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THE NPL LASER PISTONPHONE

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1. INTRODUCTION

Accurate measurements of any kind need to be based on a consistent measuring system and have a line of traceability to a reference standard. In acoustics the primary quantity is sound pressure and the standard is realised in terms of the sensitivity of a condenser microphone. It is the task of the National Physical Laboratory to maintain this standard for the UK and to provide access to it through calibration services.

Condenser microphones can be calibrated with greatest accuracy by the reciprocity method using a closed acoustic coupler [1,2]. The method is now well established for one-inch and half-inch microphones and is used up to a frequency of 20 kHz. There is however a lower limit to the frequency range, which is set by how well a pair of microphones can be coupled by a small vented volume. For this reason reciprocity calibrations are not normally performed below 63 Hz at NPL. The assumptions and practicalities of the reciprocity method also limit the types of devices that can be calibrated. To provide standards below 63 Hz and to enable a wider selection of microphone types to be calibrated, a special pistonphone has been developed at NPL.

The so-called laser pistonphone is an absolute calibration device for measurement microphones. It operates at variable frequency and sound pressure level settings, the latter being calculable from laser interferometric measurements, hence the name of the device.

2. THE LASER PISTONPHONE

The laser pistonphone is similar in principle to commercially available pistonphones in that a uniformly distributed acoustic pressure is generated within a closed cavity by the sinusoidal motion of a small piston. The cavity of the laser pistonphone is cylindrical and is 60 mm in length and diameter, with a 15 mm diameter piston housed in one end face. The microphone port is placed half way along the length of the cylinder. With this geometry, illustrated in figure 1, operation up to 250 Hz is possible with less than ±0.03 dB uncertainty due to acoustic pressure non-uniformity in the cavity. The laser pistonphone is however primarily a low-frequency device and the lower frequency limit of operation is governed by the amount of pressure leakage that occurs around the microphone seal and from the gap between the piston and its guide. The limit is determined by measuring the time constant of the static pressure decay following a step input to the cavity, and is in the range 0.5 Hz to 1 Hz.

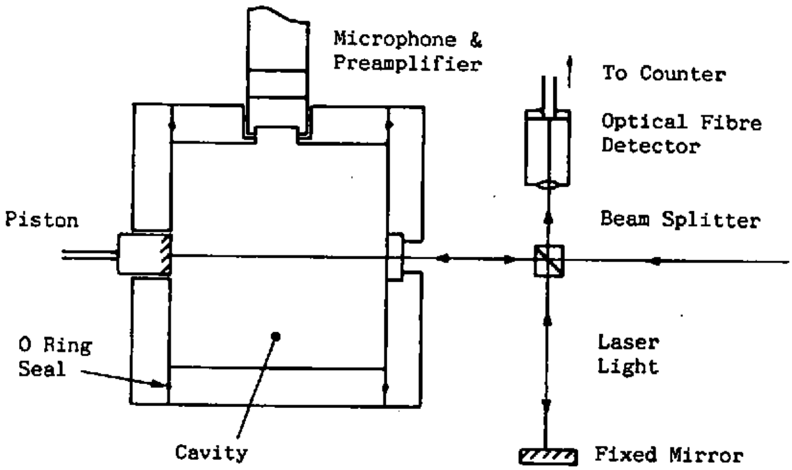

Figure 1. Layout of the laser pistonphone.

The sound pressure level generated is usually in the range 80 dB to 130 dB but a level exceeding 150 dB can be produced when necessary. The sound pressure can be calculated from the following equation, which is derived from the adiabatic gas law.

$$p = \frac{\gamma P_0 \pi d^2 \delta x}{4V}$$

where γ is the ratio of principal specific heats for air, P_0 is the atmospheric pressure, d is the diameter and δx the displacement of the piston, and V the volume of the cavity. A simple Michelson laser interferometer, employing fringe counting, is used to measure the displacement of the piston, which is of the order of 1 mm.

With these high sound pressure levels, the measurements are not affected greatly by external acoustic noise, but vibration is a potential problem. The pistonphone and interferometer are rigidly fixed to a common structure that eliminates relative movement between these two components, which would otherwise cause errors in the measurement of the cavity acoustic pressure. Further steps are taken to reduce vibration that might be picked up by the test microphone, and the whole assembly is mounted on an anti-vibration table.

3. APPLICATIONS OF THE LASER PISTONPHONE

There are several potential applications for a device such as this, and to allow it to be as versatile as possible the laser pistonphone was designed so that the main acoustic cavity is inter-changeable. A number of cavities have been manufactured to perform different tasks and others can be produced as applications arise.

3.1 Absolute calibration of microphones.

Two cavities with a very well defined shape and volume have been produced for determining the pressure sensitivity of laboratory standard one-inch and half-inch microphones. The open-circuit output voltage of the microphone is measured by the insert-voltage method and the acoustic pressure in the cavity is calculated from the measured displacement of the piston. This allows the pressure sensitivity of the microphone to be determined with an uncertainty of ±0.05 dB for frequencies between 63 Hz and 250 Hz, increasing to ±0.2 dB at 10 Hz and ±0.3 dB at 1 Hz. The major components of this uncertainty are uncertainties in the volume of the cavity, the diameter of the piston, and at very low frequencies, the pressure leakage from the cavity.

3.2 Calibration by comparison.

Measurement microphones can be calibrated by comparison with a reference microphone in a cavity that has two ports and allows two microphones to be exposed to the same acoustic pressure. This cavity can be adapted to accommodate most commercially available microphone types. Calibration by comparison achieves higher accuracy than absolute calibration for a non-standard microphone because the microphone itself may add an ill-defined and uncertain volume to the cavity.

Comparison calibrations have an uncertainty of ±0.06 dB at moderate frequencies, increasing to ±0.2 dB at 5 Hz and further still at lower frequencies. Although the acoustic pressure need not be determined in this application, and does not therefore contribute to the uncertainty in the calibration, the uncertainty in the sensitivity of the reference microphone significantly influences the overall accuracy. The reference microphone itself may have to be calibrated in the laser pistonphone, by the method given above, if the frequencies of interest for the test microphone lie below 63 Hz.

3.3 Other Applications.

As well as having applications in calibration, the laser pistonphone provides for a number of other uses. It can be used to study the low-frequency performance of microphones: with only the diaphragm exposed the pressure response can be studied, and by inserting the whole microphone capsule into the cavity, thus exposing the equalisation vent, the free-field response can be measured. Using a two-port cavity, the relative phase responses of a pair of microphones can be measured. The relative phase response is important in sound intensity measurement applications. The laser pistonphone has also provided an independent check on the accuracy of the reciprocity method of calibration, where preliminary measurements have shown agreement within ±0.05 dB in the frequency range 63 Hz to 250 Hz.

4. CONCLUSION

The laser pistonphone enables the frequency range for which sound pressure standards are held to be extended down to 1 Hz. It allows all types of microphones to be calibrated in the range 1 Hz to 250 Hz, either by absolute means or by comparison depending on the type of microphone. In addition a number of other facilities are provided for and the range of applications can be extended whenever necessary simply by designing appropriate cavities to perform the required task.

The laser pistonphone is now operational and available for use in measurement services from NPL.

5. REFERENCES

[1] INTERNATIONAL ELECTROTECHNICAL COMMISSION. 1971. Precision method for pressure calibration of one-inch condenser microphones by the reciprocity technique. IEC publication 327.

[2] INTERNATIONAL ELECTROTECHNICAL COMMISSION. Draft Document. Measurement microphones. Part 2: Primary method for pressure calibration of laboratory standard microphones by the reciprocity technique. Available from BSI as draft DC 89/21839.