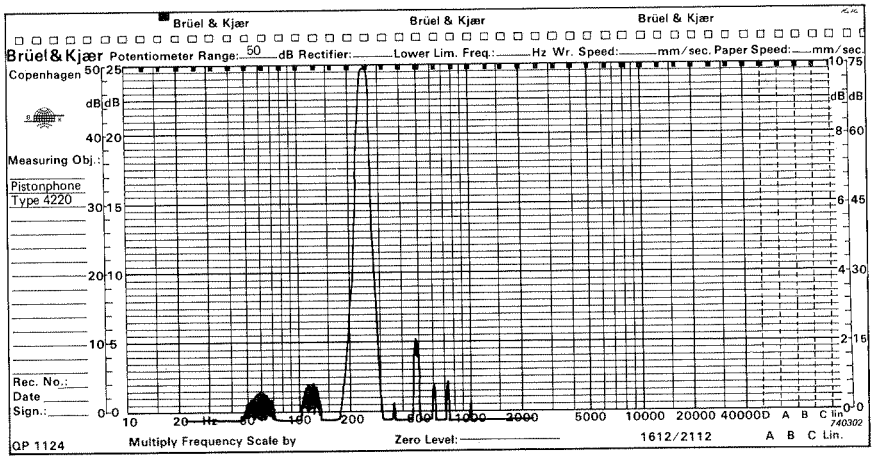

Fig.3.4. Typical frequency spectrum of the 4220

3.3. COUPLERS AND ADAPTORS

The coupler cavity of the Pistonphone 4220 has been designed with dimensions which are small with respect to the wavelength of the sound in the frequency range involved. The coupler has an opening diameter of 23,8 mm, fitting microphones with a standard diameter of 0,936 inch (as specified in ANSI S1.12-1967) such as the B & K Types 4144, 4145, 4160 or the W.E. 640 AA and MR 103.

In addition, three adaptors are supplied with the Pistonphone, enabling the opening diameter to be reduced without changing the total volume of the cavity, for use with half-, quarter- and eighth-inch diameter microphones. The adaptors are easily mounted onto the Pistonphone by pressing them into the coupler opening, and into each other (see Fig.3.5). The coupler opening and the adaptors are fitted with a rubber ring which ensures an airtight connection with the microphone under test. The coupler cavity is also fitted with a capillary tube for static pressure equalization with the atmospheric ambient pressure.

The Pistonphone can be adapted to almost any type of microphone, as a suitable adaptor can easily be made which has a smaller diameter. The use of special adaptors does not

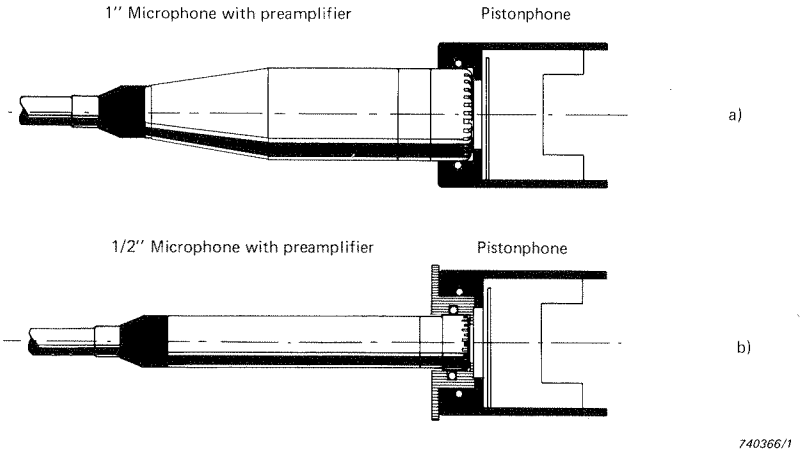

Fig.3.5. Fitting the B & K microphones on the 4220.
a) one-inch microphone
b) half-inch microphone
The total volume of the cavity is the same in both cases

offer any other problems than those of external leakages*. However, the dimensions should remain small in comparison with one quarter wavelength in order to avoid any disturbance due to wave motions in the cavity, ($\lambda/4$ in air is approximately 34 cm (13,4 in) at 250 Hz, and 26,5 cm (10,4 in) at 320 Hz).

From equation (3.3) it is seen that the SPL produced by the Pistonphone is inversely proportional to the volume V of the cavity. The nominal SPL of the Pistonphone corresponds to the situation where a B & K microphone with the normal protecting grid is inserted. In this case the total volume of the cavity is 19,733 cm^3, including the equivalent volume of the microphone: 1,333 cm^3 for B & K Types 4144, 4145. For any change in the total volume V, a corresponding correction must be made on the given SPL of the Pistonphone. See also section 2.2.

3.4. MOTOR AND FREQUENCY REGULATOR

From serial no. 501 397, the 4220 is fitted with a precision speed-controlled motor. Electrical control using the motor tachometer signal frequency as feedback, ensures regulation of the speed of rotation, which gives frequency stability within 1%, (see Fig.3.6). As the frequency stability is within 1%, the amplitude errors are well within the tolerances of the international standardized weightings A and B.

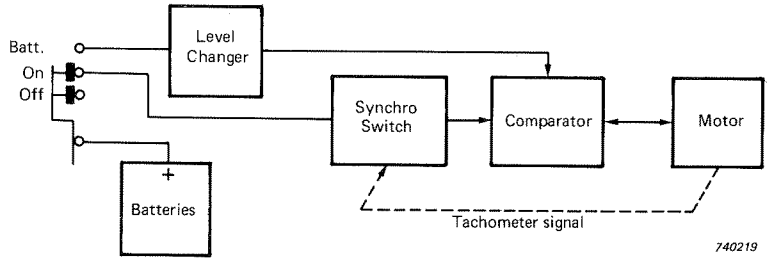

Fig.3.6. Block diagram of motor control system

* When using the Pistonphone with some types of microphone, a slight and slow variation in the reading of the indicating instruments may be noted at the beginning. This is caused by slow equalization between the pressure inside these microphones and the external pressure.

Such an accurate definition is required when calibrating Sound Level Meters, since the normal weighting functions used have non-linear frequency response. The response of "A" and "B" weightings at 250 Hz is nominally 8,6 and 1,3 dB lower than the 1 kHz frequency response.

3.4.1. Control Switch

The control switch has three positions:

"On" the battery current is fed to the motor via the regulating network, maintaining a rotational speed of 3750 rpm, to give a frequency of 250 Hz.

"Batt." In this position, the comparator reference level is changed in the electronic network to give 320 Hz (4800 rpm) which will be the frequency with new batteries. As long as the batteries are usuable the frequency will be between 320 and 250 Hz.

"Off" the battery current is switched off.

In the "On" position, the motor regulation operates, and a frequency of 250 Hz is obtained provided the power supply (batteries) gives between 9 and 6 V DC approximately.

By switching between the "On" and "Batt." positions, a quick check of the batteries is obtained. If no frequency increase can be heard, it is normally necessary to replace the batteries; the 4220 can still be used as the SPL is still correct, but the frequency produced may be lower than 250 Hz.

3.5. BATTERIES

The 4220 is supplied with Alkaline Manganese cells type IEC LR6 (American Standard size AA) B & K reference no. QB 0013. The battery holder contains 6 cells, giving a total voltage of 9 V (6 × 1,5 V) when fully charged. These will give approximately 30 hours continuous operation.

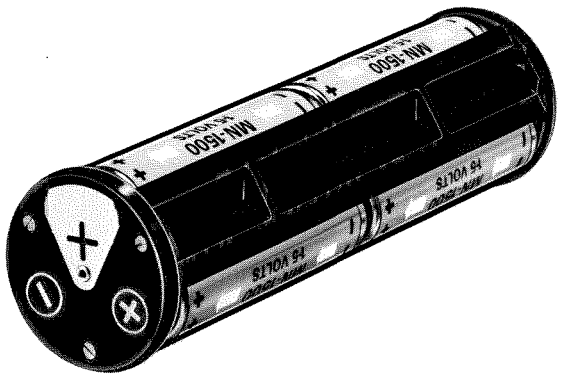

Fig. 3.7. Battery holder

The LR6 Type batteries supplied with the 4220 have a storage life of 2 years at room temperature and a working temperature range of —10 to 60°C.

Careful attention should be paid when mounting the batteries into the holder with respect to their polarity. If the holder is inverted when it is loaded into the Pistonphone, no damage will be caused, but the Pistonphone will not operate.

Alternatively, a set of standard batteries for transistor receivers may be used, and will give approximately 10 hours of continuous operation.

4. MAINTENANCE

4.1. DISMANTLING THE 4220

Dismantling the Pistonphone Type 4220 is strongly discouraged. If dismantling is absolutely necessary to change a spare part, proceed as follows (refer to Fig.4.1).

1. Remove the coupler by unscrewing it from the 4220 body.

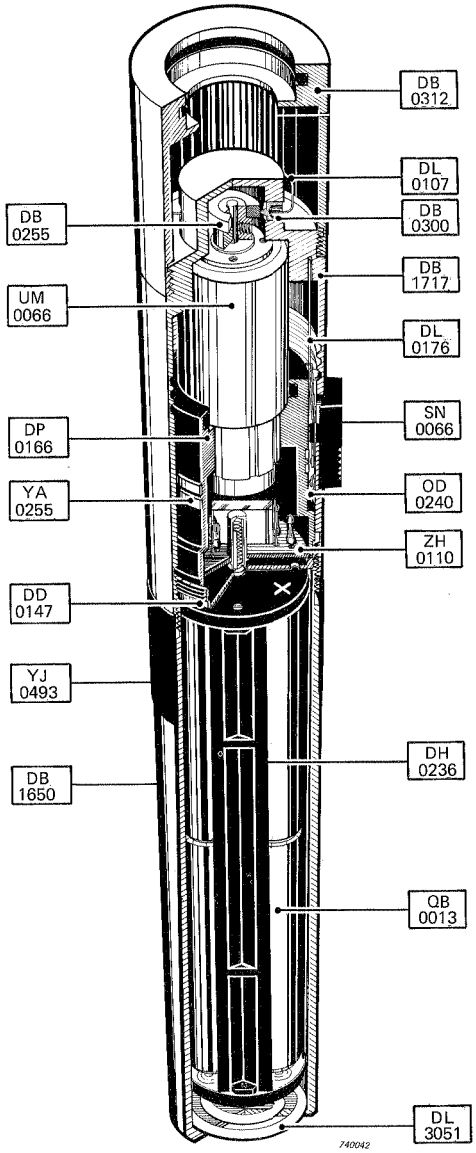

Fig.4.1. Part numbers of the 4220

2. Carefully remove the piston-retaining spring.

3. Unscrew the back cover (black) from the body of the 4220.

4. Push out the drive unit.

5. Carefully remove the two pistons.

Reassembling the 4220.

1. If necessary, the cam disc should be cleaned with a soft dry cloth.

2. Push the drive unit into the body.

3. Screw on the back cover.

4. Only if absolutely necessary, apply a minute drop of high quality oil to the cam disc (Esso "Univis" or Shell "Microtime type A Ultra Light").

5. Insert the two pistons and replace the retaining spring.

6. Screw on the coupler.

Note: The force of the retaining spring should be 20 g approximately. A lower force will cause distortion and a higher force produces excessive wear of the piston tips. Spare springs and pistons can be ordered separately (see parts diagram Fig.4.1).

⚠ **Caution:** Never touch the pistons while they are operating.

When assembly is complete, monitor the output waveform on an oscilloscope and check against another reference that the SPL is of the order of 124 dB. If one piston does not work, the SPL will be 118 dB.

To monitor the output waveform on an oscilloscope, a suitable microphone and preamplifier should be used. The procedure of section 2.1 should be applied except for points 5 and 6.