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Design of the Wendelstein 7-X inertially cooled Test Divertor Unit Scraper Element☆

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HIGHLIGHTS

- The justification for the installation of the Test Divertor Unit Scraper Element is given.
- Specially designed operational scenarios for the component are presented.
- Plans for the design of the component are detailed.

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ABSTRACT

The Wendelstein 7-X stellarator is scheduled to begin operation in 2015, and to achieve full power steady-state operation in 2019. Computational simulations have indicated that for certain plasma configurations in the steady-state operation, the ends of the divertor targets may receive heat fluxes beyond their qualified technological limit. To address this issue, a high heat-flux “scraper element” (HHF-SE) has been designed that can protect the sensitive divertor target region. The surface profile of the HHF-SE has been carefully designed to meet challenging engineering requirements and severe spatial limitations through an iterative process involving physics simulations, engineering analysis, and computer aided design rendering. The desire to examine how the scraper element interacts with the plasma, both in terms of how it protects the divertor, and how it affects the neutral pumping efficiency, has led to the consideration of installing an inertially cooled version during the short pulse operation phase. This Test Divertor Unit Scraper Element (TDU-SE) would replicate the surface profile of the HHF-SE. The design and instrumentation of this component must be completed carefully in order to satisfy the requirements of the machine operation, as well as to support the possible installation of the HHF-SE for steady-state operation.

1. Introduction

The divertor of the W7-X stellarator will evolve through three distinct phases of operation. For the first plasma, scheduled to begin in 2015, the device will operate with a limiter instead of a divertor. For the next operational phase, scheduled to begin in 2016, an inertially cooled divertor (called the Test Divertor Unit, or TDU) will be installed so that the device can operate at higher power for short pulses. Finally, an actively cooled divertor will be in place for steady-state, full power operation, scheduled for 2019. This high heat-flux divertor will use a flat tile technology that is qualified to handle heat fluxes of 10 MW/m^2 [1]. However, the edges of these tiles are qualified to a lower limit of 5 MW/m^2.

Plasma simulations have shown that a bootstrap current of up to 43 kA may evolve for certain plasma configurations. This

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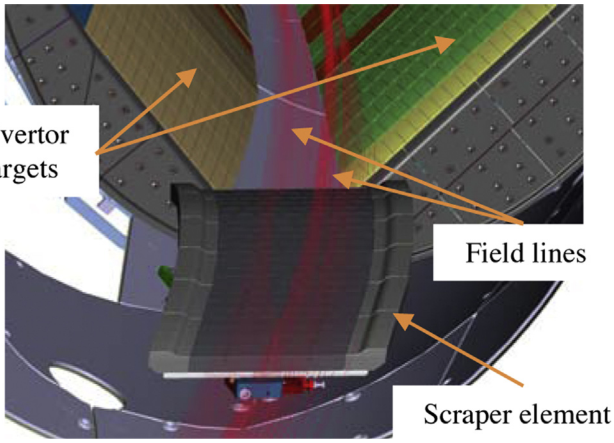

Fig. 1. View of W7-X divertor region with field lines.

could cause the edges of the divertor targets to be overloaded. A high heat-flux scraper element (HHF-SE), if placed in front of the divertor pumping gap, would intercept a portion of the convective flux and protect the divertor edges (see Fig. 1) [2]. This HHF-SE has been designed using carbon fiber reinforced carbon composite monoblocks which can withstand steady-state heat fluxes up to 20 MW/m^2 as shown by many previous studies, including those on behalf of ITER [3–6]. A HHF-SE would be placed in each of the ten W7-X divertor locations.

There are two primary questions regarding the inclusion of the HHF-SE during steady-state operation. First, will it protect the divertor edges as predicted in simulation? Second, will the HHF-SE detrimentally affect the neutral pumping efficiency? In order to answer these questions, the inclusion of an inertially cooled Test Divertor Unit Scraper Element (TDU-SE) has been planned for the short pulse operational phase.

2. Physics simulation

The bootstrap current that produces the unacceptable heat fluxes for which the HHF-SE was developed evolve over the time scales of roughly 30 s. The time scales for short pulse operation (TDU phase) will be on the order of 10 s, thus it will not be possible to create a plasma scenario with this bootstrap current that will appropriately load the TDU-SE. A set of magnetic coil currents that produce a vacuum field configuration that mimic the scenarios of concern have been developed. A 22 kA-mimic and a 43 kA-mimic configuration have been planned. The convective heat fluxes on the divertor components have been modeled using magnetic field configurations [7,8]. The strike patterns and heat fluxes that occur on the divertor target and the scraper element are shown in Fig. 2. The heat flux that results from the 22 kA bootstrap current during long pulse operation is compared with the 22 kA-mimic configuration during short-pulse operation. It is believed that the resulting flux stripes are qualitatively similar enough to draw conclusions during short pulse operation about the use of the scraper element in long pulse operation. However, the TDU-SEs will be placed in only two of the ten divertor locations. Simulations have shown that this will result in up to 40% higher load on these components. It is expected that reducing the input power into the device can compensate for this without compromising the measurements needed to assess the effects of the presence of the scraper element.

3. Design

The design of the scraper element has been done from the "top-down" with the plasma facing surface being the most critical element. The HHF-SE is the design basis for the TDU-SE, where having an equivalent top surface is a requirement for the design. Fig. 3 shows the similarities and differences between the HHF-SE and TDU-SE full assemblies along with the support base mount.

3.1. Requirements

Some of the constraints and requirements on the design of the TDU-SE can be described as follows:

- Maximum surface temperature of graphite = 1800 °C.
- Maximum surface temperature of wall panels behind the TDU-SE = 200 °C.
- Maximum temperature of stainless steel support components = 500 °C.
- Magnetic permeability <1.01 for all materials.
- Cobalt content <500 ppm for all parts.
- Assembly can be adjusted ±7 mm in each direction during installation.
- The final position of the assembly must be within ±1.5 mm in any direction of the target position.
- TDU-SE base plate structure can accept 100 kg load.
- TDU-SE can be installed from pieces weighing less than 25 kg.

Operation requirements will be satisfied under a design basis scenario, which is similar to the design bases for the TDU. A 1.25 MJ heat load will be applied, which is expected to be a rectangular

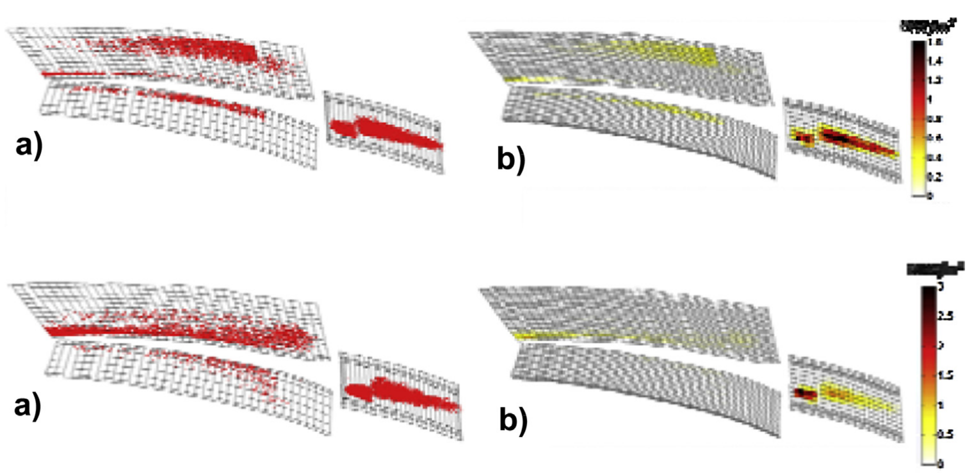

Fig. 2. Strike patterns (a) and heat flux (b) for 22 kA bootstrap current configuration (top) and 22 kA-mimic configuration (bottom).