

New method of the polymeric material properties experimental investigation under powerful energy flux impact

**B A Demidov¹, V P Efremov², Yu G Kalinin¹, E D Kazakov¹,
S Yu Metelkin³, V A Petrov¹ and A I Potapenko³**

¹ National Research Center “Kurchatov Institute”, Kurchatov Square 1, Moscow 123182, Russia

² Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhorskaya 13 Bldg 2, Moscow 125412, Russia

³ 12 Central Scientific Research Institute of the Ministry of Defense of the Russian Federation, Sergiev Posad, Moscow Region 141307, Russia

E-mail: evgenische@gmail.com

Abstract. Investigation of the polymeric material properties under powerful energy flux impact is relevant as for basic research (mathematical modeling of polymeric materials behavior in extreme conditions, testing the state equations), as for practical applications (for testing of protective coatings for space research and laboratory facilities). This paper presents the results of experimental studies of the interaction of polymeric materials with a relativistic electron beam produced by a high-current electron accelerator Calamary. Calamary facility provides a wide range of electron beam parameters: diameter 10–15 mm, the voltage on the diode up to 300 kV, the current through the diode up to 30 kA. New method of beam–target interaction area measurement was developed. The original method for the mechanical kick impulse measuring based on piezoelectric vibration sensor was presented. The dependence of the kick impulse from the power flux was obtained.

1. Introduction

One of the most important questions in the field of Power Interaction with Matter researches is the dependence of mechanical response from energy flux on the sample surface. These investigations are especially important for polymeric materials, which are used in protection shields for space and laboratory experiments [1]. Researches carried out in our laboratory demonstrated that materials with similar chemical composition may have very different response to powerful pulse impact [2, 3]. These phenomena were not made a forecast by mathematical modeling. For this reason experimental research of the different polymeric material properties under powerful energy flux impact is very relevant both for applications and mathematical models verification.

One of the most important parameter of mechanical reaction, which can be measured, rather simply is the mechanical pulse. It is possible to correlate one with the kinetic energy of matter sublimed from the sample surface for rather small energy fluxes.

Further results of experiments on interaction of an electron beam with a target from epoxy are given. The choice of material is concerned with its importance in different applications and



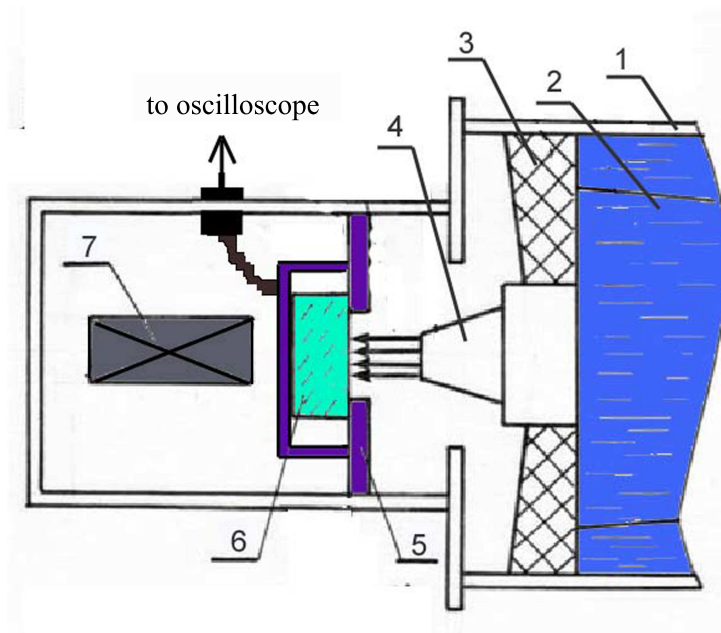


Figure 1. Scheme of Calamary accelerator: 1—accelerator chamber; 2—distilled water; 3—insulator; 4—cathode; 5—anode block with impulse detecting scheme; 6—target; 7—pinhole camera.

with existence of worked out equations of state for the polymeric materials such as epoxy [4, 5]. The main purposes were working off a technique of mechanical impulse measurement in the electron beam–target interaction experiments and research of the target impulse dependence from the energy flux.

2. Experimental set up

Experiments were carried out on Calamary electron accelerator. The scheme of experiment is presented in figure 1.

Voltage impulse on the diode was formed by the double water line with the electric length of 70 nanoseconds loaded from the Pulsed Voltage Generator. Current via the diode of the accelerator was measured by the low-inductive shunt and voltage on the diode by a capacitor divider. The experiments were made at currents via the focusing diode up to 30 kA at electrons energy up to 300 keV; current impulse duration on FWHM was about 100 ns. Epoxy target was placed to anode block, which was made of impulse detector (figure 2).

Basic element of the detector is the metal disk 1 pressed on the periphery by a nut 2 to the rubber laying 3 condensing on vacuum placed in a ring flute of output block 4 accelerators. The studied sample 5 produced in the shape of a disk with a diameter of 35 mm is placed to the special socket 6. At pulse impact of any force for a sample the metal disk starts fluctuating and amplitude of fluctuations is registered by means of a piezoelectric sensor 7 with the socket for output signal.

Piezoelectric sensor was preliminary calibrated for wide range of impulse volume. Metal balls of different mass (2–45 g) were dumped on the target surface placed in anode block from heights from 1 to 5 m. Balls bound height was measured, the signal from a piezoelectric sensor was registered. So the impulse values for different sensor amplitudes were detected. The calibrating plot of the impulse detector is presented on figure 3.

The period of detectors disc fluctuation is about 1 ms. This value is much more than ball-

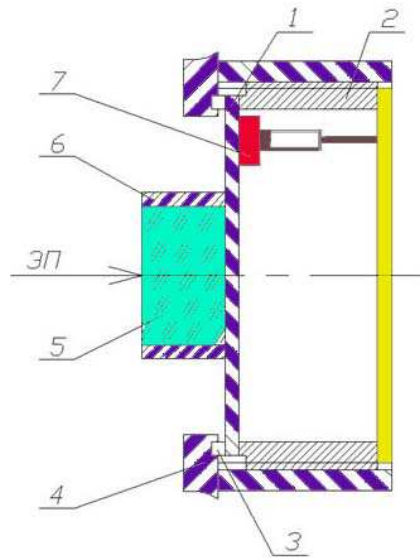


Figure 2. Impulse detector scheme.

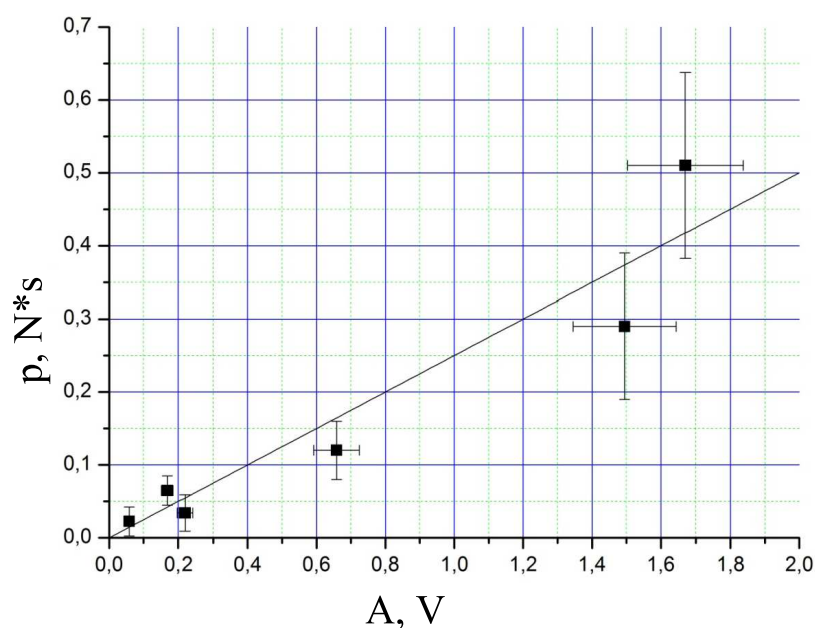


Figure 3. The calibrating plot of the impulse detector.

target interaction time and then electron beam–target interaction time. Also values of impulse in calibration and in experiments are in the similar range. So this method of detector calibration is rather correct.

New method was suggested for the beam-target interaction area measurement. Special sandwich scheme of pinhole-camera registration was applied (figure 4). This scheme provided area measurement in wide range of energy fluxes. The profile of interaction area was taken in two perpendicular flats (figure 5a) and its diameter was measured as arithmetical average between FWHMs (figure 5b).

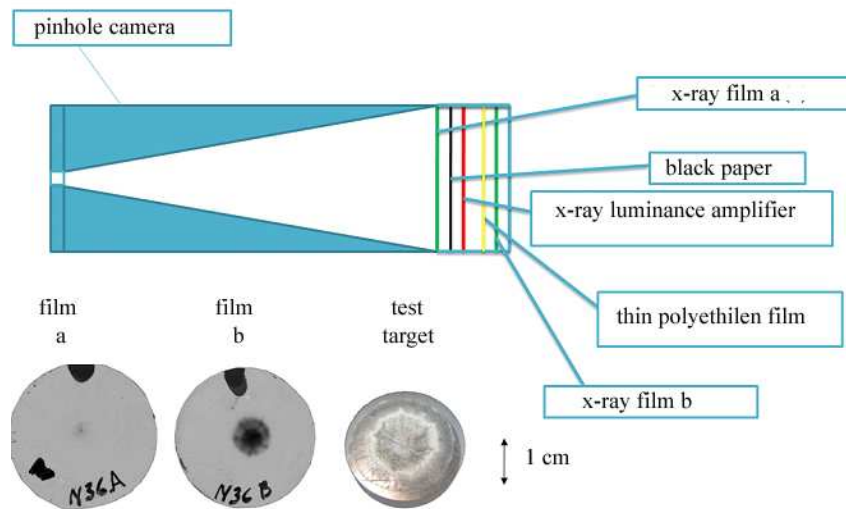


Figure 4. Scheme of beam-target interaction area measurement and the image example.

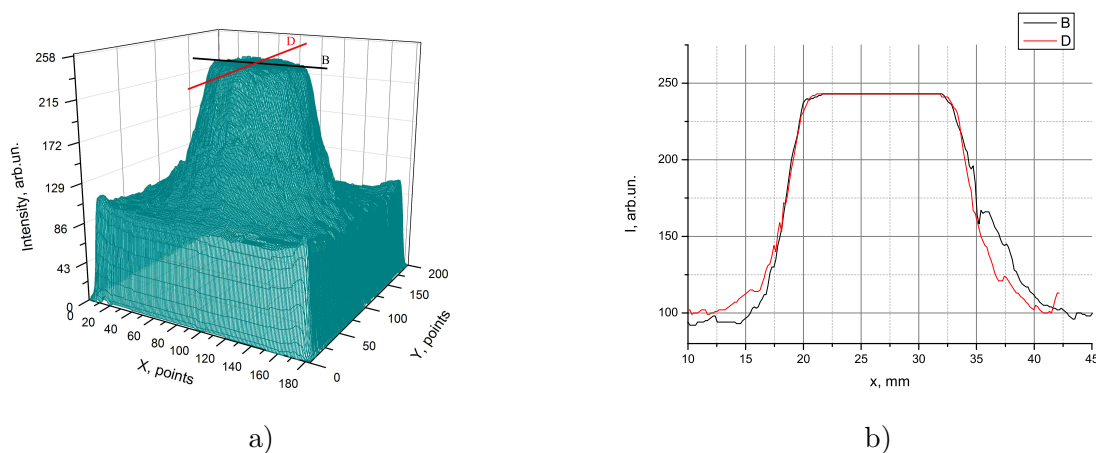


Figure 5. (a) 3D image of the interaction area. B and D—flats of densitometry. (b) Densitograms of pinhole images.

3. Experimental results

In experiments parameters of an electron beam changed in rather wide range. Beam current changed in the range of 9–27 kA, voltage on the diode — 150–310 kV. Duration of an impulse made ≈ 100 ns. Thus diameter of a bunch changed slightly and the area of interaction with a target made in the majority of experiments of about 1 cm^2 . Thus power stream density on a surface of a target varied in the range of $1.3\text{--}10 \text{ GW/cm}^2$. Characteristic temporary dependence of current, voltage (figure 6a) and the power escaped in the diode (figure 6b) are presented below.

Voltage measured by a capacitor divider on the double forming line includes an inductive component. This was taken in to account in electron energy calculation. As results of our experiments, several important relationships were obtained. These phenomena could be used for explanation the special features of epoxy target behavior under the powerful energy flux impact.

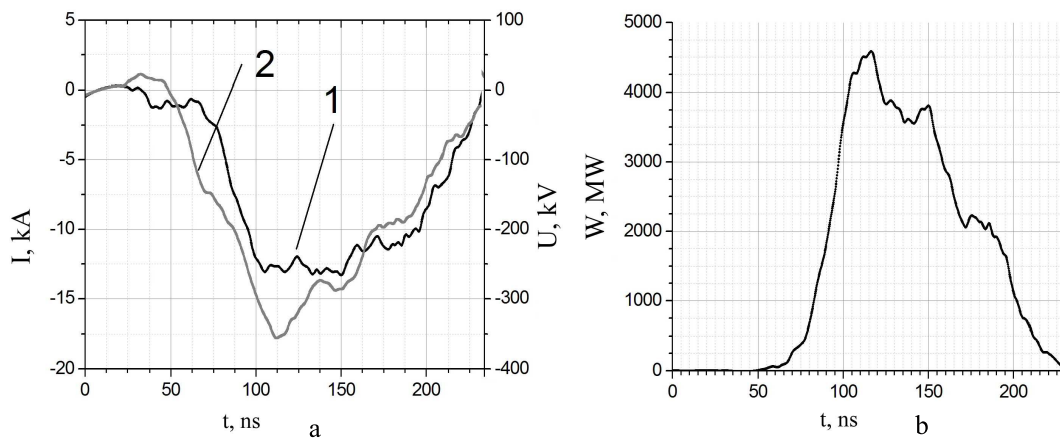


Figure 6. Example of (a) current via diod (1) and voltage on diod (2); (b) power of the beam.

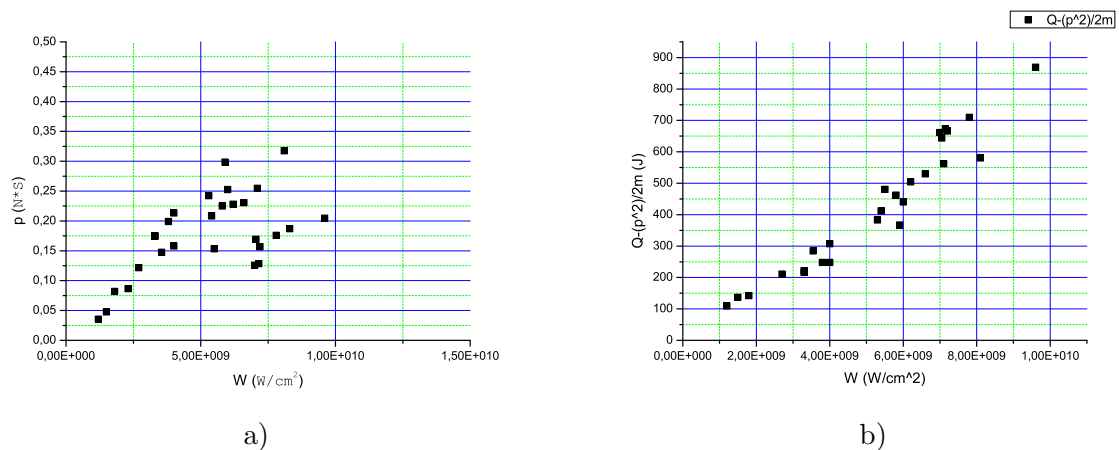


Figure 7. (a) Impulse dependence from the energy flux. (b) Non-mechanical energy dependence from the energy flux.

Figure 7a demonstrates the dependence mechanical impulse from energy flux. Grow of impulse is slowing for rather big energy fluxes. It could be concerned with the energy losses, which were not according to mechanical response (ionization, plasma heating etc) (figure 7b).

4. Conclusion

New methods of a mechanical impulse measurement and beam-target interaction area measurement were presented. Researches epoxy target response to the powerful energy flux impact Slowing of impulse grow for large energy flux was demonstrated. Most likely, it is connected with increase losses of energy on excitement, ionization and heating of the plasma target scattering from a surface.

Acknowledgments

This work was partially supported by grant of RFBR No. 15-02-03544.

References

- [1] Demidov B A *et al* 1979 *Atomnaja Energija* **46** 100
- [2] Demidov B A *et al* 2008 *J. Surf. Inv. X-ray, Synch. Neutr. Tech.* **8** 55
- [3] Demidov B A *et al* 2009 *J. Surf. Inv. X-ray, Synch. Neutr. Tech.* **9** 1
- [4] Bushman A V *et al* 1994 *Khim. Fizika* **13**(1) 103
- [5] Lomonosov I V *et al* 1995 *Khim. Fizika* **14**(1–3) 51