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DESIGN AND OPERATIONAL DIAGNOSTICS OF THE W7-X DIVERTOR

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1. Introduction

The stellarator W7-X is presently under construction at Greifswald, Germany and the start of operation is scheduled in 2006. Important aims of this experiment are the studies of energy and particle exhaust under quasi-stationary conditions and the development of a reactor relevant divertor system. In extreme scenarios particle fluxes up to $1x10^{22}$ particles/second [1] and heat fluxes up to 10 MW have to be continuously removed by the divertor components of W7-X. Corresponding to the modular design and the five identical magnetic field periods this machine will be equipped with ten divertor units arranged toroidally along the helical edge. In a first step an open divertor configuration will be explored [2]. The divertor equipment, consisting of target plates, baffle plates, cryo-pumps and control coils guarantees a large experimental flexibility and can accomodate the entire ι-range, different island sizes and positions and even an ergodized boundary layer. Moreover it allows proofs of particular scenarios, including operation with radiative boundaries with high plasma densities for which the stellarator provides favourable conditions. Succesful quasi stationary high density operation with a similar open divertor arrangement has recently been demonstrated in the presently operated stellarator W7-AS [3].

2. Divertor Design

2.1. Target Plates

The target plates of the divertor units consist of about 130 target elements which are combined to 13 modules. With two target plates per divertor unit, a total of twenty target plates will be arranged along the plasma column and cover a total area of 22 m^2. The exact position and the shape of the target plates were chosen to intercept the particle flow from the plasma along the open flux bundels at the boundary at a maximum distance from the confinement region. To limit the heat load to values below 10 MW/m^2, the focus area is adjusted to achieve a small incidence angle of $1\text{-}3^o$ at the target plates. The design of the target plates had to be approximate the ideal 3-D surfaces derived from physics by a series of planes and allow for a nearly constant incidence angle of the particles. Segementation of the 3-D surfaces led to seven standardised plane elements with dimensions ranging from 55x270 mm^2 to 55x500 mm^2. Flat carbon fibre tiles will be brazed or welded on the metallic cooling structure. Presently, the combination of CFC NB31 (SEP, France) combined with a CuCrZr heat sink is favoured.

9 to 14 single target elements are assembled to modules on a common support structure (see fig.1). These elements are actively cooled by pressurized water flow. The static pressure will be 10 bar and the inlet/outlet water temperature in the range from 30 to 80 ^oC, respectively. A prototype target module comprising 9 to 15 target elements is now being designed in detail. The design has to keep gaps between target elements small, provide flexibility for diagnostic instruments and consider requirements from the heating system.

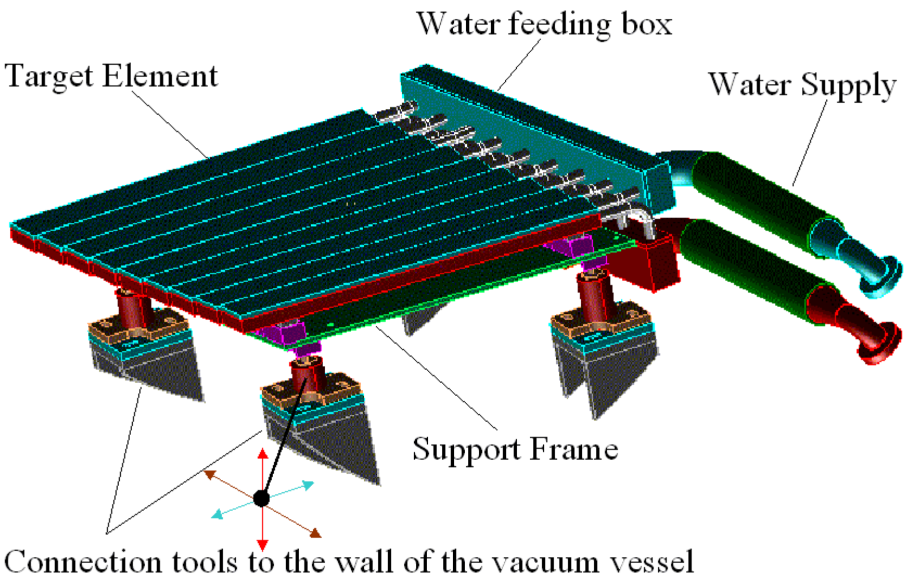

Fig.1 Prototype of target module 5

2.2. Baffle and pumping

In order to control the neutral particle flux and avoid strong recycling effects, baffles are installed adjacent to the vertical target plates. The baffle elements, covering 3 m^2 per divertor unit, are designed to withstand a power load up to 0,5 MW/m^2. The conventional concept uses flat carbon tiles clamped to a water-cooled structure.

Vacuum conditions with a base pressure less than 10^{-8} mbar are generated by turbomolecular pumps providing an effective pumping speed of 4200 l/s at the divertor box and in addition by cryopumps located behind the baffle plates allowing the pumping capacity to be increased during high-density discharges, e.g. during injection of neutral beams or pellets. In such cases particle fluxes up to 10^{22} particles/second have to be handled at pressures of about 10^{-3} mbar in the divertor.

2.3. Control coils

Two control coils are integrated in each field period. The main features of the control coils are: to control the variation of the connection length and modify the radial distance between target plates and separatrix by changing the island size at the boundary, to compensate magnetic field errors and to shift or spread the power deposition on the target plates.

3. Operational Diagnostics

To guarantee the safety of the machine and monitor the operation mode some basic diagnostics for the divertor components with data evaluation in real time are necessary. In respect of the energy balance the operational divertor diagnostics include instruments for thermography, thermometry, water flow control and measurements of thermo-currents to the divertor modules. Additionally, for the control of the particle balance localised gas feed, mass spectrometry and measurements of gas pressure inside the divertor units have to be provided.

3.1 Thermography

To be able to determine local power deposition, to detect asymmetries of heat load to the targets and to prevent damage of target elements by overheating or mechanical defects a continuous supervision of the target surface area by thermography is essential. The surface temperature of the CFC target elements must be limited to 1200°C. This temperature is determined by the thermal conductivity of the CFC material and the cooling structure. For the thermography system 10 uncooled microbolometer cameras operating with sensors in the micrometer-wavelength region and appropriate infrared optics of about 1.5 m length will be installed (see fig.2).

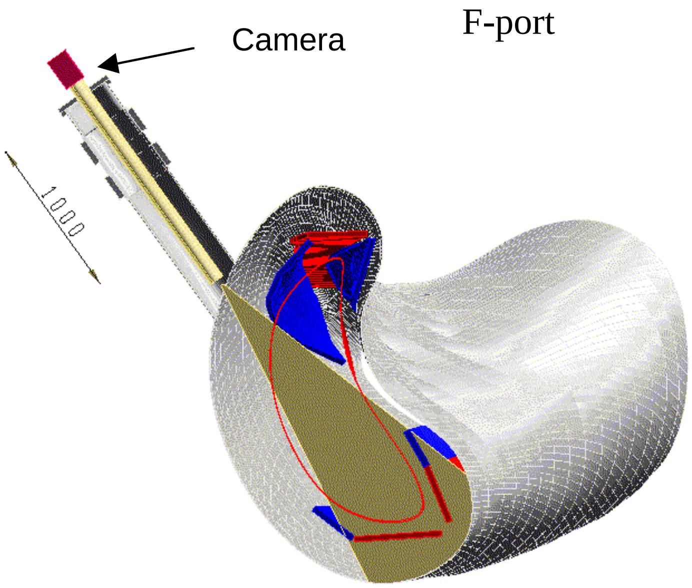

Fig.2 Cross sectional view of port F showing the IR-camera, the lens system, the field of view, the observed target plates (red) and the baffles (blue)

Currently manufactured cameras have 320x240 pixels at 12 bit resolution and operate with a frame rate of 50 Hz. The thermography system has to dispose signals indicating anomalous operation scenarios immediately. This requires image acquisition and data transfer at rates of at least 20 Mbytes/s to achieve local and temporal resolution of about 10 mm and 100 ms, respectively. This is expected to be realised in near future with digital output cameras and a frame grabber as interface to a PC host computer operating with Windows NT. The software must be able to detect invalid values of the measured surface temperature, intolerably hot target areas and strong temperature rises and has to generate control signals indicating tolerable, dangerous and unreliable operation. Data collection and processing was tested with appropriate assembly of a CCD camera and a PC-system based on a PIII 500 MHz dual processor. A software package analysing the camera data with respect to invalid values and pre-selectable threshold values was developed. Data collection and processing rates of up to 5 Mbytes/s are now achieved. Higher rates should be possible in the next few years by using more advanced hardware and software components.

3.2. Thermometry and water flow control

For thermometry and water flow control about 2000 PT100 temperature sensors and about 100 ultrasonic flow meters will be used. A PROFI bus system (SIMATIC, Siemens) has been constructed that will record and analyse the data of the thermo-sensors and the flow meters with a refresh time of about 1s. A scheme of the data acquisition system is shown in fig.3.

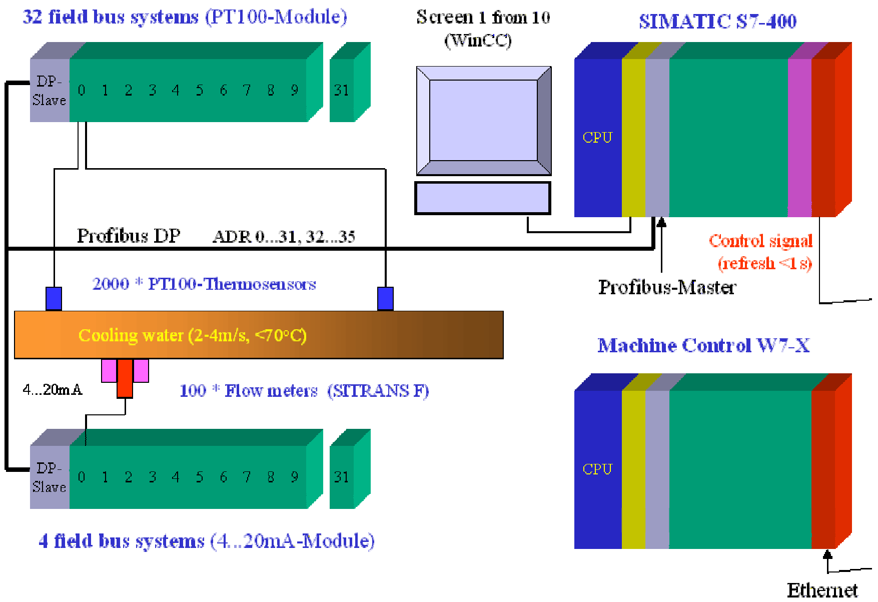

Fig.3 Schematic view of the real-time data aquisition system for cooling water calorimetry

3.3. Target current measurements

For measuring the electric potential and thermo-currents to the target modules the water cooling pipes can be used as shunt resistors. First experiments with a high-current generator showed that they have sufficiently high electrical resistance.

3.4. Neutral gas control

Control of the neutral gas distribution in the torus local gas puffing at the divertor target plates and in the main chamber will be realised with up to 50 calibrated fast valves.
The total pressure and neutral flux in the divertor chamber will be measured by ASDEX-type ionisation gauges [4] (10^{16} - 10^{20} D_2/cm^2s, time resolution 1 - 10 ms).
To get detailed information on the gas distribution inside the divertor units:

12 gauges in one module
2 in each other divertor unit (x 8 = 16);
5 in the triangular cross-sections giving a total of 33 gauges.

To measure asymmetries between the individual divertor units:

3 gauges per divertor unit - (x 10 = 30) near the striking zone for ι = 5/6, 5/5, 5/4
5 in the triangular cross-sections giving a total of 35 gauges.

The partial pressure of Helium will be measured with modified ASDEX-type ionisation gauges based on the detection of photons emitted (10^{17} - 10^{20} He/cm^2s, time resolution 10 - 50 ms). These will be installed preferably in the private flux region.
To determine the composition of the exhaust gas residual gas analysers of quadrupole type will be used in the pump ducts. They will be combined with modified Penning gauges to distinguish between D_2 and He. This makes magnetic shielding necessary.

References:

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