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The target for the new plasma/wall experiment Magnum-PSI

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ABSTRACT

The construction of Magnum-PSI is in its final stage. The aim is to provide a controlled and highly accessible linear plasma device to perform the basic plasma-surface interaction research needed for the design of the plasma facing components of future fusion devices. This contribution will focus on the thermal challenges imposed by those extreme conditions on the design of the target holder of Magnum-PSI.

The target holder is designed to allow the exposure of large size targets with variable inclination angles with respect to the magnetic field. A test set up was made to test different interlayers (grafoil®, soft metal sheets) and improve the thermal contact between the target and the heat sink. In addition, a modular target holder for sequential exposure of smaller size targets has been designed. Finite element modeling using the ANSYS code was used to optimize the cooling geometry and to predict the temperature profiles due to the heat load of the plasma. Experiments were done on the Pilot-PSI linear device to validate the thermal calculations. Calorimetry and infrared thermography were used to experimentally measure the temperature profile on the target and the heat deposition.

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1. Introduction

In the fusion device ITER, the divertor will have to be operated in a semi-detached regime to maintain the heat flux density on the divertor within the engineering limits for steady-state power handling [1]. In this regime, ion fluxes of $10^{24}\ m^{-2}\ s^{-1}$ are expected at the strike-point, with a steady state heat flux of 10 MW/m^2 with a relatively low electron temperature of 1–10 eV. Plasma-surface interaction studies under those conditions motivated the design of the Magnum-PSI device.

Magnum-PSI is a linear plasma device with a steady state 3T magnetic field [2]. The plasma is produced by a cascaded arc source. The required ion and power fluxes were already achieved in the Pilot-PSI device [3].

In the target chamber, user defined targets can be exposed to the plasma. The different targets can be attached to a target manipulator, allowing for target rotation about the same axis as the plasma beam and tilting with respect to the magnetic field. A broad range of diagnostics will be used to monitor the plasma and target conditions. For example, the surface temperature will be monitored by a fast infrared camera and a multi wavelength pyrometer. After plasma exposure, the target can be retracted to the Target Exchange and Analysis Chamber (TEAC, see Fig. 1), without breaking the vacuum, for further analysis.

The TEAC is designed to provide good diagnostic conditions and access after exposure and has more than 30 viewing ports. The TEAC can be insulated from the main vacuum system by two large gate valves and has its own vacuum pump system. This set up allows the target manipulator to be retracted from the exposure position in the target chamber to the TEAC in less than 30 s. After closing the valves, the TEAC can be pumped down to 5×10^{-5} Pa. Main surface diagnostics in the TEAC include laser induced desorption, laser induced ablation and laser induced breakdown spectroscopy.

2. Target manipulator for Magnum-PSI

The targets are mounted onto the target manipulator, which mainly consists of a cooled base plate (target holder), a worm wheel for the target rotation, and a 5 m long bellow system, containing the cooling water tubes, sensor cables and electrical cables.

The target manipulator is designed to accommodate different target sizes and geometry. For example, large (60 × 12 cm, 100 kg) targets can be rotated ±120° and tilted ±90° with respect to the magnetic field. In addition, a holder allowing 5 circular targets (30 mm diameter) to be mounted simultaneously and exposed sequentially, perpendicular to the magnetic field, is designed (see Section 3).

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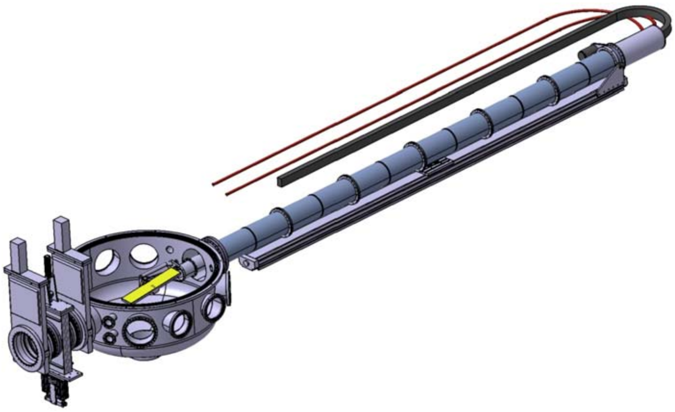

Fig. 1. The Target Exchange and Analyses Chamber (TEAC), without the top lid. Left the two gate valves can be seen. Inside the TEAC the large target holder in yellow is shown. The 5 m bellow system designed to retract the target from exposure to the TEAC is also shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.1. Target holder for large targets

In the design of the first target holder the main consideration was to create a large flexibility in mounting different shapes and sizes, and still have adequate cooling. In order to mimic the conditions expected in ITER, castellated targets (tungsten and carbon) with active and passive cooling have been designed, that can be mounted on the large target holder.

The holder consists of a stainless steel plate of 320 mm in height, 120 mm in width and 10 mm in thickness, with 12 cooling channels milled into it. Brazed on top is a 3 mm copper lid which is milled after brazing, to 2.5 mm, to ensure a good flatness of the final surface. A copper lid was chosen to ensure good heat transfer to the cooling channels. As shown in Fig. 2, 52 holes are available for target mounting. The holes are 24 mm apart in length and width. The smaller holes can be used to insert thermocouples which are necessary to monitor the bulk target temperature.

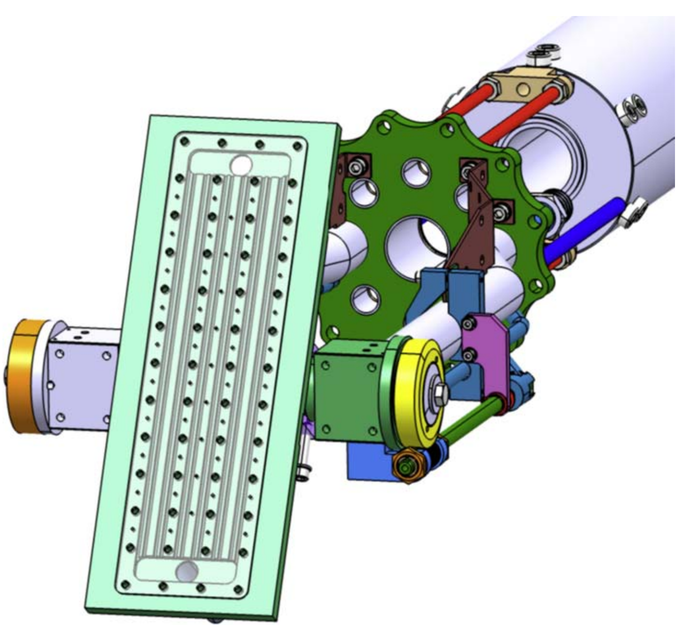

Fig. 2. The target manipulator and the holder for large targets. The copper lid is made transparent to show the water cooling channels, the mounting holes and the little holes for thermocouples. Behind the target holder, a part of the manipulator is shown.

Calculations in ANSYS are done to determine the best channel cooling geometry, based on the beam properties. Fixed parameters are the following:

- Cooling water temperature and pressure: 20 °C and 1 MPa.
- Gaussian heat flux profile with peak power >10 MW/m^2 and radii from 10 to 100 mm.
- Tunable parameters:
- Cooling channel geometry: diameter of a channel, distance between channels and number of channels.
- Surface contact improving material (see Section 3).

The water pressure available for the target is 1×10^6 Pa [4]. If the losses in the water supply pipes are about 2×10^5 Pa, ca. 7×10^5 to 8×10^5 Pa is left for the target base plate. The total flow reserved for the target is 50 l/min. Assuming 12 channels to cover the whole width of the target, the maximum flow per channel is 4 l/min. With a length of 0.3 m the smallest diameter for an acceptable pressure drop (7.5×10^5 Pa) is calculated to be 2 mm. The film coefficient in one channel then becomes 60 kW/m^2 K.

To determine the optimum position of the cooling channels, different geometries were modeled using ANSYS, with the common constraint that room for the bolts and thermocouples is needed.

The calculations resulted in the following conclusions:

- The temperature difference due to the distance between cooling channels of 5 or 7 mm in perfect conducting layers is negligible.
- The temperature difference due to the distance between cooling channels of 5 or 7 mm with imperfectly conducting layers is also within the Ansys tolerances, and therefore negligible.
- The temperature difference due to all channels or only the 4 in the middle, with perfect conducting layers, is about 110° (difference gets higher if conducting layers are not perfect) and can be adjusted by closing the cooling channels on the outside of the holder.
- The temperature difference between all cooling channels and only 4 cooling channels gets bigger for lower layer conduction.

2.2. Mock up for the Magnum-PSI target

To validate the ideal way of target mounting onto the holder, a test set up was made to determine and optimize the total heat conductivity in several configurations [5].

The test set up is half the size in the length of the Magnum-PSI target to compensate for the lower heat load during the tests, so that the water temperature rise remains measurable. Besides the length, the other major difference is the way the outgoing water channels are constructed (see Fig. 3). At the end of the plate, the eight water channels are soldered to eight cylindrical water tubes, so the possibility to measure the temperature of each channel is created for spatially resolved measurements. Other dimensions are similar to the Magnum-PSI target.

Brass is chosen for the target material in this test set up to have a good thermal conductivity and mechanical strength to ensure good mounting capability.

To improve the thermal contact between the target and the cooling plate, a thin layer of a suitable material is added. For this purpose several materials have been selected, based on both their compatibility with high temperatures and vacuum environment, and their mechanical properties. The tested materials include grafoil® (flexible graphite foil), silverfoil and Apiezon® H Grease. To make a good comparison between the materials, the measured thermal conductivity is normalized to the thickness of the layer to give the heat transfer coefficient between the target and the cooled copper plate. Since the materials are

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