A PIEZOELECTRIC SENSOR FOR PRESSURE MEASUREMENTS BEHIND A SHOCK FRONT

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The construction and measuring circuit of a pressure pickup designed for measurements in ionized gases behind a shock front are described. Calibration results are given, along with oscillograms of the pressure up to the arrival of the rarefaction wave.

The static pressure in a gas behind a shock front is one of the fundamental parameters characterizing the state of a gas flow under various interaction conditions. The most popular static sensors are the piezoelectric variety [1]. The use of piezoelectric transducers to measure pressures behind a shock front imposes a number of special demands on their design. These demands arise from the fact that a shock wave can cause the excitation of natural mechanical oscillations of the sensor casing and that oscillations can be produced by multiple reflections of the shock wave from the ends of the sensor. The principal method customarily used by researchers to attenuate this mechanical noise entails the use of acoustic waveguides in the form of rods of specific configurations and of various materials. In all the constructions used, the piezoelectric crystal is rigidly mechanically coupled with the transducer casing through the rod. This coupling is effected by the presence of tangential stresses at the attachment site of the crystal. In work with strong shock waves it is required, in addition, to isolate the piezoelectric crystal from the influence of light and heat fluxes.

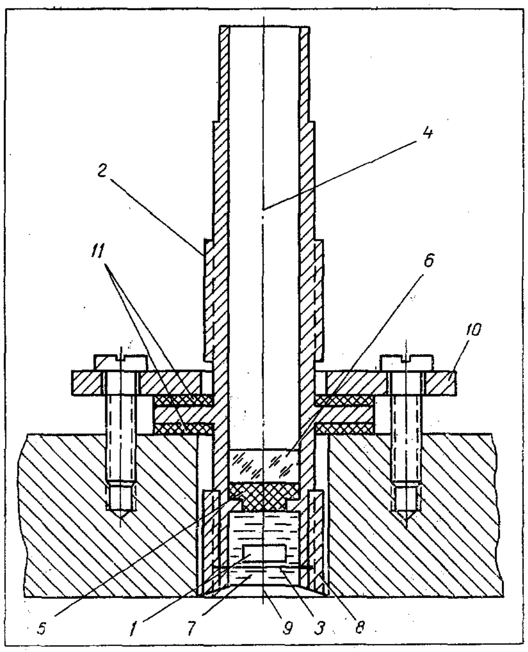

Fig. 1. Construction of the pressure sensor. 1) Piezoelectric element; 2) casing; 3) tension wire; 4) current lead; 5) insulator; 6) epoxy resin; 7) vacuum sealant oil; 8) cover; 9) diaphragm; 10) flange; 11) rubber spacers.

Below we describe a piezoelectric sensor construction (Fig. 1) in which practically complete isolation of the piezoelectric element from mechanical, optical, and thermal disturbances is guaranteed.

A piezoelectric element with a base diameter of 5 mm and height of 1 mm is suspended in its casing on two wires 0.05 mm in diameter. The wires are soldered with Wood's alloy in the center of one of the bases of the piezoelectric element. A current lead made of the same wire is soldered to the other base and runs out to the external cable through an opening in the insulator.

The casing is sealed by means of epoxy resin. The capsule, which is 12 mm in diameter and has a height of 15 mm, is filled with vacuum oil after the piezoelectric element has been fastened inside. A cover plate is screwed into the casing, drawing the diaphragm tight. The latter is made of silver foil 0.02 mm thick. The sensor is attached to the wall of the measurement chamber by means of a flange and two rubber spacers.

As a result of the absence of tangential stresses in the liquid the given construction completely eliminates the

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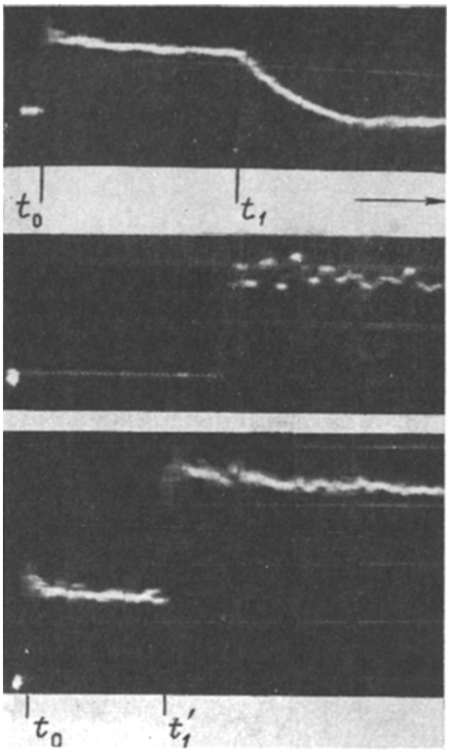

Fig. 2

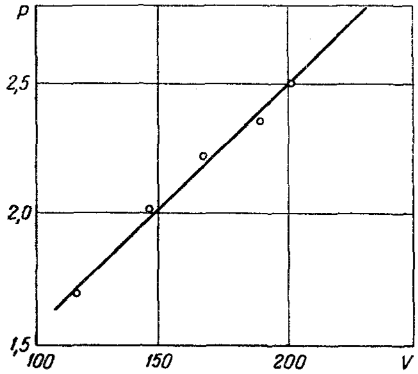

Fig. 3

Fig. 2. Oscillograms of pressures behind a shock wave.

Fig. 3. Calibration curve (P in atm; V in mV).

influence of mechanical stresses. The inclusion of the diaphragm and the small oil-filled gap scarcely diminishes the response of the sensor, but completely isolates the piezoelectric element from optical and thermal disturbances.

The time resolution of the sensor is determined by the diaphragm diameter. In our case, at a shock wave velocity of 2000 to 3000 m/sec it amounts to 2 to 4.5 μsec.

Oscillograms of typical signals recorded with the pressure sensor are given in Fig. 2.

The upper oscillogram is a record of a shock wave propagating in air with a Mach number $M_s = 1.4$; t_0 is the arrival time of the shock front, and t_1 is the arrival time of a rarefaction wave reflected from the bottom of the high-pressure chamber. The spike at the beginning of the signal is caused by the superposition on the fundamental signal of rapidly damped natural oscillations of the instrument, which, judging from their frequency, are determined by reflected waves from the ends of the capsule. The structure of the spike is clearly evident in the second photograph, which shows an oscillogram of the same process recorded with a faster sweep. The presence of the spike does not interfere with the observation of the flow pattern, because its amplitude is small in comparison with the useful signal amplitude. The lower oscillogram illustrates the flow process when a silencer is placed at the end of the shock tube. The time t_1' denotes the arrival of the reflected shock wave.

For quantitative measurements we calibrated the sensor in a shock tube in an air atmosphere. Both air and helium were used as the propelling gas. The pressure behind the shock wave was varied by variation of the incident wave Mach number and was calculated from the conventional relations [1]. In this mode of calibration the measurement error is determined by the error in the measurement of the shock wave Mach number and of the atmospheric pressure and normally does not exceed 10%. The calibration curve is given in Fig. 3.

The signals generated by means of the sensor are distinguished by a low noise level and a high stability. These characteristics make it possible to investigate not only the state of the gas near the shock front, but also to obtain dependable information on the pressure distribution throughout the entire accompanying flow domain, particularly in the presence of nonstationary interactions in crossed electric and magnetic fields. The sensor offers extremely useful potential applications.

LITERATURE CITED

1. A. G. Gaydon and I. R. Hurle, The Shock Tube in High-Temperature Physics, Reinhold, New York (1963).