PROJECT OF ROTATING CARBON HIGH-POWER NEUTRON TARGET. SIMULATION OF THE TARGET THERMAL AND MECHANICAL OPERATION CONDITIONS

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Abstract

The methods and results of the calculation of the 100kW neutron target thermal and mechanical conditions are presented. Calculation is made for optimization of the target design and consists of the thermal and mechanical stress determination.

1 INTRODUCTION

The calculation had two main goals. The first one is to determine the operational conditions of the target with the large energy release and to choose the optimum heat dissipation method, while the second one is to estimate the thermo-mechanical stress inside the most strained elements of the target. The calculation is executed following the finite different elements method. The non-stationary heat equation with the heat irradiation from the target surface were solved. The heat sources were the target elements hit by the deuteron beam, or the surfaces contacted. In the last case the distribution of energy release along the surface was supposed to be defined. It is important to note that the solution of non-stationary problem is necessary not only for the stationary distributions definition, but also for the stress determination during the process of heating, when the thermo-mechanical stress achieves the maximum.

2 TEMPERATURE SIMULATION

The neutron target can represents the disk, arranged with the graphite plates of 3cm width and 1.5-2 mm thickness. The plates are set on the titanium disk of 60 cm diameter and 1cm thickness. The disk is set on the shaft of 5 cm diameter and rotated with the frequency 30 Hz. The deuteron beam hits the graphite surface to the angle 20^0.

The computer codes are written on the basis of the heat energy conservation law for a given elementary cell: 3D code for calculations of temperature field dependence on time in the graphite part of the target. As the input data, the code takes the three-dimensional distribution of power released in the target time depending during the single turn of the wheel, the dependencies of thermal conductivity and capacity on temperature, and also the parameters of surfaces surrounding the target, that are required for the radiation heat exchange description. The output data is temperature field in the target vs. time. By this field, the following values are calculated: maximum temperature gradient, maximum temperature, temperature of graphite-to-titanium mount region, the maximum temperature oscillation amplitude per one turn, power flux into mount region, averaged through single turn.

The matched solution for 100 kW deuteron beam with the typical transverse size 1 cm is presented in Fig.1–2. The target heating is carried out under the most strained conditions - the instantaneous full power release in the relatively cool target.

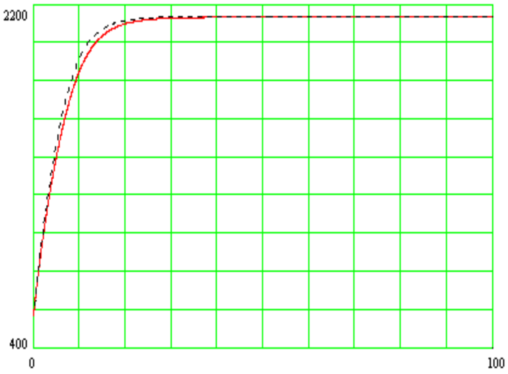

Figure 1 Maximum graphite temperature (^{0}C) vs. time (s). Solid and dashed lines - different versions of code realization (3D and 2D).

At that, for 3D code the radiation from the butt-ends was not taken into account in the border conditions in order to verify the match between 3D and 2D algorithms of calculation. The tilted target is necessary for the reduction of the maximum power density in the it to the acceptable level. A single thin metal screen made of niobium (ε_s = 0.1) is chosen as the thermal insulation at the target mount region. Maximum target temperature vs. time of heating is shown in Fig.1. Maximum temperature gradient value in the target vs. time is presented in Fig.2.

As it is seen, the calculations by 3D and 2D algorithms are well matched one to other. Some discrepancy could be explained by slightly different conditions of thermal flux into the parts. However, the parameters under control are almost coincide, especially in the steady-state conditions.

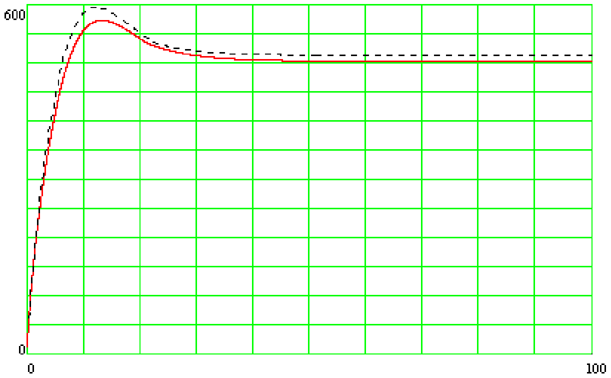

Figure 2 Maximum temperature gradientt (^{0}C/cm) vs. time (s). Solid and dashed lines - different versions of code (3D and 2D).

Taking into account the radiation from the butt-ends, the thermal flux in 3D code is increased approximately 1.5 times. Presented calculations allow to define another important target parameter - typical time of its heating at full power release. Although the performed tests were successful at instantaneous power release (the sample stood more than 500 thermocycles and wasn't destroyed), the electron microscope detected the serious changes in the sample structure. Therefore the gradual power growth with the time constant over 2 min. is recommended.

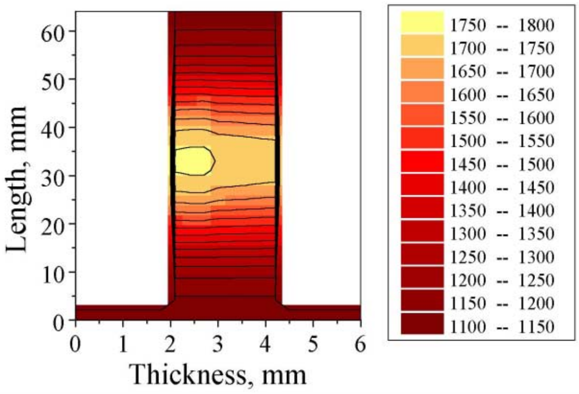

Figure 3 Temperature distribution over the section of graphite target in ^{0}C for the graphite length 64 mm and disk thickness 1 cm.

Fig.3 shows the temperature distribution along the graphite part for steady-state operational conditions for the following target geometry: titanium disk thickness - 1 cm, diameter - 90 cm, graphite thickness - 2 mm, graphite length in radial direction - 64 mm, the steady-state thermal flux into titanium - 5.38 W/cm, the temperature of cowling 718 K.

The proposed method of simulation allows to obtain the steady-state stationary solution and to estimate the typical time of reaching the operational conditions for the target. Taking into account the presented dependencies of target thermal specifications on time, one conclude that the typical time neccessary to reach the steady-state thermal conditions is determined by the heating of the titanium disk and is about 2 hours. At that, the typical time of the beam power raise up to nominal value should be around 10 minutes.

3 MECHANICAL STRESS

Within the elasticity limits (absence of plastic deformations) the stress in the titanium disk should be considered as a sum of thermal stresses and the stress due to rotation. In the case of a thin rotating disk with the axial and uniform along the axis temperature distribution.

The comparison of the simulation result of mechanical stress simultion for titanium disk of radius 45 cm rotating with frequency 30 Hz and thermal stress simulation shows that the main contribution is given by the thermal stress. Moreover, total stress never exceeds 200 MPa, and the flow limit for titanium alloys at the temperature up to 500^{0}C is 300–1000 MPa. That means that the proposed target is in the operational conditions by its mechanical parameters.

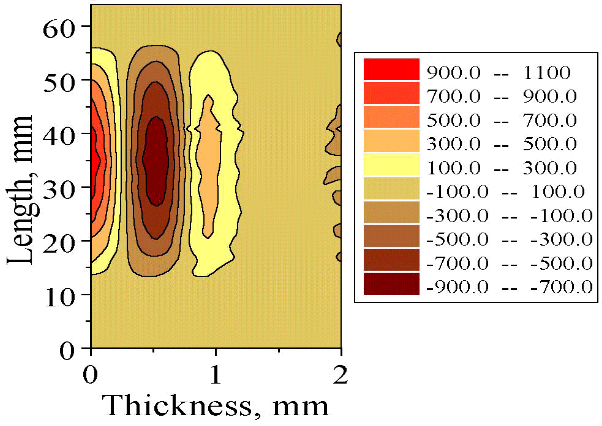

Figure 4 Distribution of the longitudinal thermal stress σ_x (kPa) over the radial section of graphite in the target

For the graphite parts the contribution of the rotation stress in the total stress is even less. The precise calculations of total thermal stress with an arbitrary 2–dimensional temperature field requires the numerical solution of system of differential equations of elasticity and rather complicated. The approximate solution for rectangular plate for the lengthwise distribution of temperature is given in [8]. Fig.4–6 shows the results of thermal stress calculations in graphite plates of target. The results corresponds to graphite temperature distribution, presented in Fig.3. Graphite thickness was 2mm, the plate width – 2 cm, α – $9\cdot10^{-6}$ K^{-1}, elastic modulus E – 10^{10} Pa.

It is seen that for graphite the stress is also far less then the ultimate stress, that is not less than $2.5 \cdot 10^7$ Pa.

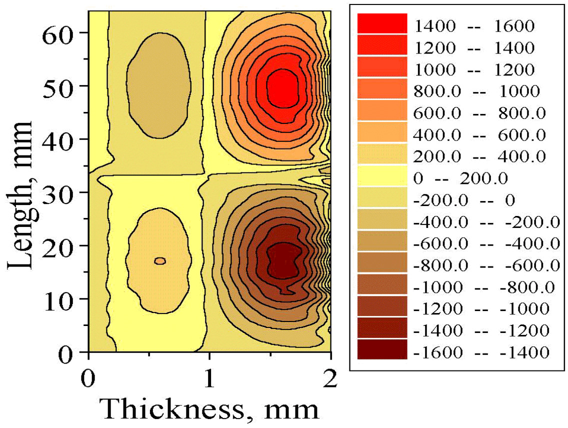

Figure 5 Distribution of tangential thermal stress τ_{xy} (kPa) over the radial section of graphite in the target

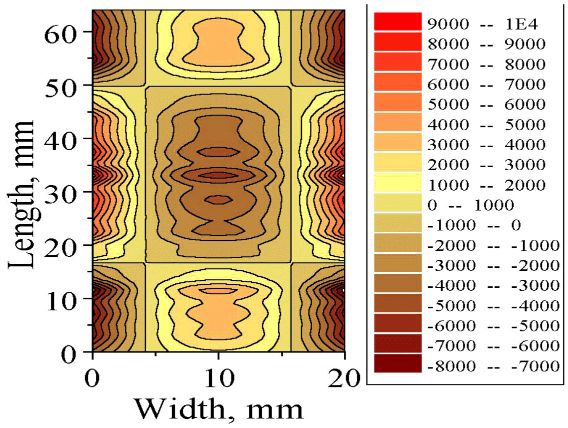

Figure 6 Distribution of longitudinal thermal stress σ_x (kPa) over surface of graphite plate in the target

4 CONCLUSION

Calculations presented in this paper shows that for chosen target geometry (graphite plate size, target diameter) at given beam parameters:

1. No graphite plate overheating occur since the temperature never exceed 1800^0C;
2. Thermal stress prevails over the mechanical one and is far from the critical value for graphite;
3. During the heating process the stress doesn't exceed the one in stationary operational conditions more than 20%, that is below the critical value. So, no preliminary target heating is required.

5 REFERENCES

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