

HIGH-POWER PROTON IRRADIATED SOLID STATE ROTATING NEUTRON TARGET: CONCEPTUAL DESIGN AND ESTIMATIONS OF THE OPERATION CONDITIONS

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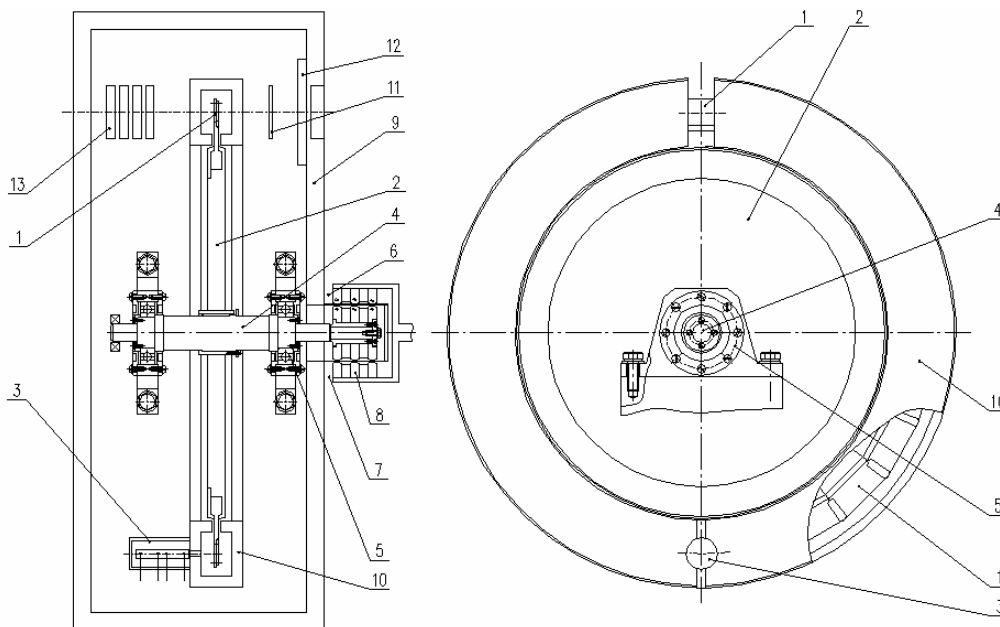


Figure 1 Neutron target layout. 1 – converter's plates, 2 - titanium disk, 3 - bolometer, 4 - shaft, 5 - bearings, 6 - vibration pick-ups, 7 - magnetic sensor of rotation, 8 - rotation input, 9 - vacuum chamber walls, 10 - cooling channel, 11 - capacitance-type pick-up, 12 - neutron beam output window, 13 – collimator.

Abstract

The project of high intensity rotating solid state neutron target for SPES project at LNL, Legnaro, Italy, is presented. Target is bombarded by a proton beam with energy 10 MeV and average power up to 300 kW. Different materials for the converter operation area (^{13}C or boron carbide) are under consideration. Target operation conditions are determined taking into account beam parameters. When the converter is made of boron carbide, it is necessary to introduce an additional target motion - the oscillation of its axis. It is shown that very important is to study the thermo-mechanical properties of the converter material, so the preliminary test is required both for converter material and for various target assemblies.

1 TARGET DESIGN

The proposed design of a neutron target represents (see Fig.1) the wheel arranged with plates 1 - 3 cm in width and 1 - 3 mm in thickness. Plates are mounted on the titanium disk 1 m in diameter and 1 cm in thickness.

The disk is set on the shaft 5 cm in diameter and rotated with 30 - 50 Hz frequency. The rotation is carried out by the magnetic clutch. The heat power deposited in the converter material can be dissipated by thermal radiation. Heat removal from vacuum chamber is carried out by water, circulating inside aluminum cooling channels that are rigidly attached to chamber's walls. Before the converter, a collimator acts as a beam position monitor. Behind the converter, a graphite plate serves to survey and monitoring eventual damages of the converter and, at the same time, protects the vacuum chamber from proton beam. For mechanical and safety reason, rotating sensors and vibration pick-ups are provided as well as the flow meters and manometers in the hydraulic system.

The most important converter parameters to investigate are the maximum operating temperature and thermo-mechanical stress distribution inside the converter itself; mechanical stress due to the rotation is far less than thermal one. In the follow the calculation of temperature distribution and thermo-mechanical stress are performed for the converter made of ^{13}C (graphite form) and boron carbide. The calculation of temperature distribution and thermo-mechanical stress is done for these materials on the basis of non-steady-state equation of heat transfer in

solid state matter. Heat sources are proton beam energy losses, distributed over the converter's volume. Heat removal from the converter surface is carried out by thermal radiation. A full collection of detailed calculations can be found in Ref. 1.

2 THERMAL CALCULATIONS

Calculations were carried out for following conditions:

- converter is assembled with T-like plates with thickness 2 mm, length in radial direction 90 mm, width 10 mm;
- plates are set on the disk 1 m in diameter;
- converter heating is carried out by the proton beam with 10 MeV energy and 30 mA mean current with normal direction to the plate surface;
- incident beam is round with Gaussian profile. Center of the beam coincides with the center of the plate;
- total beam power of 300 kW is uniformly distributed over the target azimuth;
- the dependence of material properties (specific heat and thermal conductivity) on the temperature is taken into account. Integrated thermal radiation ratio is accepted to be equal to 0.8 for graphite, and 0.45 for boron carbide.

The calculated temperature distribution for different beam spot size and maximum temperatures on the graphite converter is shown in Fig.2. The acceptable operation temperature for rotating converter (around 2000°C) can be obtained only with $\sigma_{\text{beam}} = 1.25$ cm or more. Since the heat deposition power density is rather high, the heat has no time to distribute itself over all converter volume, and the reduction of effective area of thermal radiation takes place. However, when the beam size is small, one can use the target inclination to the beam direction and, therefore, increase the effective surface of radiation. In fact, the converter inclination of 66° leads to same results as the beam size were increased from $\sigma_{\text{beam}} = 0.5$ cm to $\sigma_{\text{beam}} = 1.25$ cm.

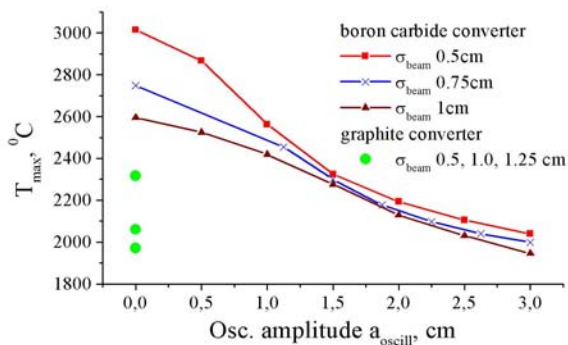


Figure 2. Maximum temperatures of solid neutron converters at various proton beam sizes and target oscillation amplitudes.

Thermal calculations for the boron carbide converter have been shown a rather different situation (Fig.2). The

maximum temperature of about 2000°C can be obtained only with $\sigma_{\text{beam}} = 2.5$ cm or bigger. The converter inclination or the increase of its diameter are not effective and cannot compensate the rise of temperature with $\sigma_{\text{beam}} = 0.5 - 1$ cm. However, additional converter oscillation (or equivalent beam oscillation) results in a reduction of the peak power density, as shown in Fig.3.

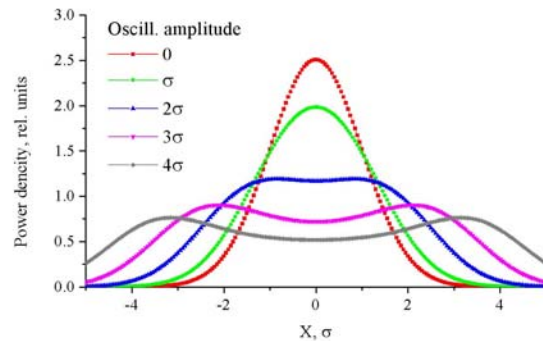
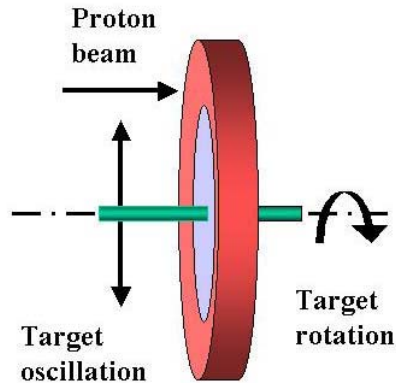


Figure 3. Scheme of neutron target motion (top) and power deposition density distribution along the converter's plate for various oscillation amplitudes of target axis.

The problem of maximum admissible converter temperature requires more detailed study:

- first, it is necessary to specify the thermal radiation ratio for materials actually in use;
- second, the experimental study of materials behavior at such a high temperature is required, as well as the study of maximum admissible operation temperatures.

3 THERMO-MECHANICAL STRESS CALCULATIONS

The total thermo-mechanical stress of the device during the operation is the result of the stresses induced by rotation and by non-uniform heating of the converter. The rotation stress is small in comparison with the thermal one and does not contribute essentially to the total

stress. The thermal stress has been evaluated referring to the method described in Ref. 2-4.

Being the ultimate strength of MPG-brand graphite around $(2 - 4) \cdot 10^7$ Pa, the calculated thermo-mechanical stresses are relatively far from the ultimate values.

Similar results were obtained for the converter made of boron carbide. Fig.4 shows the maximum normal stress (σ_x) along the proton beam direction, maximum normal stress (σ_y) across the beam direction, and maximum tangential stress (τ) in the boron carbide converter for different size of a proton beam and different converter oscillation amplitudes. The ultimate strength for boron carbide is about $5 \cdot 10^{10}$ Pa, but stress in calculations never exceeds 10^9 Pa.

4 CONCLUSION

Main condition that influences on the calculation accuracy of converter operation regimes is the careful study of material thermal and mechanical properties, i.e. thermal radiation ratio and thermal expansion ratio, thermal conductivity and specific heat, elastic modulus and ultimate strength in dependence of temperature within the range 1500-2500°C. Preliminary experimental study of samples made of certain materials is required. Most useful seems the test, which includes the heating of specially produced samples by electron and proton beam under conditions which are close to converter operation conditions.

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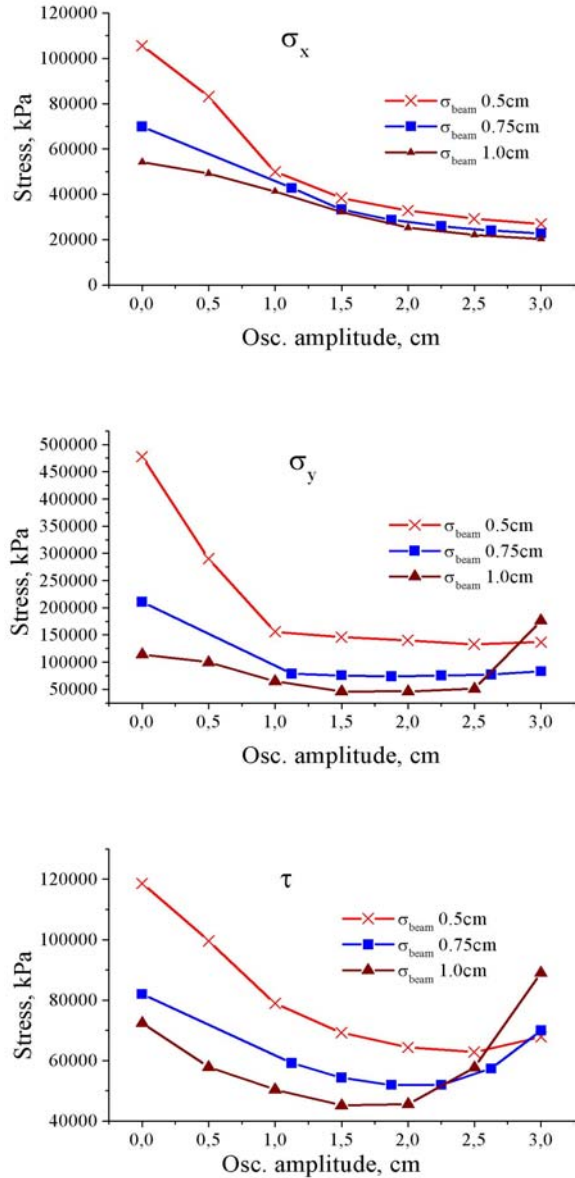


Figure 4. Maximum normal stress along the beam direction σ_x (top), normal stress across the beam direction σ_y (middle) and tangential stress τ (bottom) in B_4C converter plates vs. target oscillation amplitude for different size of incident beam.