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On the Alignment of the Scraper Elements at Wendelstein 7-X

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Increasing the energy input at Wendelstein 7-X needs protection of the divertor front and the pumping gap from thermal overload. Two passive cooled test scraper elements have been installed in front of two out of ten divertor units. Their influence on the plasma experiments is being checked for decisions on the future upgrade of Wendelstein 7-X in-vessel interior. The paper reports on the manufacture and alignment accuracy of the components. The machined graphite surface fits well to the design. Handling, even inside the restricted space of the vacuum vessel, turned out to be feasibly, especially due to the use of fitted bearings to mount the heavy components. Alignment of each of the two scraper elements was achieved within a tolerance of 1.5 mm with respect to the as-built position of the corresponding divertor unit.

Keywords: Wendelstein 7-X, installation, metrology, as-built manufacture, divertor, scraper elements

1. Introduction

Wendelstein 7-X (W7-X) is equipped with ten symmetric arranged divertor units consisting of horizontal and vertical targets each (fig. 1). Up to now, W7-X is operated with inertially cooled test divertor units whereas the maximum energy per discharge is limited to 80 MJ. For future operation campaigns (OP 2 and further), with long pulses up to 30 minutes, the test divertor will be replaced with water cooled divertors consisting of target elements with a plasma facing surface of CFC tiles welded onto a water cooled CuCrZr structure. However, the edge tiles of the target elements are qualified for reduced heat load due to a larger distance to the water cooling.

In OP2, in some configurations a transient toroidal plasma current develops (in ~ 1 minute) which causes a shift of the strike line on the divertor and a temporary overload of the edge tiles. One way to prevent overloading these edge tiles is the installation of so called Scraper Elements (SE) in front of the divertor units scraping off parts of the strike lines that would otherwise hit these edge tiles of the divertor (fig 2) [1].

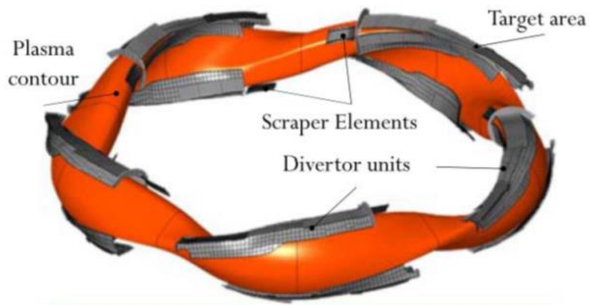

Fig. 1: Arrangement of the ten divertor units in relation to the plasma at Wendelstein 7-X. (Looking into toroidal direction) A scraper element is located in front of each divertor unit.

In the present plasma operation phase of W7-X (OP 1.2b) the principle behavior of SEs is tested, especially their capability of thermal protection as well as their influence on the pumping rate. These investigations are made on two inertial cooled test-SEs installed in the modules 3 and 5 of W7-X. Dedicated configurations have been developed [2] to mimic these toroidal currents of OP2 in short pulse operation of OP1.2. In these configurations, the SEs will intersect the strike lines. To ensure that the SEs will not be overloaded in the these configurations and not be loaded at all in other configurations planned for OP1.2, tight tolerances are imposed on the SE shape and alignment. A comparison between similar plasma operation with and without SE is expected to provide important physics input for the decision whether 10 fully water cooled SE should be installed for operational phase 2 of W7-X.

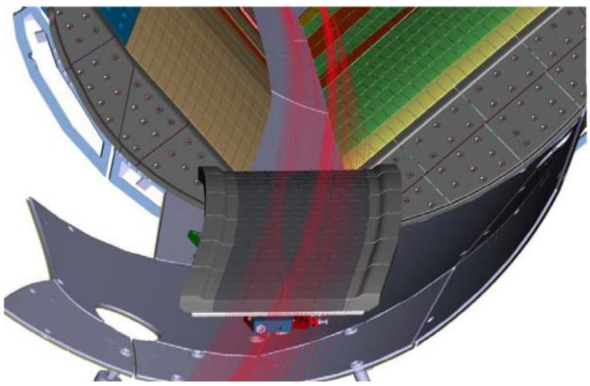

Fig. 2: CAD of the scraper element in front of the divertor unit. The heat flux lines strike the scraper and the divertor targets behind the scraper. The edge tiles adjacent to the gap between left and right divertor targets is shielded by the scraper element.

2. Basic Design of Scraper Elements

An entire SE-unit consists of three main subunits: a.) support elements for fixation of the SE on the present inner vessel structures, b.) a baseplate which can be precisely adjusted in position and c.) the first wall

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consisting of graphite blocks mounted on a stiff stainless steel frame (graphite - backing plate unit) (fig. 3) [3].

Since SE installation takes place in a complete furnished Vacuum Vessel (VV) and no removal of present components was foreseen the SE are mounted piggyback on existing stainless steel wall panels. Therefore three existing lock nuts of the wall panels are replaced by new support elements which fasten the present components and provide an interface for the fixation of the base plate. The support elements are not adjustable. Their resulting position depend on the actual position of the present wall panels which had been adjusted in a general accuracy of 1.5 … 2 mm in space before W7-X went into operation.

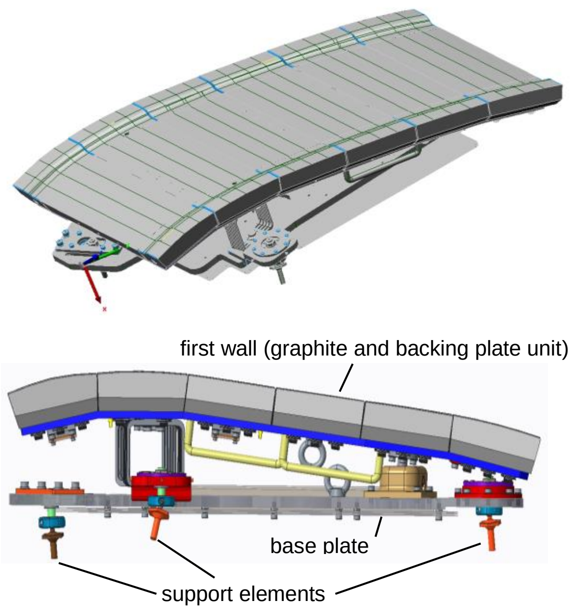

Fig. 3: CAD of the scraper element. Base plate and graphite - backing plate unit are preassembled and aligned to each other outside VV. After preassembly they are dismounted and each part is independently moved into VV and mounted there.

The base plate is fixed by bearings on the support elements. One of the bearing is a fixed one whereas the other two allow sliding of the base plate due to thermal expansion in one and two directions respectively. The bearings allow a very fine position adjustment of the base plate within ranges of ±7mm in all three directions: toroidal, poloidal and normal to the base plate. The base plate carries another set of bearing elements to hold the first wall. These bearings are designed using fitted components. By means of these fitted components dismantling and reassembly of the backing plate can be performed within a very high repetition accuracy of only a tenth of a millimeter. Initial alignment of the first wall to the base plate is made in a preassembly step outside of the VV including the geometrical survey.

The graphite blocks are made from similar graphite used for the test divertor at W7-X. Their surface has to be manufactured very accurately compared to CAD. Steps between single blocks have to be lower than 0.2mm to avoid leading edges which can result in a thermal overload during plasma operation. The maximum allowed surface temperature of the graphite is limited to 1800°C. The blocks are fixed on a stiff stainless steel backing plate which guarantees the geometrical accuracy of the surface shape.

Both the first wall and the base plate contain measurement marks representing the best fit alignment of the graphite surface with respect to the CAD.

For work safety and handling reasons, the dead weight of the components to be installed inside VV is limited to about 25 kg. Equilibration of functionality and design feasibility of the SE ended up in a dead weight of 27.5 kg and 12.1 kg for first wall and the base plate respectively.

3. Installation and Alignment of Scraper Elements

For plasma physical reasons the SE has to be aligned relative to the corresponding divertor unit. The alignment tolerances are: ± 1.5 mm in toroidal and poloidal direction and ± 1.5 mm perpendicular to the plasma axis. In addition the graphite surface should not be tilted more than ± 0.5° around a local toroidal axis and ± 0.2° around a local poloidal axis.

Assembly of SE had started with a preassembly of base plate and first wall including an adjustment of both to each other, performed outside the VV. In a following geometrical measurement the graphite surface was probed and best fit aligned to CAD, and all measurement marks got new as-built co-ordinates (fig. 4).

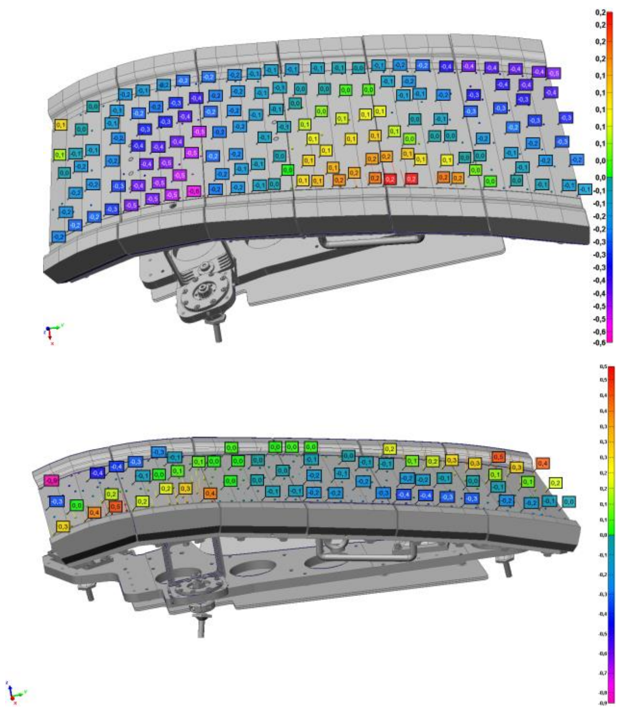

Fig. 4: Comparison of as-built graphite surface to CAD of SE 38 (upper part) and SE 59 (lower part). In the plasma physical relevant center of the surface the steps of neighboring graphite blocks are lower than the required value of 0.2 mm

Fig. 4 shows that in the most important areas of the graphite surface the steps between neighboring blocks fulfill the requirements of less than 0.2 mm. Only at the plasma physical non-relevant edges of the graphite the steps slightly exceeds the tolerances. For achieving an optimized alignment of the SE the co-ordinates determined in that preassembly step are again best fit aligned to the as-built position of the corresponding divertor unit measured before W7-X went into operation. The resulting co-ordinate shifts of that procedure amounts to approx. 1 mm for each SE.

During previous completion phases of W7-X the local deformation of the VV due to evacuation of the cryostat, surrounding the VV, was checked. Transition from vacuum to environmental pressure inside the cryostat deforms the VV locally by approx. 1 mm. Since actual SE-assembly takes place with both vessels under the same environmental pressure, which is very similar to the operational situation when both vessels are evacuated, adaptation of the target SE-coordinates to vessel deformations became not necessary.

Installation of the SE starts with mounting of step protections in the SE-area and temporal removal of surrounding in-vessel components necessary to get access to fixation points of the measurement device and measurement marks.

Installation and alignment processes inside VV are usually done by two people. On the one hand both people have to support each other in the very difficult working environment, on the other hand more than two people are usually not able to work at one place in the restricted space of VV.

In a first installation step the support elements and the base plate were mounted. Adjustment processes inside VV are usually performed using a articulated arm with a measurement range of $r < 1.25$ m and a nominal measurement uncertainty of $\delta = 0.078$ mm inside that volume. For orientation of the measurement system usually 5 … 6 reference points are used which should be distributed around the measurement object as best as possible. For measurements inside VV a typical uncertainty of the orientation process is a RMS-value of ≈ 0.2 mm calculated using the deviation of all reference points used. In case of the RMS-value exceeds 0.4 mm the orientation process has to be repeated.

Adjustment of the base plate was performed with in an averaged alignment deviation of 0.7 mm, whereas no measurement target exceeds a deviation of 0.9 mm. Between base plate and first wall both components are equipped with thermo-elements which allow a temperature monitoring of the graphite and steel during plasma operation.

Simple fitting of the first wall into the base plate bearings completes the SE-assembly (fig. 5). A final measurement of the SE-position checks the resulting deviations. Both SE were installed within the required tolerances, see for example fig. 6. Since no deviation shows a value of > 1.5 mm a separation of the deviations shown in x-, y-, z-direction into local toroidal, poloidal and normal directions is not necessary.

Fig. 5: Fitting the first wall into the bearings on the base plate. Repetition accuracy for re-installation are only some tenth of a millimeter. No further alignment is necessary.

Fig. 6: Alignment residuals of the final position of SE 58. All measurement marks are inside a sphere with $r < 1.5$ mm and meet the accuracy requirements.

4. Summary

In the W7-X completion phase 1.2b two passive cooled SEs have been installed in modules 3 and 5 to test their functionality (fig. 7). Tight tolerance requirements could be easily met, thanks to the statically determined support system, which excludes over-constraining the system. The well accessible adjustment features on the base plate and reference marks for position measurements further facilitated installation.

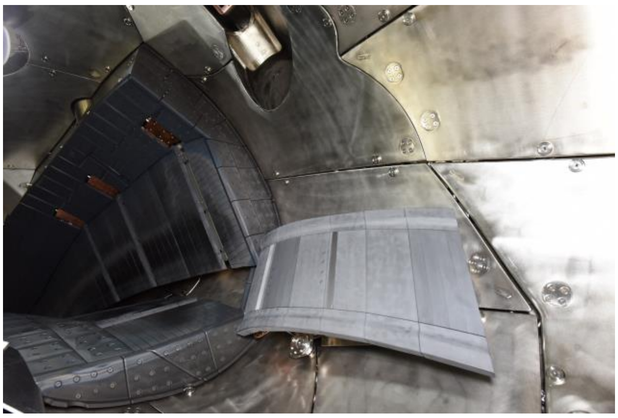

Fig. 7: Final assembled scraper element, piggyback mounted on wall shield elements. In the background: the graphite target elements of the horizontal and vertical divertor and some adjacent baffle modules.

After final machining of the SEs a geometrical measurement shows that the graphite surface fit very well to the designed shape. In general the steps between neighboring graphite blocks meet the required values of less than 0.2 mm. Only on the plasma physical non-relevant edges of the graphite the requirements are slightly over stepped.

The handling of all components was practicable; even though the weight of the backing plate-graphite unit amounts 27.5 kg. Due to bearings which allow dismounting and reassembly within a repetition accuracy of only tenth of a millimeter the main alignment process of the components can be performed outside the VV in a separate preassembly step.

It could be shows that the in-vessel alignment of the SE is feasible within the required tolerances of ± 1.5 mm in each of the predestinated dimensions: toroidal, poloidal and normal to base plate.

In general, it can be assessed that the test-SEs are assembled and aligned well in accordance to the design. Now the properties of the SEs are investigated in the running experiments. Based on the analysis of the SE-behavior with respect to the shielding efficiency and the remaining pumping rate further steps on upgrading the in-vessel interior of W7-X can be defined.

5. Acknowledgement

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