UTILIZATION OF THE ELECTRON-INERTIAL EFFECT IN SHOCK LOADING TO MEASURE ROD STRAIN

Yu. G. Kashaev, S. A. Novikov,
and V. A. Sinitsyn

UDC 531.78.781

A coil with a large quantity of wire turns was set into rapid rotational motion and abruptly braked in the widely known tests of Tollmien [1]. By using a galvanometer connected to the coil leads, the magnitude of the current caused by the inertial motion of the free electrons relative to the ions of the crystal lattice was measured. The charge separation thus caused results in the origination of an electric field decelerating the electron motion. Consequently, the electron motion will be as if they were acted upon by an electrif field of intensity E defined by the relationship

$$-eE = -mw, \tag{1}$$

where e and m are the charge and mass of the electron, respectively; and w is the acceleration during braking ($w < 0$).

A detailed examination of the electron-inertial effect is given in [2]. An expression can be obtained from (1) for the current in the loop:

$$i_+ = \frac{m}{e}\frac{S}{\rho}w, \tag{2}$$

where S is the rod cross section and ρ is the specific resistivity.

Using the data in [3], it can be shown that (2) is even applicable for the case of shock loading of a rod in the elastic strain domain.

The electron-inertial effect was investigated in metal rods under impact in [4]. The current was measured by using a solenoid within which was the rod being investigated. It was shown, for example, that under the impact of a Textolite by a copper rod the magnitude of the current in the latter reaches several milliamperes, i.e., is a quantity easily measurable.*

Direct measurement of the time dependence of the acceleration $w = f(t)$ is quite convenient for strain investigation.

It can be shown from (2) that the strain of a rod in the elastic domain is determined by the expression

$$\varepsilon(x, t) = \frac{ke\rho}{mSc}\int_0^\tau i_+ dt,$$

where c is the speed of sound and k is a calibration factor.

As is known, investigation of the dynamic strain is conducted in the majority of cases by using strain gauges which are glued to the surface of the structure being investigated. The dynamic compression and tension diagrams for rods are recorded by the same method (see [5], for instance).

---

*In particular, it is proposed in this paper to use this effect to determine the strain under impact.

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 139-143, March-April, 1977. Original article submitted April 6, 1976.

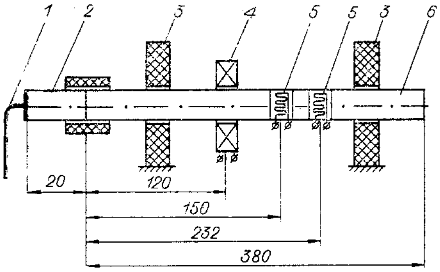

Fig. 1

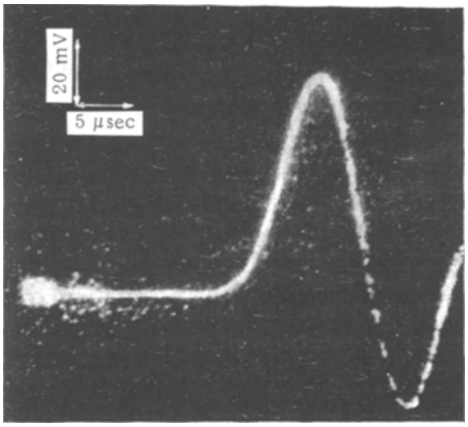

Fig. 2

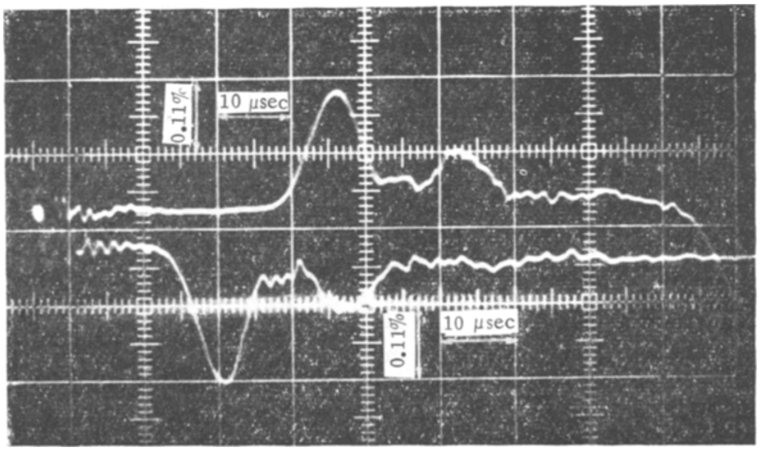

Fig. 3

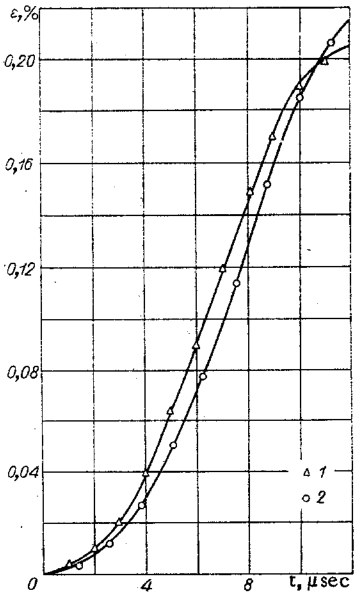

Fig. 4

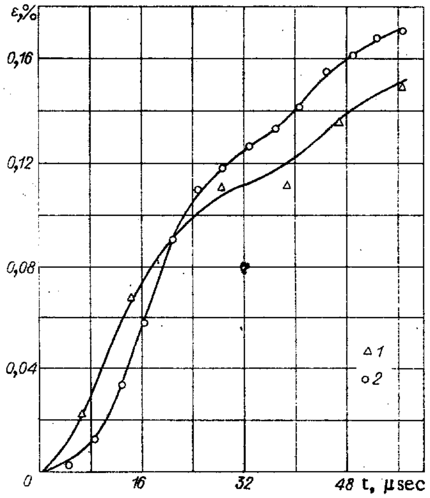

Fig. 5

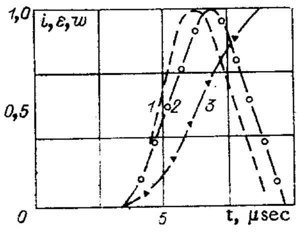

Fig. 6

Utilization of the electron-inertial effect is hence of great interest for the investigation of the dynamic strains of rods of materials to whose surface it is impossible to glue strain gauges (possessing poor adhesion to glues, for example, or strongly heated materials).

Certain results of using this effect to investigate the behavior of metal rods during the propagation of elastic waves excited by the explosion of a small quantity of explosive are presented in this paper.

The test diagram is presented in Fig. 1. A titanium rod 6 (α-phase) of diameter $\phi = 13.7$ mm and specific resistivity $\rho = 55$ $\mu\Omega \cdot$ cm was selected for the measurements in the first series of tests. The rod was loaded by exploding a layer of high explosive 1 glued to a steel impactor 2 of the length $l = 20$ mm. The oscilloscopes were triggered from the pulse of the detonator ignition through a delay line. The strain of the rod during wave propagation was recorded by the strain gauges 5 of the 2FKPD-5-100 brand, and the electron acceleration current by the inductive transducer 4. The whole assembly was mounted on polyfluoroethylene resin supports 3. A ferrite ring of NM wound with $n = 80$–100 turns of copper wire was used as inductive transducer.

The ferrite ring with the wire turns was shielded by aluminum foil from the influence of external electromagnetic fields, and a 2-mm-wide annular slot was made in the shield on the rod side.

The inductive transducer was used in the current transformer mode with the load resistor $R_l = 50$ Ω during the measurements. Before the measurement, the transducer was calibrated at frequencies $f = 10$–100 kHz according to the current transmission factor.

It was shown during the experiments that magnetization of the ferrite cores occurs; hence, it was necessary to demagnetize them by an alternating current with amplitude damping to zero before each test.

The maximum difference between values of the strain in the rod measured in the same test by using electrical strain meters and the inductive transducer was 7.5% in this series of experiments.

A steel rod of the brand ZOKhGSA of 13.7-mm diameter and 45 $\mu\Omega \cdot$ cm specific resistivity was selected for measurement in the second series of tests. A 20-mm-thick foam-plastic washer of density $\gamma = 0.57$ g/cm^3 was mounted between the impactor and the rod and was used to extend the shock pulse. The maximum difference between the values of the strain measured in the very same test by the two methods mentioned was not more than 14.7% in this series of tests. Typical "acceleration–time" and "strain–time" oscillograms are shown in Figs. 2 and 3, respectively.

Results of processing these oscillograms in the form of the dependences $\varepsilon(t)$ are represented graphically in Figs. 4 and 5, respectively, for the first and second series of tests, where the curves 1 correspond to measurements obtained by using the electric strain meter and the curves 2, to measurements obtained by using the inductive transducer.

The curve $\varepsilon(t) - 3$ corresponding to measurements obtained by using an electrical strain meter, the curve $w(t) - 1$ obtained by differentiating the curve $\varepsilon(t)$, and the curve $i(t) - 2$ corresponding to the electrical signal recorded from the inductive transducer are presented in Fig. 6. It is seen from a comparison of the curves for $w(t)$ and $i(t)$ that the character of the record of the electrical signal recorded from the current transformer $i(t)$ is similar in shape to the acceleration wave $w(t)$.

The experiments conducted show that the electron-inertial effect during shock loading can be used for contactless measurements of the strain for high-speed testing of materials.

LITERATURE CITED

1. I. E. Tamm, Principles of the Theory of Electricity [in Russian], Nauka, Moscow (1966).
2. I. M. Tsidil'kovskii, "Electrons and holes in an inertial force field," Usp. Fiz. Nauk, 115, No. 3 (1975).
3. R. H. Parmenter, "The acousto-electric effect," Phys. Rev., 89, No. 5 (1953).
4. B. N. Stikhanovskii, "On the origination of electric current during impact on metal and semiconductor solids," Izv. Sibirsk. Otd. Akad. Nauk SSSR, Issue 8, No. 3 (1973).
5. A. P. Bol'shakov, S. A. Novikov, et al., "On obtaining tension diagrams of specimens under explosive loading," Zh. Prikl. Mekh. Tekh. Fiz., No. 1, 184 (1975).