AUTOMATED DEVICE FOR MEASURING THE ELASTIC PROPERTIES OF METAL WIRES IN THE REGION OF ELASTIC AND PLASTIC DEFORMATIONS

A. I. Korobov, Yu. A. Brazhkin, and A. N. Ékonomov

An automated experimental device for comprehensive measurement of the elastic properties of metal wires under strong, nearly rupturing deformations is described. The device is equipped with a computer and can measure simultaneously the deformation of and acoustic-wave velocity and amplitude in metal wires of various diameters as functions of the applied force. The measurement results determine the static and dynamic Young's moduli as functions of deformation.

Today, considerable attention is being devoted to the acoustic properties of metals under considerable, nearly rupturing deformations. Defects accumulate in the materials studied, which greatly affect the acoustic properties of the materials. These studies are of considerable interest to specialists in nondestructive testing in establishing a correlation between the strength characteristics of metals and their acoustic properties [1, 2]. The creation of plastic deformations in metal specimens while simultaneously exciting acoustic waves in them involves certain experimental difficulties. Of interest are thin metal wires, which have a number of advantages for the study of acoustic properties: first, it is fairly simple to prepare a practically unlimited number of identical specimens of various materials of any length; and, second, these specimens have a small cross-section, which makes it easy to create considerable stresses (up to rupturing) in them and to produce high-intensity acoustic waves with a transmitter of relatively low electrical power.

For comprehensive studies of the acoustic properties of metal wires over a wide range of deformations (up to plastic), we developed a computer-equipped automated experimental device. A diagram of the device is shown in Fig. 1; it includes a system for creating controlled deformations in the specimen under tension and an automated ultrasonic apparatus.

The system for creating specimen deformations is based on a standard CAMAC crate. The metal wire 4 (henceforth, the specimen) is attached between a lower bracket 3, located on a stand 1, and a upper attachment platform 5. The platform can slide vertically along two guide rods 40 cm long practically without friction. The guide rods are attached to a special frame on the housing of the apparatus (the frame and rods are not shown in Fig. 1). The position of the frame on the housing can be changed in 6-cm steps, so that the distance between the lower bracket 3 and the platform 5 can be varied from 10 to 120 cm.

The force $F$ applied to the specimen 4 is varied by changing the weight of the tank 6, which is connected through a pulley system to the upper platform 5. The tank's weight is varied by adding or removing water. The maximum force applied to the specimen is 200 N. The rate of change of the applied force can be changed by changing the rate of filling (emptying) of the tank. The force is monitored by a DPU-0.02-7 dynamometer 7 with a range of 0–200 N. This force-application system makes it possible to create in a specimen with cross-section $S = 1 \text{ mm}^2$ controlled stresses $\sigma = F/S$ in the range of 0–200 MPa. The measuring element in the dynamometer is a calibrated elastic steel ring whose deformation is a linear function of the force applied to it. The deformation of the ring is measured by a linear differential transformer (LDT) 8, which is an electromechanical device that produces a dc voltage that is proportional to the displacement of the probe [3]. The voltage is measured by an analog voltmeter and sent in parallel to a 12-bit analog-to-digital converter (ADC) 9, which is con-
Fig. 1. Experimental device: 1) stand; 2) ultrasound sending transducer; 3) lower attachment of wire specimen; 4) specimen; 5) upper movable attachment with ultrasound receiver; 6) tank; 7) dynamometer; 8) instrument with inductive transducer for measurement of force $F$; 9) analog-to-digital converter; 10) instrument with inductive transducer for measurement of specimen elongation $\Delta L$; 11) ultrasonic device; 12) computer.

The sensitivity to changes in applied force is 0.25 N, and the reduced relative error of force measurement does not exceed 1%.

The application of force $F$ moves the platform 5 and increases the length of the specimen 4. The displacement of the moving platform (i.e., the specimen elongation $\Delta L$) is measured by a second LDT 10, which converts the absolute elongation of the specimen to a dc voltage, which is measured by an analog instrument and sent through the ADC 9 to the computer 12. The sensitivity of the LDT is 5 V/mm. To increase accuracy, each change in specimen length is measured 100 times and then the results are averaged. This substantially reduces the effect of vibrations on the measurement results, and the error of specimen-length measurement does not exceed 0.5 μm.

The propagation time and amplitude of acoustic waves in the specimen are measured simultaneously with its length. Acoustic measurements are performed by an automated ultrasonic device operating in the pulsed mode 11. The device measures the amplitude of an acoustic signal with an error of not more than 2% and its propagation time with an error not exceeding 0.1 nsec [4].

All measurements are performed automatically. The rate of water delivery into the tank is set by a valve to create a slowly varying force $F$, and a program is launched for simultaneous measurement of the force applied to the specimen, the change in its length, and the amplitude and propagation time of acoustic waves $\Delta \tau$ in it. These data are sent to the computer for processing and documentation. The duration of one measurement cycle, in which the controlled parameters are practically unchanged, does not exceed 1 sec. The measurement cycle is repeated after a time interval set at the beginning of the experiment from the computer keyboard (usually, 10–15 sec). The duration of a single experiment, up to specimen breaking, is 3–4 h. More than 1500 measurement cycles are run in this time.

This device was used to study copper wire with diameters $d = 0.75$ and 0.9 mm. The initial wire length before measurements $L = 110$–115 cm. The wire specimen was attached by conical caps soldered to both ends, which served simultaneously as acoustic-wave concentrators. Piezoelectric acoustic transducers 2, which excited and received acoustic waves in the specimens, were attached to these concentrators by means of salol. The ultrasonic apparatus operated in the pulsed mode. The sending transducer received radio-frequency pulses with a certain duty factor. The receiving transducer observed several acoustic pulses. Measurements of the time $\tau_0$ between two successive pulses and their amplitudes allowed evaluation of the absorption and velocity of acoustic waves in the undeformed copper wires $v_0$. The acoustic-wave velocity was determined by the formula $v = 2L/\tau_0$, the absorption, as $\alpha = [20\log(A_n/A_{n+1})]/2L$, where $A_n$ and $A_{n+1}$ are the amplitudes of two successive acoustic waves.