OBTAINING HIGH PULSED PRESSURES

V. G. Belan, A. E. Voitenko, and A. I. Ivanchenko

Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Vol. 9, No. 1, pp. 95-97, 1968

An apparatus for the magnetic compression of hollow metal cylinders (metallic theta pinch), built at the Institute of Nuclear Physics, makes it possible to transmit considerable amounts of energy, initially stored in a capacitor bank, to the accelerated metal [1,2].

The apparatus is shown schematically in Fig. 1, where C is the capacitor bank, 1 is the discharger, 2 is a solenoid, 3 is the liner (diameter 119 mm, length 150 mm, wall thickness 1-3 mm), and 4 is the solid compressed rod (diameter 15-40). The capacitor bank employed has a capacitance $C = 6 \cdot 10^{-2}$ F at a voltage V = 4 kV. The total inductance of the discharge circuit L = 50 cm. Under ordinary experimental conditions the weight of the copper or aluminum liner accelerated toward the axis is about 200 g at a velocity on the order of 10^5 cm/sec. The discharge current, passing through a single-turn coil, creates an accelerating magnetic field in the gap between the coil and the liner. The ratio of wall thickness to skin layer is such that during the acceleration interval the field has almost no time to penetrate into the interior cavity of the liner. The pressure exerted by the accelerating magnetic field on the outer surface of the liner is about $2 \cdot 10^3$ atm.

The apparatus is chiefly intended for experiments on plasma compression [1]; however, the possibility of electromagnetic acceleration for a considerable mass of metal to a high velocity makes its use possible for a number of other experiments.

In particular, it is possible to obtain under laboratory conditions pressure pulses exceeding 10^5 atm, which usually can only be obtained with condensed explosives [3]. The high pressures occur in connection with impact deceleration of the accelerated liner on a metal rod mounted coaxially with the liner (Fig. 1).

Figure 2 shows half a solid copper rod compressed under these conditions and then cut in two along a plane at right angles to the longitudinal axis. Rupturing of the solid metal and the formation of a cavity took place in the second phase of the process—during sudden relief of the external pressure. The slightly deformed end of the rod was outside the liner and did not experience direct impact.

The pressure at the liner-rod contact boundary at the moment of impact, calculated in the acoustic approximation which applies well under the conditions in question, is given by [4]

$$p = \rho_1 D_1 u \left(\frac{\rho_2 D_2}{\rho_1 D_1 + \rho_2 D_2} \right),$$

where ρ is the density, D is the speed of sound in the metal, u is the velocity of the projected liner, and subscripts 1 and 2 relate to the liner and the rod, respectively. For the steel rod employed, a copper liner, and a liner velocity of $0.7 \cdot 10^5$ cm/sec the above formula gives a pressure of about $1.3 \cdot 10^5$ atm.

Fig. 2

To measure the pressure we used the method described in [3,5]. The rod was made of low-carbon steel of "steel-3" grade. After impact the rod was cut, and the surface of the cut was polished and etched so that a macrograph could be taken. The parts of the metal where the pressure exceeded $1.3 \cdot 10^5$ atm underwent structural changes clearly apparent in the macrograph [5].

A macrograph of a steel rod, obtained by the method described, is shown in Fig. 3. The initial diameter of the rod was 15 mm. The blackened areas correspond to regions where the pressure exceeded the above-mentioned critical value of $1.3 \cdot 10^5$ atm; there are three separate areas of blackening because, in this experiment, there was no azimuthal symmetry. Figure 4 presents micrographs (magnification 1300×) of regions (a), where the pressure was subcritical and there were no structural changes, and (b), where the pressure was greater than the critical value and structural changes did take place.

The duration of the pressure τ is on the order of the sum of the times required for the deceleration wave to pass through the liner wall and for the expansion wave to pass in the opposite direction, i.e., $\tau \approx 2\delta/D_1$. At the moment of impact the thickness of the liner wall $\delta \approx 0.5$ cm, and, correspondingly, $\tau = 2$ μsec.

The method used to determine the pressure is a threshold method and does not make it possible to determine by how much the pressure actually obtained exceeds the critical value of $1.3 \cdot 10^5$ atm. Clearly, under the existing experimental conditions the pressure does not greatly

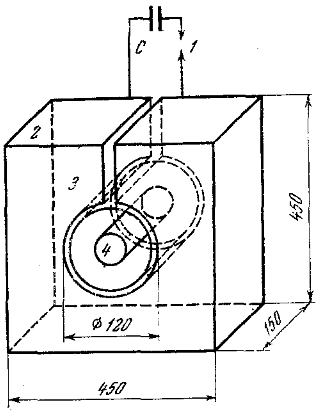

Fig. 1

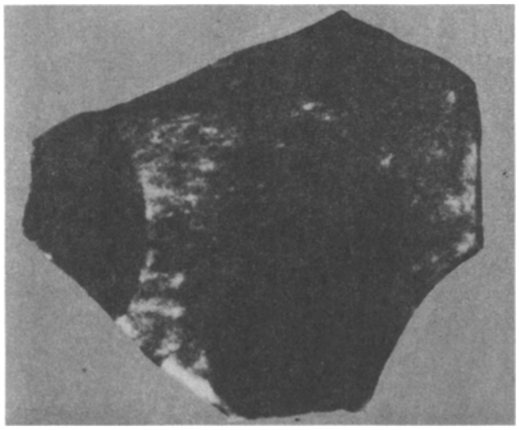

Fig. 3

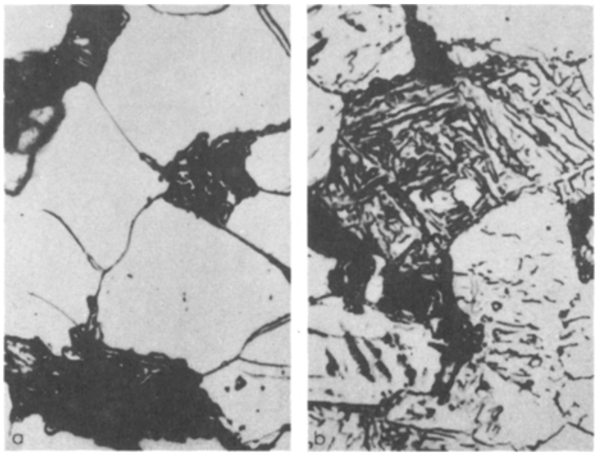

Fig. 4

exceed this value. If the symmetry of the liner motion could be improved, there would be some hope of obtaining a cylindrical shock wave inside the rod and an increase in the pressure as this wave converged on the axis. Pressures at the center of the rod on the order of $3 \cdot 10^5$ atm might be obtained in this way.

The described method of obtaining high pressures can be useful in conducting certain physical experiments at high pressures, for example, in investigating structural changes in solids. The compressed specimen can easily be intensely heated or cooled, placed in a magnetic field, etc. The method might also be useful in solving engineering and technical problems: the synthesis of artificial materials, explosive welding, etc.

The authors thank S. G. Alikhanov for his assistance with the experiments and M. P. Erastov and T. M. Sobolenko for preparing the micro sections.

REFERENCES

1. S. G. Alikhanov, G. I. Budker, A. V. Komin, V. A. Polyakov, and B. S. Estrin, "Experiments with dense, hot plasma," Proc. 7-th Intern. Conf. on Phenomena in Ionized Gases, Belgrade, vol. 1, 1966.

2. S. G. Alikhanov, G. I. Budker, G. N. Kichigin, and A. V. Komin, "Metal shell collapse in a magnetic field," PMTF [Journal of Applied Mechanics and Technical Physics], no. 4, p. 38, 1966.

3. L. V. Al'tshuler, "Use of shock waves in physics," Uspekhi fizicheskikh nauk, vol. 83, no. 2, p. 197, 1965.

4. Ya. B. Zel'dovich and Yu. P. Raizer, Physics of Shock Waves and High-Temperature Gasdynamic Phenomena [in Russian], Fizmatgiz, 1963.

5. L. V. Al'tshuler, D. M. Tarasov, and M. P. Speranskaya, "Deformation of steel by explosion-created shock waves," Fizika metallov i metallovedenie, vol. 13, no. 5, p. 738, 1962.

22 June 1967 Novosibirsk