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Design of high power neutron converter for the SPIRAL-2 facility

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Abstract

Thermo-mechanical simulations performed in order to determine the basic geometry and physical characteristics of the neutron production target for SPIRAL-2 facility, to define the appropriate beam power distribution, and to predict the target behavior under the deuteron beam of nominal parameters (40 MeV, 5 mA, 200 kW) are presented. The simulation is done on the basis of ANSYS program complex
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1. Introduction

The presented paper contains the preliminary results of the thermo-mechanical simulation performed in order to determine the basic geometry and physical characteristics of the neutron production target for SPIRAL-2 facility [1], to define the appropriate beam power distribution, and to predict the target behavior under the deuteron beam of nominal parameters (40 MeV energy, 5 mA current, 200 kW total power). The simulation is done on the basis of ANSYS program complex [2]. Main physical values under study are: the temperature distribution over the target, the temperature gradient, the stress (both thermo-mechanical and caused by the inertia loads), and the deformation of the construction due to the loads applied.

The neutron converter has been conceived as a high speed rotating target (Fig. 1) which limits the peak surface temperature of converter materials well below 2000 °C. Graphite made of natural carbon and density of 1.8 g/cm^3 (MPG-brand graphite) has been chosen as converter material. The target assembly consists in a wheel rotating under vacuum with a frequency of 10–50 Hz; the converter plates are located at the extremity of the wheel and mounted on a stainless-steel holding by means of graphite clamps aimed at the reduction of the thermal flux from the graphite converter to the metal disk. The thermal power deposit in the converter material is dissipated only by thermal radiation. Heat removal from vacuum chamber is carried out by water (liquid metal) circulating inside aluminum cooling channels fixed to the chamber's walls. Critical components of the experimental device have been studied in [3], followed by the prototyping phase of [4].

In the simulation the monochromatic beam impinges the converter at a normal angle in the middle of the converter's plate. In order to investigate different target operational modes and to select the most appropriate variant to be applied, different beam profiles (Gaussian of 1 cm, 2 cm and 3.5 cm width and flat beam of 3.5 cm) are considered. For each beam profile the temperature distribution over the target is calculated and the target diameter is matched so as to maintain the converter temperature well below 2000 °C.

2. Results

The temperature distributions over the target are obtained for the different beam profiles calculated for the

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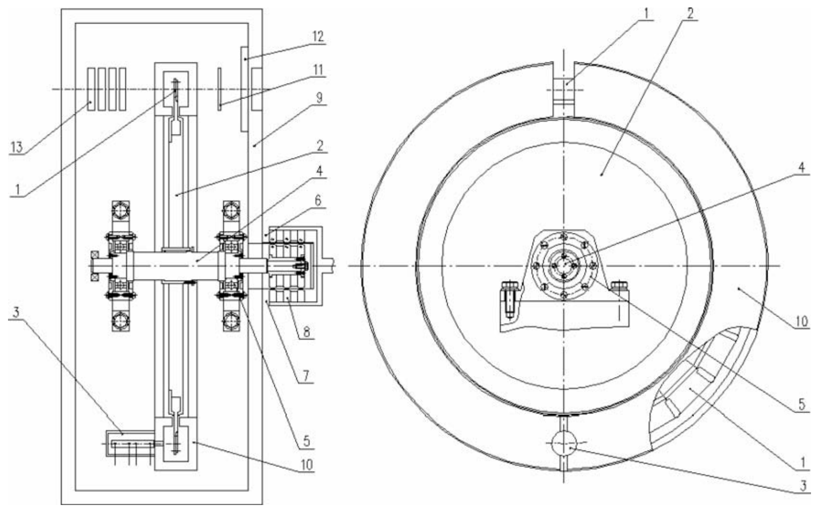

Fig. 1. Rotating converter assembly. (1) – converter material, (2) – stainless-steel disk, (3) – bolometer, (4) – rotating shaft, (5) – bearings, (6) – vibration pick-ups, (7) – rotation magnetic sensor, (8) – rotation system, (9) – vacuum chamber, (10) – cooling channel, (11) – pick-up, (12) – output window, (13) – beam collimator.

converter thickness of 6 mm and length of 80 mm, the thickness of the metal disk is 10 mm. Those parameters were obtained through a detailed study aiming to optimize the converter performances. The main results of the ANSYS simulations are summarized in Table 1.

Fig. 2 shows the result of calculation for the flat beam profile and the diameter of 80 cm.

Both transverse beam size and beam profile affect the maximum converter temperature and, hence, the target diameter. Flat distribution gives much stronger effect of temperature reduction, than the beam size increase at Gaussian distribution. The maximum temperature of metal parts of the construction, though being less than 600 °C, yet increases with the beam size growth. This is caused by the hot area location relative to metal disk: it is closer for the wider beam. The maximum temperature gradient in the converter (Fig. 3) never exceeds 100 °C/mm, which is far from the ultimate gradient for MPG-brand graphite. Notice that in the experiments, the target model graphite withstood the temperature gradient of around 150 °C/mm without any destruction and serious degradation in its structure [3].

Table 1
Target diameter, maximum temperature of the converter, maximum temperature of the metal part, maximum temperature gradient versus different beam profiles

Beam	Target diameter (cm)	Maximum temperature of converter (°C)	Maximum temperature of metal (°C)	Maximum temperature gradient (°C/mm)
Gaussian 1 cm	180	1993	458	98
Gaussian 2 cm	160	1999	479	77
Gaussian 3.5 cm	135	1992	498	58
Flat 3.5 cm	80	2001	524	61
Flat 3.5 cm	95	1850	512	52

The total stress in the target is generally a combination of the stress due to rotation of the construction and the thermo-mechanical stress which is the result of target non-uniform heating. Simple estimations show that thermo-mechanical component of stress contributes mainly at the converter area, where the temperature gradient reaches the maximum value. Meanwhile, the stress due to inertia forces plays the main role at the target basis, i.e. where the metal disk is set on the shaft. In such a way, the analysis could be subdivided into two parts and carried out separately for inertia loads and thermo-mechanical stress. The main parameters under study are the three components of stress, von Mises stress, and the components of deformation as a result of thermo-mechanical loads.

The three components of stress, von Mises stress, and total deformation of the converter plate under the flat beam 3.5 cm wide have been calculated for a graphite nominal temperature of 2000 °C and 1850 °C (Fig. 4). The maximum value of 1.64×10^7 Pa ($T_{\mathrm{nom}} = 2000$ °C) is represented by the longitudinal component of stress (the edges of the graphite plate act as the stress concentrators). Nevertheless, being the breaking point of the MPG-brand graphite of about 5×10^7 Pa in the range of 1000–2000 °C, the converter operates rather far from critical condition.

The dependence of the stress value on the length and the thickness of the graphite plate was also studied. The increase in plate thickness causes the growth of thermo-mechanical stress, while the reduction of the plate length gives the stress reduction. However, taking into account the temperature growth over the metal part of the construction with the reduction of the plate length, it does not seem reasonable to reduce the length of the converter plate.

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