PROJECT OF ROTATING CARBON HIGH-POWER NEUTRON TARGET. RESEARCH OF GRAPHITE PROPERTIES FOR PRODUCTION OF HIGH INTENSITY NEUTRON SOURCE

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Abstract

Results of MPG-class graphite properties research are presented. It is experimentally tested, that this kind of material can operate at high temperature conditions that are required for high power neutron target operation. The method of lifetime estimation is proposed. It is shown, that this material can stand under high temperature up to a few thousand hours.

1 INTRODUCTION

The proposed project of neutron source is based on the neutron target irradiated by the deuteron beam with energy 20 MeV, beam diameter 1 cm, average power up to 100 kW. The target represents the rotating disk with the operational area made of graphite. The target is cooled by its thermal radiation. Size, operational conditions, and lifetime are determined mainly by the maximum admissible temperature conditions of used material. The goal of the present paper is to define these conditions

2 GRAPHITE PROPERTIES

One can offer to use heat-resistant dense graphite MPG-6 class as the target material. It is intended for the operation in vacuum or inert sphere at the temperature up to 2300-2500^{0}C. Its physical and mechanical properties are listed in Tab.1 (data are given by the manufacturing plant).

3 EXPERIMENTS WITH GRAPHITE SAMPLES

To test the graphite reliability at the target thermal conditions, series of experiments are done, aimed:

- to define the admissible number of thermocycles (fast heating up to operational temperature and fast cooling down to room temperature);
- to define the maximum admissible temperature gradient;
- to define the temperature jump influence;
- to define the lifetime in the temperature range 2200 - 2500^{0}C.

Table 1. Physics and mechanical properties of graphite MPG-6 class

density, g/cm^3	1.76-1.88
ultimate strength at 20^{0}C, kN/cm^2 compressive cross-breaking tensile	 10 - 12 5 - 7 2.5 - 4
elastic modulus (dynamic, at 20^{0}C), 10^3 kN/cm^2	1.0-1.5
specific resistance at 20^{0}C, Ohm·mm^2/m	11-16
thermal conductivity ratio at 1000^{0}C, kJ/(m·h·K)	181-189
average temperature expansion ratio in the range 20-1500^{0}C, $10^{-6}\cdot K^{-1}$	8.0-8.8
radius of dominated pores, µm	3-8
total contents of admixtures	$5\cdot10^{-5}$-10^{-4}

To carry out these tests, a special testbench was made (see Fig.1). Graphite samples with the cross-section about 1.5x1.5 mm and length 15-20 mm were heated in the vacuum volume by the pulsed current The pulse width was 96 µsec, the repetition rate was 50 Hz. These conditions correspond to the operational conditions of the target, rotating with frequency 50 Hz. Current and voltage oscillograms were registered, then radiated power, average temperature, and temperature jump were calculated. Control of the temperature distribution over the sample surface was also realized by the pirometer through the window in the vacuum volume. Upon the completion of the test the sample was then tested by the

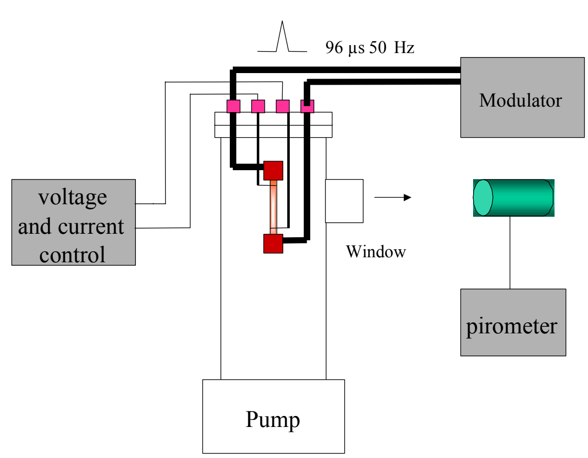

Figure 1. Installation layout

electronic microscope.

Thermocycle test was carried out as follow: the sample was fed by the packet of heating current pulses of 30 sec duration. It was heated up to the temperature 2000^0C. Then the next 30 sec the sample was got cold down to the room temperature. As the result, the sample stood more than 500 cycles without destruction. Fig.2 show the protocol of the test. Note that for the first 200 cycles the sample resistance was risen up to 7% and then was stabilized on a new level, that point to stabilization of the sample material structure in a new level after its partial destruction, and success to stand the thermal stress of such a kind. This means the target doesn't require preliminary heating before the deuteron beam release.

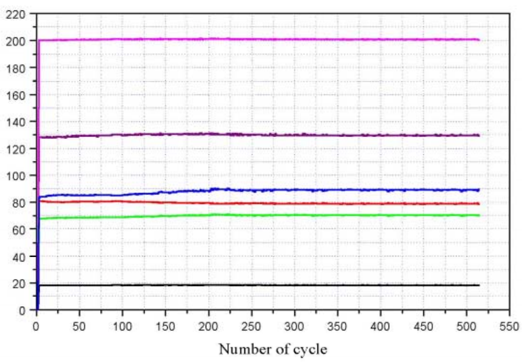

Figure 2. Protocol of graphite sample thermocycle test. Top to bottom: sample temperature in the end of heating T*10 (^{0}C), heating power (W), sample resistance (mOhm), current pulse amplitude (A), voltage pulse amplitude (mV), temperature jump (^{0}C).

The measurements of the temperature distribution along the sample at quasi-stationary temperature 2000^0C with the pirometer gave following results: maximum temperature was detected in the middle of 16 mm long sample. The temperature was 80^0C lower at the edges of the sample. Thus, graphite stable stands the temperature gradient up to 100^0C/cm.

To define the target lifetime the sample was heated by the current pulses and remained at constant average temperature in the range 2200-2500^0C. The change in time of the sample resistance indicated the change in graphite properties. The sample resistance was increased in time with the rising speed, and at 20-25% resistance growth the sample was destroyed. Time interval between the moment when the sample reached the operational temperature, and the moment when it was destroyed, was defined as the lifetime. Fig.3 shows the protocol of the test for lifetime. The sample was destroyed after 1 hour while it stood at the average temperature around 2445^0C.

In order to define the temperature jump influence on the target lifetime the sample was heated by 50 Hz AC. Sample lifetime depended on the temperature only. On the other hand, the temperature jump at pulsed current heating 2-3 times exceeded the calculated one for normal operational conditions. That means that the main factor of target lifetime is its average operational temperature.

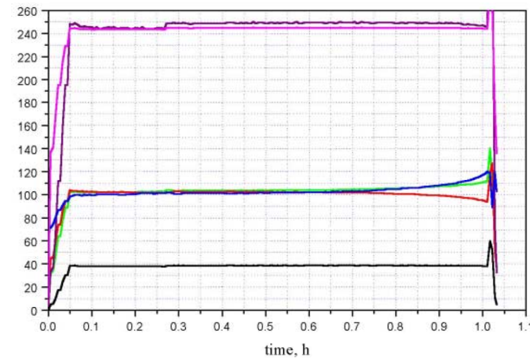

Figure 3. Protocol of graphite sample tested for the lifetime. Top to bottom: heating power (W), sample average temperature T*10 (^{0}C), sample resistance (mOhm), voltage pulse amplitude (V), current pulse amplitude I*10 (A), temperature jump (^{0}C).

4 LIFETIME ESTIMATION - A MODEL

One can use the following model for the interpretation of experiments: the sample material is porous, pores are long and narrow with typical transverse size L and longitudinal l. Then the sample conductivity is $g \approx g_0(1-S_c/S_s)$, where $S_c = const_1 Ll$ - the total area of the pores in the sample transverse cross-section, S_s - the sample cross-section area. Pores are connected with the sample surface via their butt-ends of area $S_{ch} \approx const_2 L^2$. The graphite vapor is diffused from the pore surface through these butt-ends. The graphite vapor flux is $U \approx const_3 n V_t S_{ch}$, where n - vapor concentration in pores, V_t - mean thermal speed of the evaporated graphite. Since pores are long and narrow, one can assume that graphite vapor is saturated inside and then

$$U \approx \frac{const_4 L^2 P_C}{\sqrt{T}} \quad (1)$$

where P_c - the saturated graphite vapor pressure at a given temperature T. On the other hand, graphite is evaporated from the pore surface changing its transverse size: $U \approx const_5 S_c dL/dt$, where $L(t) = L_0\exp(At)$ with

$$\cdot \ A = Const P_C / \sqrt{T} \quad (2)$$

So, the measured experimental dependencies should be approximated by the formula:

$$R(t) = R_0/(1 - const \cdot \exp(At)) \quad (3)$$

that seems to happen (see Fig.4).

The dependence of the graphite saturated vapor pressure $P_C = const \cdot \exp(-B/T)$, where, according to

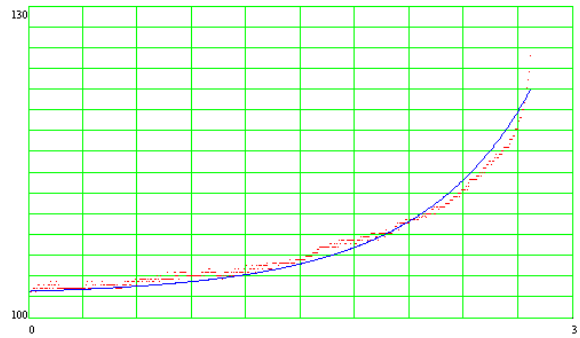

Figure 4. Dependence of sample resistance (mOhm) on time (h) at temperature 2400^0C. Dots – measured values, solid line – approximation by formula (2.3)

various data [1,2] $B = 9.2 \div 9.45 \cdot 10^4$ (T measured in ^{0}K). In that case the sample lifetime depends on the temperature as follow:

$$\tau = Const\sqrt{T}\exp(B/T) \qquad (4)$$

Fig. 5 shows the experimental data for samples lifetime dependence on temperature. The lifetime is determined after sample resistance 20% growth - at that time its strength (in the present model it depends on time the same way as the conductivity) is decreased for the same 20%.

The experimental data are in good agreement with the curve gave by the formula (4) with $Const = 3 \cdot 10^{-17}$. The lifetime defined in such a way at 2100^0C appeared to be 300-400 hours, about 2000 hours at 2000^0C, and about 10000 hours at the operational temperature 1800^0C.

5 CONCLUSION

From what has been said, it might be assumed, that graphite proves to be the appropriate material for the neutron target irradiated by the deuteron beam of high power. It can stand under very high (1800^0) temperature over a long period of time (a few thousand hours) Notice that the use of graphite as the basic target material essentially simplify the target and make it inexpensive, reliable and safe.

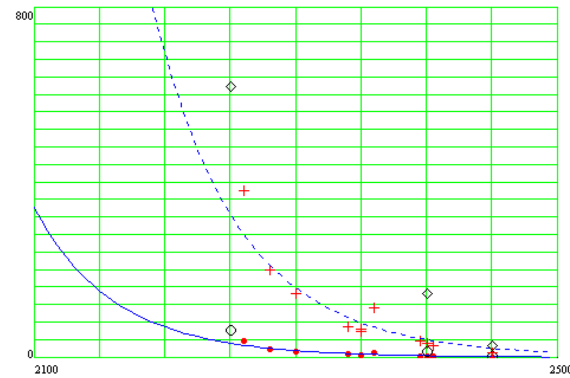

Figure 5. Dependence of samples lifetime (h) on temperature (^{0}C). • and O – measured values, + and ◊ – same values multiplied by factor 10, solid line – approximation by formula (2.4), dashed line – same values multiplied by factor 10.

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