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Temperature effects on the mechanical-acoustic properties of condenser microphones: experimental characterization

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Abstract

Condenser microphones are originally designed for airborne acoustic measurements. For this reason, their electro-mechanical behavior is well-known and characterized almost in atmospheric conditions. However, more and more applications, such as acoustic thermometry, gas metrology or thermoacoustics, require the use of electrostatic transducers (as acoustic transmitters or receivers) in gas conditions that differ significantly from atmospheric ones. Previous experiments using the electrostatic actuator technique evidenced the relevant influence of the static pressure and the type of gas on the frequency response of condenser microphones. The same technique is used here to characterize the mechanical properties of a 1/4" microphone's membrane in vacuum at temperatures between 80 K and 300 K. The resonance properties of the membrane are then obtained and expressed as function of the temperature. Thus, they are used in comprehensive models of condenser microphones whose validity as function of the temperature is experimentally checked. Also, an improved model of condenser microphone coupled to an electrostatic actuator is developed for the sake of this work. By improving the supporting models and experimental methods, this work is expected to drive the design of new electrostatic transducers and promote an advance of the calibration procedures, as required for specific applications.

Keywords: Condenser microphones, calibration, temperature, resonance of membranes

1 INTRODUCTION

The global behavior of measurement condenser microphones has been abundantly studied [1, 2, 3, 4]. This behavior is those of a circular metallic membrane, loaded by the thin air film between the membrane and the backplate, which is connected to a small back cavity. The validity of existing is checked experimentally almost in usual working conditions for such kind of transducers, i.e. in atmospheric conditions.

However, these electrostatic transducers, designed and optimized almost for airborne applications, are used in more and more applications, such as acoustic thermometry, gas metrology or thermoacoustics, in gas conditions that differ significantly from atmospheric ones [5, 6, 7]. For this purpose, their behavior is not known with a sufficient accuracy. Previous experiments using the electrostatic actuator technique evidenced the relevant influence of the static pressure and the nature of the gas on the frequency response of condenser microphones, which is consistent with the effects predicted by existing models [8, 3]. Nevertheless, these models still do not take into account the effects of the temperature on the mechanical properties of the microphone's cartridge and membrane.

The aim of this work is to provide new experimental data on the effects of temperature on the behavior of a microphone (in particular on its mechanical properties) in order to suggest some improvements to the models currently available, and even provide new ones, for the sake of applications requiring the use of electrostatic transducers in extreme or non atmospheric conditions.

In the present paper, the experimental techniques chosen for this work and the set-up carried out at the LCM are first described and few promising results obtained are then shown and commented.

2 EXPERIMENTAL APPROACH

2.1 Electrostatic actuator for relative calibration of microphones

Relative calibration of condenser microphones consists in determining its response to a pressure field, uniform across the membrane, as a function of the frequency. To achieve that, the electrostatic actuator is a simple and easy technique to carry out [9, 10, 8], requiring very few specific equipment.

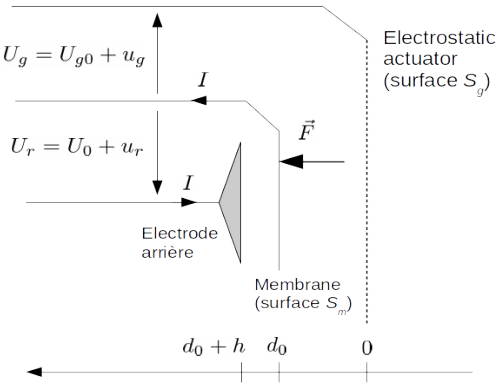

Figure 1. Relative calibration of a microphone using the electrostatic actuator technique.

As shown on Figure 1, the actuator is a grid placed in front of the membrane of the microphone at a distance d_0 (few millimeters). An oscillating voltage $U_g(t) = U_{g0} + u_g(t)$ is applied between the actuator and the membrane in order to have an electrostatic force on it

$$F(t) = F_0 + f(t) = -\frac{\varepsilon S_g}{2D(t)^2}\left(U_{g0} + u_g(t)\right)^2 . \tag{1}$$

The oscillating part $f(t)$ of this force simulates a pressure field on the membrane $p = f(t)/S_m$ assumed to be uniform. The voltage $U_r(t) = U_{r0} + u_r(t)$ is then measured at the output of the microphone, through its preamplifier (electrical input impedance Z_e). If required, the open-circuit voltage u_{r0} at the output of the microphone in response to the electrostatic actuator can be measured using the inserted voltage technique [11].

Finally, the response of the microphone to the actuator is proportional to its pressure sensitivity σ :

$$\frac{u_{r0}}{u_g} = -\frac{\varepsilon U_0}{d_0^2}\frac{S_g}{S_m}\sigma\frac{Z_A}{Z_A + Z_L} , \tag{2}$$

where Z_A and Z_L are respectively the acoustic impedances of the microphone and of the gas film between the membrane and the actuator. In atmospheric conditions, Z_L is assumed to be negligible compared to Z_A, that leads to

$$\frac{u_{r0}}{u_g} \approx -\frac{\varepsilon U_0}{d_0^2}\frac{S_g}{S_m}\sigma . \tag{3}$$

Actually, this method cannot be carried out to perform absolute calibrations because the distance d_0 between the membrane and the actuator cannot be measured with a sufficient accuracy. However, the frequency response of a microphone contains interesting information on the mechanical-acoustic behavior of a microphone, especially on its resonance properties. Moreover, the electrostatic actuator technique can be carried out in vacuum, allowing us to determine the mechanical properties of the microphone's membrane independently of its acoustic front and back loads.

2.2 Experimental set-up carried out for controlling temperature, pressure and gas conditions

Recently, experimental efforts have been done in order to characterize the effects of ambient conditions on the electro-mechanical-acoustic behavior of condenser microphones [8, 12]. These works all rely on the use of the electrostatic actuator technique, carried out in a pressure vessel allowing to perform measurements under various gas, pressure and temperature conditions.

The experimental set-up carried out in the present work is shown on Figure 2. A 1/2" actuator is placed on the top of a 1/4" measurement microphone (GRAS type 40BF). The microphone cartridge and its preamplifier are fixed in vertical position in a pressure vessel. The temperature regulation is achieved by a thermostated liquid bath of ethanol and water, liquid nitrogen or nitrogen vapors.

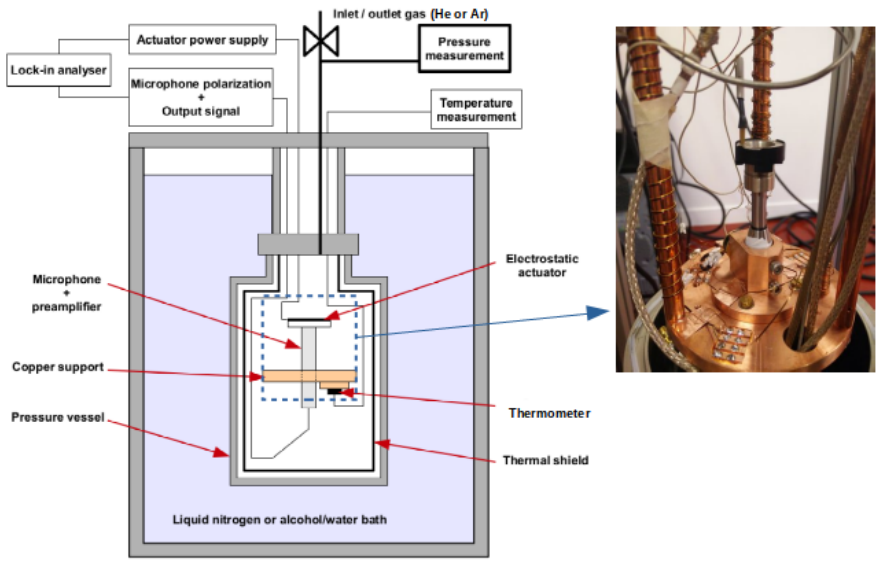

Figure 2. Experimental set-up carried out in order to characterize the effects of the gas, pressure and temperature conditions on the behavior of condenser microphones.

The pressure vessel can be filled with helium or argon gas, or set in vacuum. The static temperature inside the vessel is monitored by several thermometers thermally linked to the microphone.

The necessity of using long cables in such an experiment implies important to electrical perturbations caused almost by cross-talk. As a consequence, we chose not to polarize the electrostatic actuator: the membrane is then submitted to an equivalent acoustic pressure generated by the actuator at twice the frequency of the generator.

In order to avoid electric arching, the polarization voltage of the microphone is here 125, 100 or 50 V instead of 200 V.

The electric signals are generated and measured by a lock-in amplifier in a frequency range from 200 Hz to 100 kHz.

The inserted voltage technique has been carried out here in order to cancel the effects of the preamplifier on the response of the microphone to the electrostatic actuator.

3 INFLUENCE OF THE TEMPERATURE ON THE MECHANICAL PROPERTIES OF THE MEMBRANE

The response of the microphone to the electrostatic actuator has been measured in vacuum at several temperatures. The behavior of the microphone in these conditions is then reduced to those of a membrane in vacuum submitted to an oscillating uniform force field, its mechanical properties depending on the temperature.

The temperature range here is from about 80 K to 300 K, which is those of interest in low temperatures acoustic thermometry. Since the electric impedance of the preamplifier depends on the temperature, we noticed the use of the inserted voltage technique has a significant contribution in the measurement results [12].

This experiment first showed that the kind of microphone and preamplifier we used work at temperatures lower than 100 K, which has not been observed before to our knowledge. Regarding the results then obtained at several temperatures, the response of the membrane to the actuator in vacuum can be described as a simple resonant function, characterized by the resonance frequency f_0 and the damping ξ [13]. The values determined for these two parameters are plotted as functions of the temperature on Figure 3.

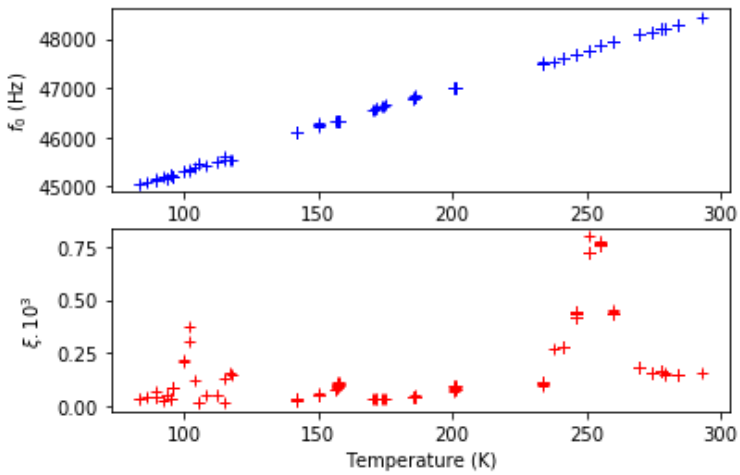

Figure 3. Measured resonance frequency and damping of the membrane of a microphone in vacuum as functions of the temperature.

These results highlight the great influence of the temperature on the resonance properties of the membrane. One can see three populations of points on each graph, related respectively to a specific temperature range and a dedicated system for the temperature regulation (liquid nitrogen, cold nitrogen vapor, liquid ethanol-water mixture). For practical reasons, the measurements in the lowest and highest temperature ranges have been performed before those in the temperature range from 120 to 220 K. It can then be noticed that the effects of the temperature on the properties of the membrane seem to be reversible.

The global trend for the resonance frequency f_0 of the membrane is a straight line. A least mean squares optimization lead to a slope of 16.1 Hz/K and 43755 Hz y-intercept. These parameters can now be introduced in existing modelling procedures [3, 4] for describing the global behavior of microphones, including the effects of the temperature on the gas properties and on the mechanical properties of the membrane.

The behavior of the damping ξ seems to be more complicated with local maxima and we hardly could suggest a function to describe this trend. Actually, it is not problematic since when using a microphone under gas pressure (even very low), the damping due to viscous and thermal effects in the gas film between the backplate and the membrane is much higher than the structural damping of the membrane.

4 CONCLUSIONS

The analysis of the whole experimental data set obtained here is still in progress for *(i)* characterizing the influence of the polarization voltage on the mechanical properties of the membrane and *(ii)* the global effect of the temperature on the mechanical-acoustic behavior of the microphone when used in helium gas. These experimental results should then be compared to those obtained by using modelling procedures already available, in which the effects of the temperature on the resonance frequency of the membrane are introduced, making use of the results in vacuum presented here.

However, these models do not take into account the acoustic behavior of the gas film between the membrane and the actuator, which effect should be negligible in atmospheric conditions, but significant at high static pressures. Then, an improved model of condenser microphone coupled to an electrostatic actuator is currently developed for the sake of this work relying on previous analytical advances [4, 15].

By improving the supporting models and experimental methods, this work is expected to drive the design of new miniature electrostatic transducers and promote an advance of the current microphones calibration procedures, as required for specific applications.

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