ECRH –Antennas and In-Vessel Components for the W7-X Stellarator

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***Abstract*— The development of the ECRH-antennas and in-vessel components for cw operation in the Wendelstein7-X stellarator is presented together with first test results.**

I. Introduction And Background

THE super-conducting Wendelstein7-X stellarator (W7-X), which is under construction in Greifswald (Germany), will be equipped with a 10 MW ECRH system at 140 GHz. The ECRH will be the main heating system and the only one, which is capable of CW operation [1]. Therefore, it has to cover a wide experimental parameter range and its components should have a high reliability. The antenna system consists of 12 individually movable mirrors including two spare beam lines with a toroidal steering range between ±15° and ∓ 35° and a poloidal steering range of ±25°. This highly flexible system allows heating and current drive with the second harmonic X- and O-mode at 140 GHz at full power and 104 GHz at half power. It also provides operation at the third harmonic X-mode at a lower magnetic field. Its maximum toroidal launch angle enables the Bernstein wave heating of ultra high density plasmas beyond the O2-cutoff by OXB-mode conversion. For heating scenarios with an incomplete single pass absorption specially designed reflector tiles will be installed into the inner wall graphite heat shield opposite to the launching antennas. The transmitted power as well as the beam position at the heat shield will be measured by about 120 small mono-mode pick-up antennas, which are incorporated into the heat shield and the reflector tiles. Furthermore, the high heat load conditions in cw-operation necessitate a reliable technical solution for the in-vessel components, which can sustain both, the power load of the microwaves and the plasma radiation.

II. Development And Test

The development of the ECRH-antenna has been performed in two steps. First a single mirror mock-up was built, see Figure 1. This mechanical prototype of this front steering launcher was tested for reliability and steering precision. In addition it was exposed to a microwave field up to 500 kW/m^2 in our microwave stray radiation test chamber. In the next step the final ECRH launchers were designed and are fabricated now. Figure 2 shows a CAD sketch of the plug-in launcher.

The launchers consist of one fixed and one movable mirror. The movable mirrors are adjusted by two rods (one for each degree of freedom) with bellows as vacuum barrier which are connected to linear drives. The two rods also serve as supply and return water pipes for the necessary CW cooling of the mirrors. Each adjustment rod is equipped with a Cardan and a ball joint which are bypassed by helically bent stainless steel pipes. The ball joint is necessary to assimilate the torque which occurs when the rods move.

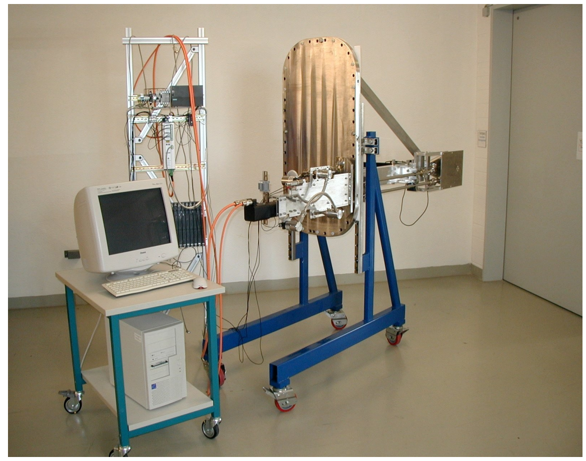

Figure 1: Test setup of the prototype

The test of the vacuum bellows and the water supplies was done in the test chamber for ~10000 cycles. It turned out that the lubrication-free ball joints were the most critical part. They have now been replaced by ceramic joints which are suitable for the in-vessel conditions.

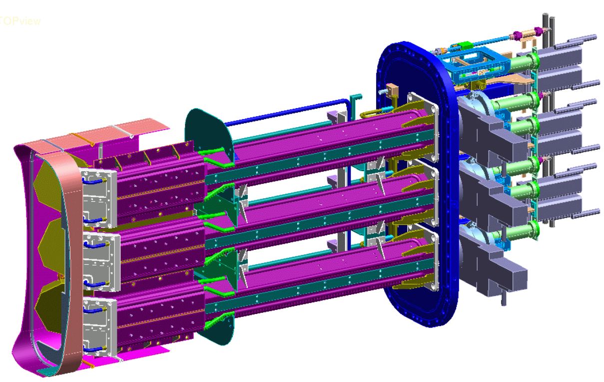

Figure 2: CAD drawing of the ECRH plug-in launcher with 3 beam lines

In addition to the four W7-X ports, which allow for low field side launch with up to 12 beams in total, W7-X provides two single beam ports for special purposes like advanced current drive scenarios. Here, a remote steering antenna is under design [2]. It is has no movable parts inside the torus and is based on the Talbot effect in waveguides. Due to this effect, an oblique input beam on a corrugated square waveguide is reproduced at the output if the distance to the input is a multiple of $4a^2/\lambda$, where a is the waveguide width/height and λ is the vacuum wavelength. So if the vacuum window is placed on the waveguide input, the movable mirrors can be placed outside the

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torus. Figure 3 shows the infrared image of a remote steering antenna in a high-power test at W7-X.

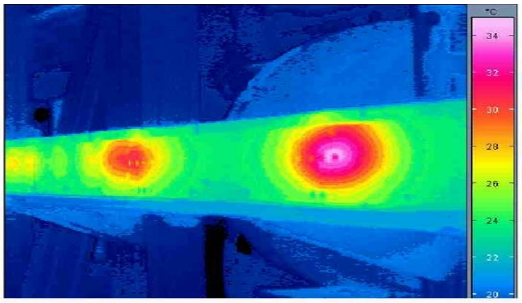

Figure 3: IR image of a high power remote steering experiment [2]

For the O2 and X3 ECRH scenarios with an incomplete single-pass absorption microwave reflectors have to be installed at the inner vessel wall. These tiles consist of a TZM (titanium, zirconium, molybdenum) alloy mirror surface. This material is characterized by a high heat resistivity and a sufficiently high microwave reflectivity. The TZM tiles are clamped on a water cooled copper structure. In addition they are equipped with transmission measurement pick-up antennas, which are incorporated into the tile (see Figure 4).

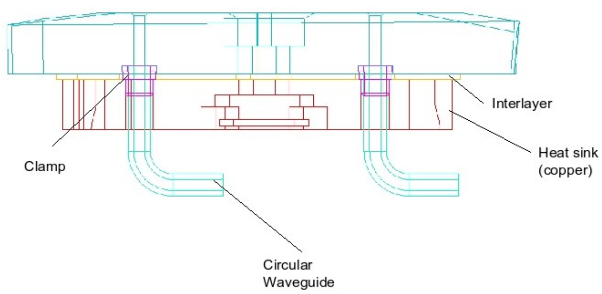

Figure 4: CAD drawing of the TZM tile (total width 11cm)

The thermal properties of the tile have been simulated with ANSYS for different beam profiles. In addition, a test tile has been manufactured and was successfully tested with a 500 KW 140 GHz beam which is the maximum expected power after a single-pass absorption on the high-field side.

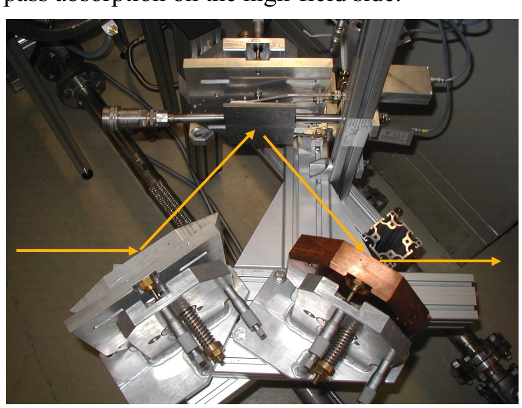

Figure 5: Test setup for the TZM tile

The thermal analysis was carried out with an infrared camera. In order to visualize the correct surface temperature, strips with black body characteristics have been fixed at the back side. This allowed for a correction of the lower emissivity of the TZM material. Figure 5 shows the measurement setup. Figure 6 shows the corresponding infrared image. An infrared reflector was placed behind the tile to observe the backside with the strips for the emissivity enhancement. In Figure 6, the left square is the tile and the right square is the reflector behind.

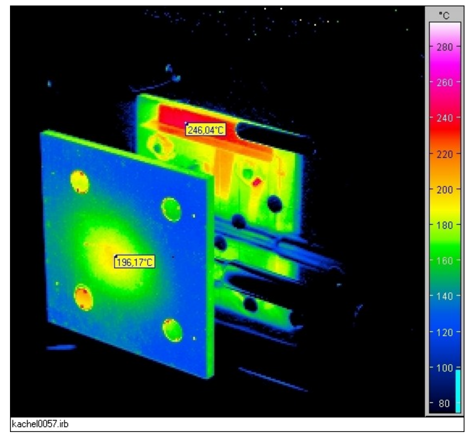

Figure 6: Infrared image of the TZM tile in a high power test

The transmission measurement consists of approximately 120 circular waveguides with a length of 5 m and an inner diameter of 2 mm. These waveguides allow for the measurement of the non-absorbed power and the polarization. The waveguide bends introduce a phase shift between the different polarization directions. Therefore it is necessary to compensate this phase shift for each waveguide. The successful compensation of the bends by means of a properly squeezed (and hence birefringent) and rotated waveguide section was already demonstrated for a prototype. A backup solution for the TZM tile with graphite instead of TZM is possible in the case that the tile produces too much high-Z impurities in the stellarator.

III. SUMMARY

The major ECRH in-vessel components for W7-X have been designed and are currently manufactured. Integrated vacuum leak and heat load tests have shown that the individual components have the necessary reliability and can bear the in-vessel conditions.

REFERENCES

[1] V. Erckmann, P. Brand, H. Braune, G. Dammertz, G. Gantenbein, W. Kasparek, H. P. Laqua, H. Maassberg, N. B. Marushchenko, G. Michel, M. Thumm, Y. Turkin, M. Weissgerber, A. Weller, W7-X ECRH Team at IPP Greifswald, W7-X ECRH Team at FZK Karlsruhe, W7-X ECRH Team at IPF Stuttgart, "Electron Cyclotron Heating for W7-X: Physics and Technology", Fusion Science & Technology, Volume 52, Number 2, August 2007, Pages 291-312

[2] B. Plaum, G. Gantenbein, W. Kasparek, K. Schwörer, M. Grünert, H. Braune, V. Erckmann, F. Hollmann, L. Jonitz, H. Laqua, G. Michel, F. Noke, F. Purps, A. Bruschi, S. Cirant, F. Gandini, A.G.A. Verhoeven, and ECRH groups, "High-power tests of a remote-steering antenna at 140 GHz", Fusion Science and Technology, Volume 50, 1–14, 2006

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