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PIEZOELECTRIC PULSE TRANSDUCER WITH MATCHED AMPLIFIER FOR MEASUREMENT OF FAST VARYING PRESSURE

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A piezoelectric transducer with an electronic matching circuit has been built and tested for measuring the pressure behind a shock wave with a high time resolution. Here its construction is described and the test results are reported.

Intensive studies of shock waves have in recent years been stimulated by a tremendous interest in shock wave dynamics in liquids and gases as well as in hypersonic gasdynamics, high-temperature thermophysics, chemical kinetics, and magnetohydrodynamics. Many studies have dealt with the measurement of absolute pressure and of pressure variation profiles behind a shock wave. In most of those studies the authors used pressure gauges which they themselves had built. For such measurements one widely uses transducers where an electric signal is produced by deformation of an elastic element like a piezoceramic one [1-10]. Piezoelectric pressure transducers are wideband devices (with a high time resolution), inasmuch as deformations of a few microns are sufficient for polarizing the piezoelectric cell and, consequently, its inertia is not involved with large displacements of the center of mass but determined by the time in which its steady state of strain is reached.

These authors have developed and tested a pressure pulse transducer with a matching amplifier which ensures a microsecond time resolution in measurements of fast varying pressures. The piezoelectric transducer includes a matched acoustic absorbing rod (waveguide), as has been proposed [1-3], for eliminating the effect of the shock wave reflected by the faces of the piezoceramic cell. This transducer and the matching amplifier are simple in construction and ensure a high time resolution.

The construction of the pressure gauge is shown schematically in Fig. 1. Cylindrical specimens of grade TsTS-19 lead zirconate-titanate, 4 mm in diameter and 1 mm in wall thickness, were used here. One face of the piezoceramic cell 2 is soldered with Wood metal to the cylindrical zinc waveguide 3 and the other face is fastened with a thin conductor 8 to the brass case 1. With the aid of a rubber gasket 4 and a nut 5, waveguide 3 together with the piezoceramic cell 2 already soldered on and with conductors 6, 8 is inserted into and centered in the case. The clearance space inside the case is filled with beeswax so that vibrations of the case will not be recorded by the instrument. In order to minimize electric pickup, no window has been provided for soldering the conductor 6 to the coaxial connector 7. Conductor 6 is grade LÉShO enamelled single-silk 7 × 0.07mm Lietz wire.

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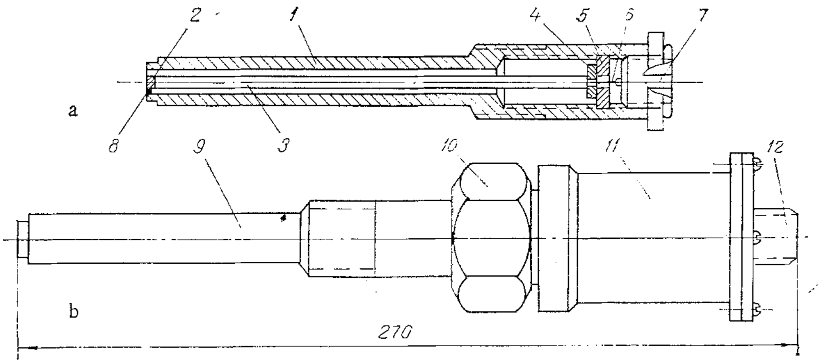

Fig. 1. Construction of piezoelectric transducer (a) and view of transducer with matching amplifier (b): 1) case; 2) piezoceramic cell; 3) waveguide; 4) rubber gasket; 5) nut; 6, 8) connecting conductors; 7) Sh1 connector (Fig. 2); 9) piezoelectric transducer; 10) nut; 11) container with matching amplifier; 12) Sh2 connector (Fig. 2).

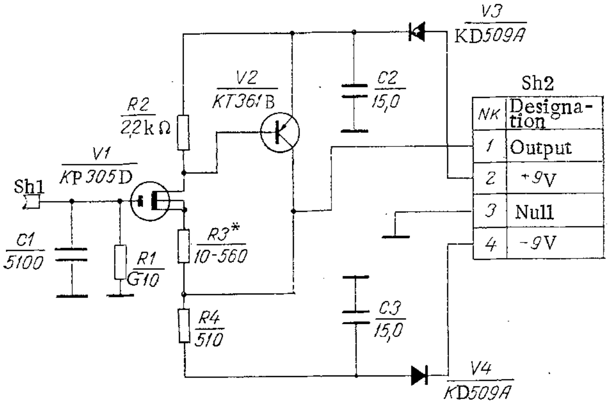

Fig. 2. Basic electric circuit of the matching amplifier.

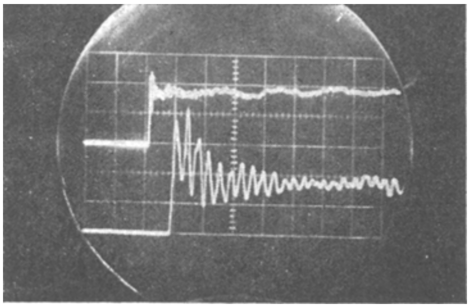

Fig. 3

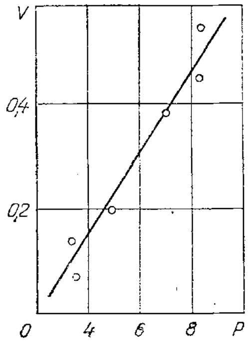

Fig. 4

Fig. 3. Comparison of pressure oscillograms recorded by our transducer (upper beam) and by a Kistler Co. piezoelectric transducer during an experiment in a shock tube; sensitivity of the vertical-deflection amplifier 200 mV/div, sweep 20 μsec/division, pressure behind the shock wave 1 MPa.

Fig. 4. Calibration curve of piezoelectric pressure pulse transducer; voltage (V), pressure $P \cdot 10^5$ Pa.

According to measurements, the layer of solder between the piezoceramic cell 2 and waveguide 3 is not thicker than $5 \cdot 10^{-3}$ cm. The transmission coefficient K_t of this solder film was calculated according to known expressions [5, 11]. Assuming that the wavelength in the film is 0.5 cm, which corresponds to the condition that the leading edge of the strain wave constitutes a quarter of a sine wave, and assuming that the width of this edge is equal to the mean rise time of the transducer signal (1-1.5 μsec), we find that in the given construction with the acoustic impedances of the ceramic, the solder alloy, and the waveguide material $24 \cdot 10^5$, $(19-36) \cdot 10^5$, and $33 \cdot 10^5$ $g \cdot cm^{-2} \cdot sec^{-1}$, respectively, the transmission coefficient of the solder film remains $K_f \geq 0.97-0.98$ over the entire $(19-36) \cdot 10^5$ $g \cdot cm^{-2}$ sec^{-1} range of its acoustic impedance. This estimate agrees with experimental data obtained by measuring the ratio of amplitudes of modulating signal fluctuations to the amplitude of the useful signal on oscillograms taken during recording of pressure variations in a shock wave. In our experiments this ratio was 2-3%.

The cylindrical zinc waveguide, 150 mm long and 4 mm in diameter, was produced by casting. With a waveguide of this length, a reflected signal was recorded after ≈ 100 μsec with an amplitude not exceeding that of the original signal by more than 5-7%.* Estimates of the time resolution Δt achievable with a transducer of this construction, in measurement of varying pressures which load the entire surface of the piezoceramic cell simultaneously, indicate that $\Delta t \leq d/C = 0.5$ μsec is feasible with a piezoceramic cell $d = 1$ mm thick and a velocity of sound $C = 3.1 \pm 3\%$ km/sec in grade TsTS-19 material.

It is well known that in the simplest situations the width of the leading edge of the transducer output signal,† which corresponds to the deformation time of the piezoceramic cell, depends on the same variables. According to measurements of the leading edges of signals from transducers mounted on the lateral surface of a shock tube, their width lies within the 1-5 μsec range. It is noteworthy that such a transducer can resolve pressure variations in time finer than Δt too, but for this the oscillogram must be split into two segments and the initial segment of length Δt must be processed by the already known method [2].

For the purpose of fulfilling certain requirements with respect to transducer impedance and load resistance R (ensuring a functional correspondence between variations of the applicable pressure and of the voltage across R), we have developed a matching amplifier according to the basic schematic diagram in Fig. 2. Its input impedance, measured on the discharge curve of a charged calibrating capacitor (with leakage resistance of capacitor and switch not lower than 10^{10} Ω) is at least 10^8 Ω.

Pressure transducers thus assembled in sets with an individual matching amplifier each were calibrated in a shock tube according to an already known procedure [2, 3]. Their sensitivity was found to be within 0.4-0.6 V/MPa. Typical pressure oscillograms recorded simultaneously with our transducer and a Kistler Co. piezoelectric transducer during an experiment in that shock tube are shown in Fig. 3; the calibration curve of such a transducer is shown in Fig. 4. It appears here that with a Kistler Co. transducer, which uses a quartz crystal, the ratio of amplitudes of parasitic modulating fluctuations to the amplitude of the useful signal on an oscillogram exceeds 20-30%. According to the graph in Fig. 4, the deviation of experimental points from the mean (calibration) curve does not exceed ± 5%. Results of calibration of 13 transducers with individual matching amplifiers indicate that their calibration curves remain linear up to a 10-MPa pressure behind the shock wave, such a pressure being attainable in our experimental shock tube.

In conclusion, we will note that the mechanical strength and the life of such transducers can be improved by the use of an electroconductive adhesive based on grade ÉD-20 epoxy resin with grade NPK fine-disperse nickel powder filler [8] instead of solder for the interconnections. The sensitivity of transducers with such interconnections remains within the same range as that of transducers where interconnections have been made with a low-temperature solder.

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*In order to remove the limitation on the measurement time imposed by the finite length of the waveguide, it is necessary to build a transducer with the back end of the rod absorbing (dissipating) the energy of the strain wave. Such attempts to simulate a semiinfinitely long waveguide have also been made [5, 6, 9].

†The problem of distortion of a shock wave in a transducer due to three-dimensional effects has not been given sufficiently thorough treatment in the references cited here, but the results of those studies do not indicate that this problem is a serious one.

NOTATION

d, thickness of the piezoceramic cell, mm; C, velocity of sound in the ceramic, km/sec; Δt, time resolving power of the transducer, μsec; and K_f, transmission coefficient of the solder film.

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ANALYTICAL METHOD OF CALCULATING THERMAL PROCESSES AND THEIR EFFECT ON EMISSION IN SOLID-STATE LASER WITH NATURAL COOLING

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Analytical expressions are derived for calculating the change in energy characteristics of a solid-state laser with natural cooling due to heating and thermal deformation of the active medium.

The intense heat generation in components of a solid-state laser and the significant effect of thermal processes on the emission [1, 2] call for their special analysis. Most studies made till recently dealt only with thermal processes in lasers with forced cooling. The interaction of emission processes with thermal processes is most complex in lasers with natural cooling [4, 5], but this case has not been studied sufficiently. Meanwhile, thermal processes are most pronounced in such lasers and have here a definite effect on the emission.

Operation of a laser with natural cooling is characterized by a relatively low intensity of heat transfer and, as a consequence, a long transient period. This causes the emission characteristics of the laser to change continuously from pulse to pulse, until either a thermal steady state or cutoff of emission is reached. The more important laser characteristics in this case are the limiting pulse repetition rate f_l at which the laser can operate in the steady state without emission cutoff and the limiting operation time before emission cutoff τ_l, the latter depending on the repetition rate. These parameters must be estimated for predicting the

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