Design of the Neutron Converter for the SPIRAL-2 Facility

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INTRODUCTION

The paper reports the design of the neutron converter for the SPIRAL2 facility. It contains the results of the thermo-mechanical simulation performed in order to determine the basic geometry and physical characteristics of the neutron converter and the preliminary engineering solution for the “nuclear” integration of the converter inside the production module.

The thermo-mechanical simulations are performed on the basis of ANSYS tools [1]. Main physical parameters under study are: the temperature distribution over the target, the temperature gradient, the cooling system and the deformation of the construction due to the loads applied. The drawing of the “nuclear” integration in the production module are done by using the 3D code Catia [2].

TARGET DESIGN AND BEAM PARAMETERS

The neutron converter has been conceived as a high speed rotating target which limits the peak surface temperature of converter materials well below 2000 °C. Graphite made of natural carbon has been chosen as converter material to be employed with deuteron beam. The converter assembly consists in a wheel rotating under vacuum with a frequency of 6-15 Hz; the converter plates are located at the extremity of the wheel and mounted on a stainless-steel holding. The thermal power deposit in the converter material is dissipated only by thermal radiation. Heat removal is carried out by water cooling panels located around the wheel, inside to the module.

Deuterons of 40 MeV energy and 5 mA current (200 kW) represent the primary beam which produces the neutrons in the converter. In the simulation the mono- chromatic beam impinges the converter at a normal angle in the middle of the converter’s plate. The beam profiles at the converter level are well defined by the beam dynamics.

Two different beam power are considered: 50 kW and 200 kW. For both beam powers the profiles are Gaussian and they widths are of 10 mm (6σ) and 40 mm (6σ), respectively [3]. The stopping length for 40 MeV deuterons occurs to be around 5.5 mm for natural carbon with density of 1.8 g/cm³, which is in good agreement with [4]. For safety reason the thickness of the converter has been chosen of 7 mm.

THERMO-MECHANICAL ANALYSIS

The ANSYS simulation performed aimed at the investigation of the thermo-mechanical characteristics of the converter being exposed to intense deuteron beam, so the main analysis type is steady-state thermal/structural. The main construction materials are AXF-5Q POCO graphite [5] and stainless steel AISI304. All the material properties are taken as temperature dependent because of the wide operational temperature range. Thermal and structural loads were applied to the target model. Both deuteron beam profile and calculated beam power losses in the converter are taken into account.

The main goal of thermal analysis is to obtain the temperature distribution over the target, to define the minimum target diameter for each beam profile, and to determine the appropriate converter’s plate length and thickness. Main criteria in the selection of the target diameter is the maximum converter temperature (it should not exceed 2000 °C) and the maximum temperature of the metal part of the construction (it should be less than 600 °C). Temperature fields over the target are calculated for two beam power. In all cases the converter thickness is 7 mm, the length of the converter plate is 80 mm (50 kW) and 100 mm (200 kW), the thickness of the metal disk is 10 mm. Temperature distributions for 10 mm (6σ) and 40 mm (6σ) Gaussian beams are calculated (see fig. 1). Based upon temperature distributions the target diameter is defined for each beam profile, the results are presented in next table 1.

Table 1. Converter diameter, maximum temperature of the converter, maximum total stress and inertial stress vs. different beam profiles.

<table>
<thead>
<tr>
<th>Beam</th>
<th>Dia. [mm]</th>
<th>Temp. [°C]</th>
<th>Stress [MPa]</th>
<th>Inertial [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 kW-10mm</td>
<td>520</td>
<td>1800</td>
<td>25</td>
<td>90</td>
</tr>
<tr>
<td>200 kW-40mm</td>
<td>1200</td>
<td>1700</td>
<td>12</td>
<td>25</td>
</tr>
</tbody>
</table>

Thermo-mechanical analysis of the metal part is carried out in the axial symmetry approach. The maximum thermo-mechanical stress value of 390 MPa is observed at the clamping region, where temperature gradient is considerable. The stress value of around 4·10⁸ Pa, though rather high, seems not to be critical for a number of heat-resistant...
austenitic steels designation that can stand the stress of $4.5 \cdot 10^8$ Pa for few thousand hours at over 500 °C.

Mechanically the converter is conceived as an independent unit that can be remotely handled for maintenance or replacement. A mechanical adaptation permit the use of the converter coupled to different UC targets and ion sources by removing the local shielding. The “delay window” is integrated in the rear cooling panel.

INTEGRATION IN THE PRODUCTION MODULE

The production module is essentially a shielded box that contains the converter, the target and the ion source dedicated to the production of the radioactive ions. The production module becomes highly radioactive and contaminated. After irradiation it is isolated by valves and disconnected from external supplies of power, water, control cables and remotely transported to a hot cell to undergo maintenance via remote hand-operated manipulators. In fact, the production module components have to be designed in accordance with the nuclear technological approach.

An exploded view of the production module and of the converter is shown in fig. 2. The production module is conceived to host both the converter designed for 50 kW and 200 kW. All the servitudes are concentrated on the central flange.

CONCLUSIONS

Based upon the analysis carried out, the converter has been designed as a rotating unit which includes: the solid disk attached to the shaft, a number of metal sectors fastened to the solid disk, graphite clamps and a set of graphite converter’s plates. Two different converters have been designed to accept 50 kW and 200 kW deuteron beams. For 50 kW the converter has a diameter of 520 mm and for the 200 kW the diameter is 1200 mm. This difference in diameter of converter has been chosen to limit the maximum temperature well below 2000 °C. Nuclear technological approach allows to design a suitable integration of the converter inside the production module and its remote handling internally the hot cell.