HIGH-POWER PROTON IRRADIATED SOLID STATE ROTATING NEUTRON TARGET: FIRST TESTS OF CONVERTER MATERIALS

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Abstract

Scheme and first experimental results of thermo-mechanical tests are presented for materials proposed for the production of high-power solid state rotating neutron target. Operation conditions are simulated with the high power electron beam that bombards the samples made of material under study. Scheme and principles of experiment are described. Results of first tests of high temperature MPG-6 graphite samples are presented. Methods and principles of further experiments are discussed.

1 INTRODUCTION

Series of experiments with samples are proposed to study the acceptable operation conditions for various materials intended for neutron converter production. The sample of cylindrical shape is placed in vacuum chamber and irradiated by the electron beam. It is necessary to control the beam current and energy, as well as temperature distribution over the sample surface. Measured are the maximum admissible power and power density, which can be accepted and radiated by the sample. This scheme of experiment makes possible to determine both maximum admissible thermal load and material properties, such as thermal radiation ratio, thermal conductivity, ultimate strength, on the basis of measured temperature distribution over the sample surface. It is also possible to work out the basic principles of materials tests before the converter manufacturing.

2 EXPERIMENTAL DEVICE

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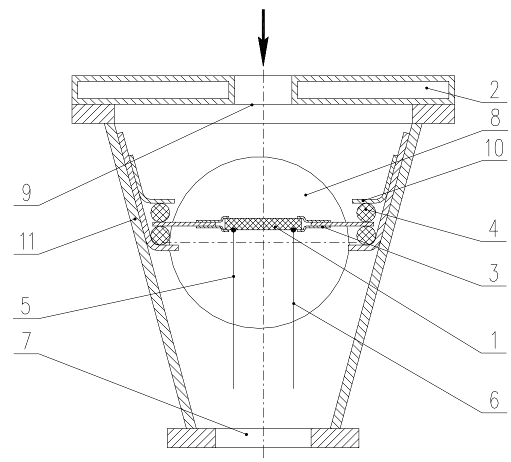
Fig.1 shows the installation layout and a view of experimental device. Holders (3) of sample (1) are set on the ceramic insulators in order to prevent the electric contact between the sample and grounded vacuum chamber (11). The electron beam hits the sample from above through the window (9) in the input flange (2), that connects the chamber with the electron accelerator.

Provided are following:

- thermocouple (5) – for sample temperature control;
- discharge conductor (6) - for measurement of electric current in the sample, induced by the electron beam (current collection);
- optical window (8) - for sample telecontrol;
- accelerator control system - for accelerated beam current and energy control.

The beam position and size are controlled by magnetic correctors and accelerator focusing system respectively.



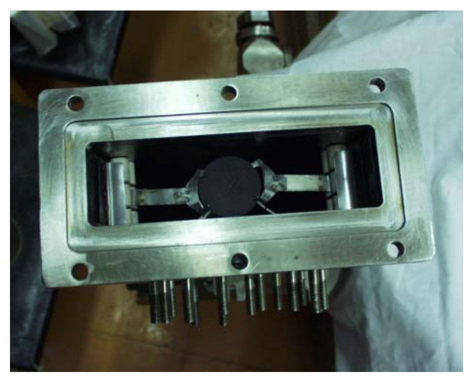


Figure 1. Installation layout (top) and view of experimental device (bottom). 1 – sample, 2 – input flange, 3 – sample holders, 4 – insulators, 5 – thermocouple, 6 – discharge conductor, 7 – pumping flange, 8 – optical window, 9 – input window, 10 – insulator holders, 11 – vacuum chamber

Experiments were carried out on ELV-6 accelerator [1-4], which was developed and manufactured in BINP. The accelerator can produce the continuous electron beam in energy range 0.5-1.5 MeV, with a current from a few μA up to 50 mA. The beam has Gaussian transverse distribution of current density, its diameter can be varied from 3-5 mm to 4-5 cm. Electron beam parameters listed above are used for simulation of the sample heating-up by the proton beam with required energy and power.

3 EXPERIMENTS AND RESULTS

The experimental check-up of the thermal and thermo-mechanical calculations performed to define the target operation conditions is of great significance. If one knows the beam current distribution and its energy, one can determine the distribution of heat power deposited in the sample. The calculated distribution is then compared with the measured one; both the technique of calculation and thermal parameters of the material can be specified. Finally, one can compare the calculated stress in the sample with the experimental one to specify the sample's lifetime.

The material study by means of electronic microscope is also done before and after heating-up aimed at a research of material structure changes affected by the heating-up. A number of samples made of ^{12}C (standard graphite and MPG-6 graphite) are manufactured for the experiment.

First experiments were done aimed at test of experimental scheme itself and working-out the principles of heating-up, measurements, and data processing. A sample made of MPG-6 graphite was 45 mm in diameter and 2 mm in thickness. The sample temperature was controlled by the platinum-rhodium thermocouple, the current collection was measured using the shunt resistor. Visual control was carried out by TV camera and attenuating filters. The electron beam energy was 1.4 MeV during experiment.

The current transverse distribution in the electron beam was preliminary measured. The round beam had Gaussian distribution with $\sigma = 8.25$ mm. The beam was then focused on the sample center by magnetic correctors, and gradual rise of its current was started. Maximum current measured in the sample was 273 μA.

In order to define the original heating power by current collection, the simulation of electron beam pass through the sample was done with the use of GEANT package and experimental data. It showed the residual of 23.5% of beam electrons and 57% beam energy losses in the sample. Thus the total heating power was 927 W. The distribution of heating power density is shown in Fig.2, above. The numerical simulation of temperature distribution over the sample was done on the basis of these data, results of simulation are presented in Fig.2, below. Maximum temperature detected on the sample axis 1.3 mm deep down its surface was around 1570^0C, minimum - on the sample edge - 1217^0C. Maximum temperature gradient appeared to be around 20^0C/mm.

According to the temperature distribution obtained, thermo-mechanical stress in the sample was estimated in the approach of a disk that is uniformly heated in thickness. Result of mechanical calculations is presented in Fig.3. It is seen, that maximum stress value was 8-10 MPa. This value is far enough from ultimate strength for MPG-6 graphite, but close to calculated stress for converter operation conditions.

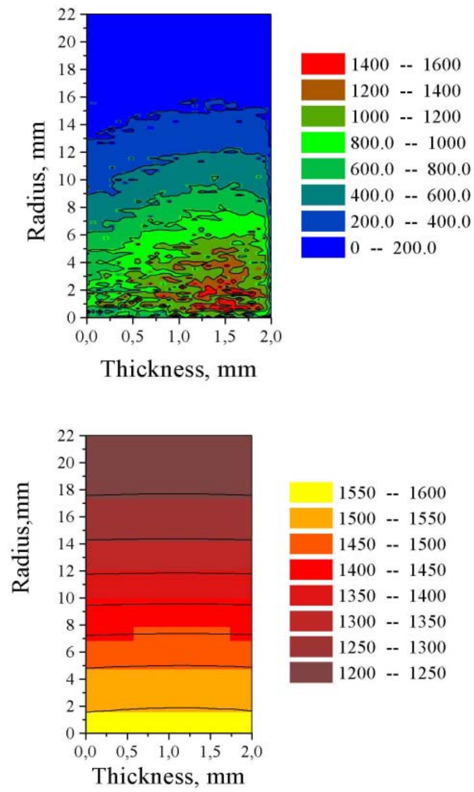


Figure 2. Distribution of heating power density (W/cm^3, top) and distribution of temperature (^{0}C, bottom) over the sample heated by electron beam, ^{0}C.

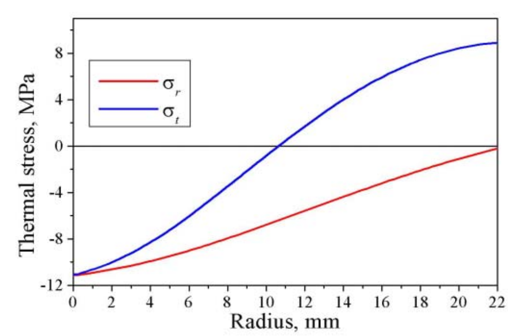


Figure 3. Radial σ_r and tangential σ_t stress in the sample vs. radius.

Fig.4 shows pictures of sample, obtained from TV camera monitor, at different heating power. The attenuated optical filter was set in front of the camera objective. Current collection 273 μA was detected on the sample during experiment, but after 30 min of operation under working conditions the frame started to lose its mechanical strength, and the experiment was stopped. Nevertheless, the sample stood the heating with no destruction.

Study of samples with the use of electronic microscope showed:

- The microstructure of heated sample's surface is quite uniform despite the non-uniformity of its brightness;
- Surfaces of heated and control samples are quite different - size and specific area of heated sample's pores located on the surface are larger than those of control sample. Moreover, there was no any sharp insertion observed on the heated sample's surface. However, these differences may be explained by removal of insertions and fragments appeared in pores (and closing them) due to sample mechanical treatment.
- Picture of sample break showed the identity of material structure for heated and control samples: differences were observed only at a few microns deep down the sample surface.

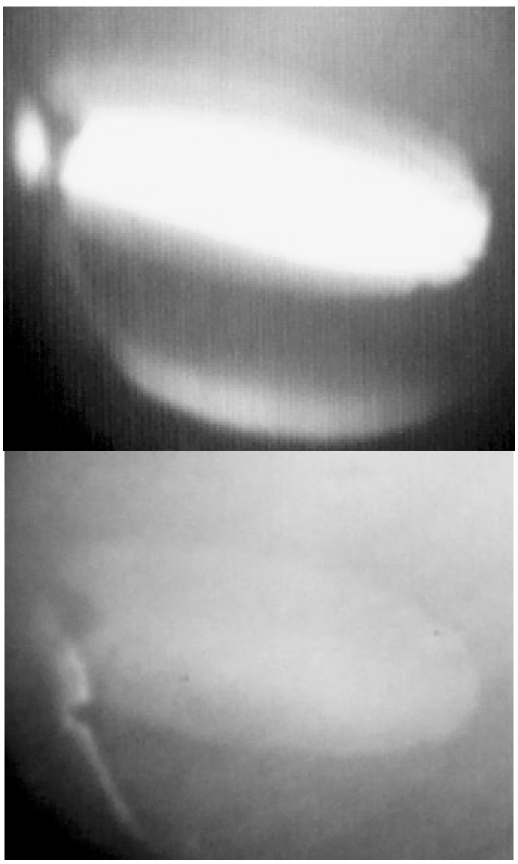


Figure 4. Pictures of MPG-6 graphite sample heating by electron beam. Top - current collection 158 μA (estimated heating power 504 W), bottom – current collection 273 μA (heating power 927 W, through the optical filter).

4 CONCLUSION

First tests of samples heated by the electron beam showed the validity of chosen experimental methods. The sample made of MPG-6 graphite stood the heating-up to 1600^{0}C with no destruction and significant change in its internal structure. Maximum power density appeared to be around 250 W/cm^2, the cubic density of power deposition reached 1.5 kW/cm^3, thermo-mechanical stress in the material was around 10 MPa, which is close to calculated operation conditions for neutron converter.

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