ENVIRONMENTAL INFLUENCES ON MICROPHONES AND SOUND CALIBRATORS

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1 INTRODUCTION

In order to make reliable acoustical measurements, the instruments used must have accurate calibrations that are traceable to national standards. Measurement microphones and sound calibrators are used to provide this traceability. These instruments are normally calibrated in the laboratory at close to reference environmental conditions. However, in use they may be required to operate over a wide range of environmental conditions, particularly if they are used outdoors. It is therefore important to consider the effects of environmental influences on these instruments. This paper describes the pressure, temperature and humidity dependence of measurement microphones and sound calibrators and how they are designed to minimize these effects.

2 MICROPHONES

2.1 Basic construction and operation

The type of microphones we are here concerned with are the measurement microphones specified in IEC 61094-1 and IEC 61094-4, and referred to as laboratory standard (LS) and working standard (WS) microphones respectively. They are often described as condenser or capacitor microphones because the basis of their operation is an air dielectric capacitor. The two capacitor plates are formed by the diaphragm, a thin stretched metal membrane which is exposed to the sound field and moves in response to changes in pressure, and the back plate, which is fixed in position and in many cases has holes in it to allow the free movement of air within the microphone capsule. An external polarisation voltage is usually applied to this capacitor to maintain a constant charge. Then, when the diaphragm moves in response to the sound pressure, the resulting changes in capacitance are transformed into voltage variations. Some microphones are pre-polarised by having the charge fixed into the materials. These do not need an external polarizing voltage.

The microphone capsules are cylindrical in shape and come in a number of sizes. IEC type 1 microphones are nominally one inch in diameter, type 2 a half-inch, type 3 a quarter-inch and type 4 an eighth-inch. Working standard microphones are of robust design, intended for use outside the laboratory. They are provided with a protection grid that covers the diaphragm in order to prevent damage (see figure 1). Laboratory standard microphones have been designed specifically for establishing primary standards, though they also find application elsewhere. As such they have a geometrically simple design and an exposed diaphragm, required for reciprocity calibration (see figure 2). The internal construction of the microphones are almost identical. The diaphragm forms part of the outer body of the microphone and the backplate forms the central output terminal. The back plate is supported in the main body of the microphone by a ring of material with high electrical insulation properties (typically it is made from silicone-treated quartz, synthetic sapphire or a synthetic ruby). This insulator then closes the space behind the diaphragm to form a back cavity within the microphone. It is important that the air pressure within the back cavity is the same as that outside, since variations in static pressure can be much greater than the pressures associated with sound. To achieve this pressure equalization a narrow vent connects the back cavity either to the back of the capsule, where it can be used with a dehumidifier, or through the side of the casing to the outside air[1]. The vent is designed to be effectively closed at normal operating frequencies, and is the primary reason that most microphones have a low frequency cut-off at around 2 Hz to 5 Hz.

The sensitivity of the microphone is governed by many parameters such as the size of the diaphragm, its mechanical properties such as tension and mass, the spacing between the diaphragm and backplate, the compliance and damping provided by the close back cavity, and the polarising voltage, where this is applied externally. The environmental conditions influence some of these parameters resulting in the microphone sensitivity having some corresponding dependence.

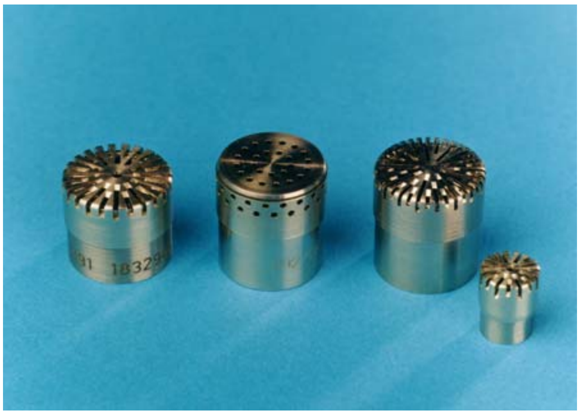

Figure 1. Working standard microphones

Figure 2. Laboratory standard microphones

2.2 Pressure Dependence

Static pressure affects the acoustical properties of the air enclosed in the back cavity of the microphone capsule but has no effect on the properties of the diaphragm itself. The air enclosed behind the microphone should be considered an integral part of the microphone since the sealed cavity presents an acoustic impedance to the diaphragm (predominantly a compliance at low frequencies) and thus influences its dynamic behavior. Static pressure influences both the mass and the compliance of the enclosed air but not its resistance. At low frequencies, the overall sensitivity of the microphone is therefore governed by the parallel combination of the compliances of the diaphragm and back cavity.[2] Now, the back cavity compliance is inversely proportional to the static pressure. An increase in static pressure therefore decreases the effective compliance (or increases its stiffness), making it less easy for the diaphragm to vibrate, effectively reducing the sensitivity of the microphone. The pressure coefficient, that is, the change in sensitivity for a given change in static pressure, is therefore negative at low frequencies. From measurements on typical samples of microphones it is found that the pressure coefficient generally lies in the following ranges in the low frequency region:

LS1 microphones: -0.01 dB/kPa to -0.02 dB/kPa

LS2 microphones: -0.003 dB/kPa to -0.008 dB/kPa[2]

The same data should be applicable to WS1 and WS2 microphones since they share a similar internal construction.

The precise geometry of the back cavity of the microphone has a large influence on the pressure dependence, particularly at frequencies greater than half the resonance frequency of the microphone. At these frequencies the dependency depends largely on the wave-motion in the cavity behind the backplate and so can be affected by details such as the holes in the backplate and the precise geometry of the cavity.[2] It cannot, therefore, be assumed that two microphones of the same IEC type but made by different manufacturers, will have the same characteristics.

At very low frequencies (2-5 Hz), the microphone's pressure sensitivity becomes independent of the static pressure because isothermal conditions will exist and thus decrease the compliance of the cavity.[2]

Changes in air density influence the speed of sound which needs to be taken into consideration during the pressure reciprocity calibration procedure.

2.3 Temperature Dependence

The temperature dependence of the microphones is governed by two effects. First, thermal expansion of the housing can slightly alter the separation of the diaphragm and backplate and, more significantly, increases the diaphragm tension, decreasing microphone sensitivity[2]. Second, the acoustical impedance of the back cavity is influenced by temperature, and as noted above, will affect the microphone sensitivity. This time the predominant factor is the air density, which decreases as the temperature increases. The compliance of the back cavity is also inversely proportional to density, so an increase in temperature causes an increase in compliance (or decrease in stiffness), resulting in an increase in the microphone sensitivity. At higher frequencies, the thin layer of air between the diaphragm and the backplate also has an influence[1]. Notice then that two effects produce changes in opposite directions. Through careful selection of materials and housing design, the microphone manufacturers can arrange for these two effects to produce changes of equal magnitude, thereby producing a microphone with a low overall temperature dependence. The low frequency temperature coefficient is typically 0 dB/K with a spread of $\pm$0.005 dB/K for both LS1/WS1 and LS2/WS2 microphones[2]. Changes in temperature also slightly affect the resonance frequency of the microphone, making the temperature dependence more influential at high frequencies.

If microphones are exposed to extreme temperatures they are likely to experience irreversible changes in sensitivity due to thermal expansion and the release of diaphragm tension that may occur as a result of it.

2.4 Humidity Dependence

When microphones are calibrated by the reciprocity technique, as described in IEC 61094-2, the humidity must be measured and taken into account in calculations of the speed of sound within the coupler, but the effect of humidity on the microphone sensitivity itself is too small to be measurable. Humidity affects the acoustic properties of the air in the microphone back cavity in the same way that temperature does. Both the air density and the speed of sound, and therefore the compliance of the back cavity, depend on humidity, but the effect is an order of magnitude smaller than temperature. For example a 30% change in humidity is equivalent in magnitude to only one degree Celsius[3].

Condensation inside the microphone can effect the electrical insulation between the diaphragm and backplate. This can be the cause of an increased noise level or microphone instability. Back vented microphones are designed to be used with dehumidifiers so that they can be used in very humid environments without suffering from these problems.

3 SOUND CALIBRATORS AND PISTONPHONES

3.1 Pistonphones

Sound calibrators are designed to produce a constant sound pressure level at a particular frequency. They are used for calibrating microphones and setting up sound level meters prior to use. Pistonphones are a type of sound calibrator that operate by means of the movement of small pistons. When a microphone has been coupled to a pistonphone, there is a sealed, air filled cavity within the device. The pistons oscillate in and out of the air filled cavity, creating a small volume displacement in the static volume. The sound pressure level within the cavity can be determined from the following equation:

$$SPL = 20\log\left(\frac{\gamma P\delta V}{V}\right) + 93.9794$$

where γ is the ratio of specific heats for the gas in the cavity, P is the static pressure of the gas in the cavity, δV is the change in volume due to the movement of the pistonphones and V is the total volume in the cavity. The numerical value of '93.9794' derives from the reference sound pressure needed to express the level quantity.

The sound pressure level generated by a pistonphone is therefore directly dependant on static pressure. Pistonphones are often supplied with barometers for this reason. In order to correct the sound pressure level to the value that would be obtained at standard pressure, a correction of – 20 log (P/P_0) must be applied, where P_0 is standard atmospheric pressure 101.325 kPa.

Temperature has a minimal effect on pistonphones. Thermal expansion causes changes in volume, but the effect is insignificant when compared with the effect of temperature on the microphones used in conjunction with the pistonphone. Temperature must be considered, though, when establishing the influence of humidity on a pistonphone. The humidity correction is a function of relative humidity, temperature and pressure; all of which influence the properties of the enclosed air.[4] Again, the effect is small and need only be considered if the pistonphone is to be used as a laboratory standard, class 0, instrument. Manufacturers provide data for humidity corrections in the manual for the instrument in question.

3.2 Sound Calibrators

Other types of sound calibrator operate by a variety of means but are designed to keep environmental influences to a minimum. Many sound calibrators make use of a feedback loop to maintain a constant sound pressure. The microphone to be calibrated is subjected to a sound pressure generated by a loud speaker. The sound pressure is monitored by the calibrator's reference microphone and corrected by the electronic circuit if necessary.[5] In this way, the required sound pressure level is maintained regardless of environmental influences and also changes in cavity volume due to applying differing microphone types. What small effects are produced by changes in pressure and temperature are due to their influence on the calibrator's reference microphone and only need to be considered when the calibrator is used under extreme temperature and pressure conditions.

Some older models, for example, the Brüel & Kjær type 4230, utilise a different technique. They have a low impedance driver which leads to a large effective volume. In this case the sound pressure is produced by an oscillating membrane. The low acoustic impedance is achieved by constructing the moving components of the device so that they resonate at the frequency the device is designed to operate at, typically 1000 Hz. When a microphone is coupled to the calibrator, it is close to the oscillating membrane so there is a small volume of air trapped between the two. The only part of the device that could be significantly influenced by static pressure and other environmental influences is the air cavity behind the oscillating membrane. In the same way as in the sealed cavity inside measurement microphones, the air pressure in this cavity effectively changes the stiffness of the membrane. In order to counteract this problem, a Helmholtz resonator, with a resonance frequency of 1000 Hz, is coupled to the cavity, giving the whole system a very low acoustic impedance at this frequency[6], thereby creating minimal influence on the operation of the sound source.

Given that sound calibrators have environmental dependence, it is necessary when specifying the performance of these to put limits on these dependencies. Such specification is formalised in BS EN 60942:2003, which specifies a number of classes of instrument to cover the range of devices found in practice, from laboratory standard devices to lower grade working devices. In each class it specifies the limit for the environmental dependency, for example for the Class 1 device, which might represent a high performance type of device that would nevertheless still be used in the field, the limits for operation within the environmental ranges 65 kPa to 108 kPa, -10 ^{o}C to +50 ^{o}C and 25% to 90% RH are as follows:

The frequency of the signal produced by the device must be within 1% of the frequency produced at reference conditions. Tolerance limits for the variation of total distortion and generated sound pressure level from their values at reference conditions are displayed in the table below.

Range of nominal frequencies (Hz)	Total distortion (%)	Generated sound pressure level (dB)
31.5 to < 160	4	0.5
160 to 1250	3	0.4
> 1250 to 4000	4	0.6
> 4000 to 8000	4	0.8
> 8000 to 16000	4	1.0

Within the environmental ranges 97 kPa to 105 kPa, 20 ^{o}C to 26 ^{o}C and 40% to 65% RH, there is also a tolerance limit for short term fluctuation of 0.2 dB between 31.5 Hz and 160 Hz and 0.1 dB from 160 Hz to 16000 Hz[7].

Some devices require corrections to be made in order to meet some of these tolerance limits. For example, as previously discussed, pistonphones require corrections to be made for the effect of static pressure. Devices of class LS and class 1 that require corrections to be made for static pressure are designated class LS/C and class 1/C and class 2 devices that require corrections for any environmental factor are designated class 2/C.

4 CONCLUSION

Traceability for airborne acoustical measurements is established through the calibration of microphones and sound calibrators. The operation of these instruments is affected by ambient temperature, static pressure and humidity, therefore corrections for these environmental parameters must be applied to the measurements made using these instruments to ensure accuracy. Microphones are particularly susceptible to changes in pressure: an increase in static pressure will cause a microphone to become less sensitive. Two temperature effects act in opposing directions, enabling manufacturers to design instruments that are almost temperature independent. The effect of humidity on microphones is negligible unless condensation forms. The sound pressure produced by pistonphones has a direct dependence upon static pressure whereas other types of sound calibrators have been designed to be pressure independent. Temperature and humidity have small effects on sound calibrators that can be ignored unless the device is to be used as a laboratory standard instrument.

5 ACKNOWLEDGEMENTS

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