Conceptual design of DTT magnetic diagnostics

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The Divertor Tokamak Test (DTT) is a new tokamak device whose main mission is to explore innovative divertor concepts for DEMO and test them in heat loads conditions on plasma facing components relevant to a fusion reactor [1]. The device is presently going through a detailed design process, and the tendering process has started for some of the components. Magnetic diagnostics for plasma current and shape control, and vertical position stabilization are essential diagnostics for tokamak operation, and are the first diagnostic components that will need to be ready for installation and commissioning when DTT vacuum vessel and magnets are assembled.

Operative conditions:

The DTT operational conditions for in-vessel and ex-vessel magnetic diagnostics resemble those that will be encountered in ITER (high heat flux, long pulses, large electromagnetic stresses), except for the 14MeV neutron effects [1].

The operative temperature of the vacuum vessel should be included between 40° and about 100°C, with the latter temperature only reached during programmed baking cycles. The first wall operative temperature should be dynamically determined by the thermal load produced by the DTT plasma, and it should be bounded between 100 and 300°C. The operative temperature inside the cryostat is varying depending on the sensor's position: sensors located on the outer surface of the vacuum vessel should be thermally grounded to vessel temperature, but they are also very close to the thermal shield that protects the central solenoid which operates at 80K, therefore giving rise to large thermal gradients [1].

The pulse length can be a critical parameter both for possible neutron induced voltages, and for neutron total fluence calculation. The pulse can last up to 100s to the flat top end in absence of non-inductive current drive. When the tokamak will be operated in deuterium the expected maximum 2.5 MeV neutron yield rate is 1.0-1.5 x10^{17} n/s with a total neutron production of ~3×10^{22}n during its lifetime. The available space for magnetic diagnostics is limited by the interface with other in-vessel components, in the HFS a radial space of only 1.5cm is available for in-vessel magnetic sensors hosted behind the first wall. A radial space of 2cm is available for magnetic sensors hosted between the vacuum vessel and the thermal shield. The bandwidth requirements are not very stringent for ex-vessel coils, since the magnetic field penetration time for the vacuum vessel is of the order of 40ms. For in-vessel coils the bandwidth requirements are set by the ability to control the plasma vertical position in the most unstable plasma shape. Fast coils dedicated to MHD studies are required to capture at least low frequency Alfvèn activity, with a bandwidth of 2-4MHz.

Effective Area, sensitivity and number of sensors

This section describes the analysis procedure carried out in order to determine the number of in-vessel magnetic pick-up coils for the DTT tokamak.

In order to assess the performances of each of the considered sets of sensors, filamentary currents were located each of the squares shown in [1]. The currents were turned on one at a time (with a current of 1A) and the sensors were used to estimate each filament current and position.

This problem has been solved under the additional simplifying assumption of not neglecting any current flowing in the external active circuits or in the passive structures surrounding the vessel. Moreover, the ideal measurements (i.e. without noise or measurement errors) have been considered.

Several options have been considered. The magnetic sensors have been located along the vacuum vessel inner and outer shell contours. Only bi-axial sensors have been considered up to now, and no mechanical constraints were taken into account when choosing their

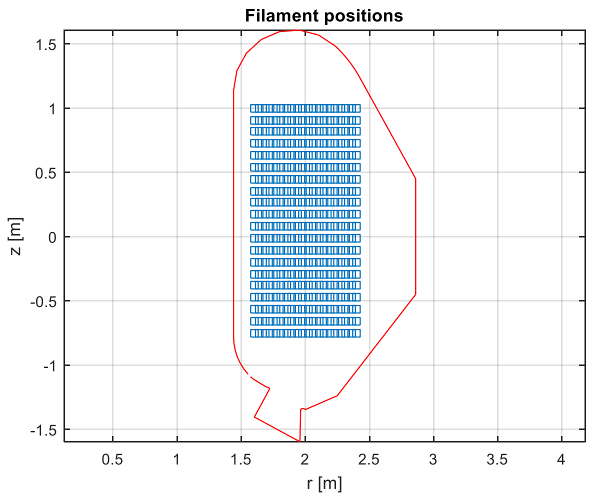

Figure 1. Positions of the current filaments used for the analysis.

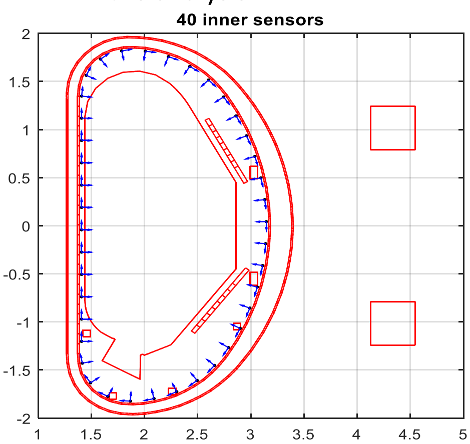

Figure 2. Positions of the in-vessel biaxial sensors (40 sensors).

positions. An example of 35 biaxial sensors location can be seen in Figure 2.

From the analysis, it results that a number of internal sensors ≥ 40 guarantees a relative error on the plasma current smaller than the 0.5% and a total error on the centroid position smaller than 5mm for all the considered filamentary currents. A number of outer sensors ≥ 40 guarantees a similar precision on the centroid position and an error on the plasma current below 0.1%, due to the increased distance from the plasma edge.

The test has been repeated considering also a plasma equilibrium generated by the

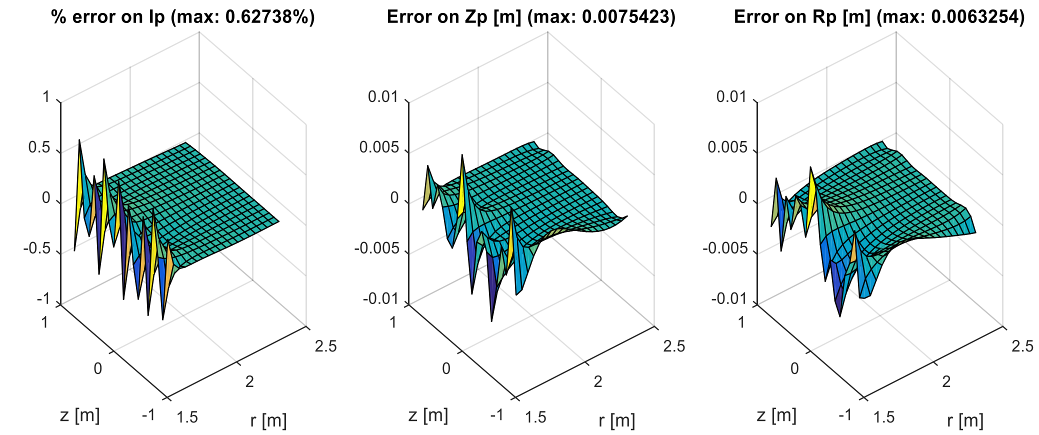

Figure 3. Error on the reconstruction of plasma current, vertical and radial position of the current centroid as a function of the current filament position (40 sensors).

CREATE-L code using both 40 and 45 sensors. (the sensors are not evenly spaced because of the configuration of the CREATE-L code, where only a small number of virtual sensors were available). The same sets of sensors have been used to estimate the plasma current and the centroid coordinates of a single null plasma equilibrium. The results are shown in Figure 4 for the 40 internal sensors configuration, which meet the needed reconstruction accuracy.

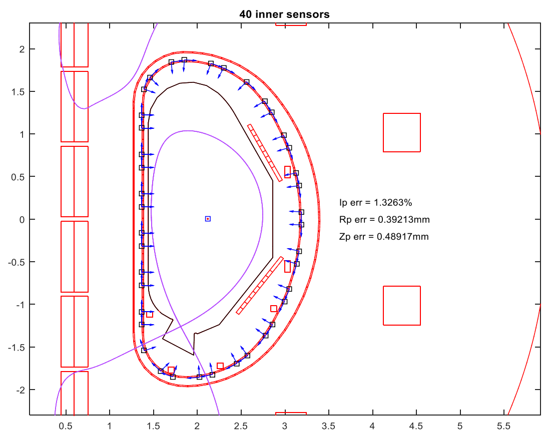

Figure 4. Last closed flux surface and current centroid reconstructed with CREATE-L (40 sensors).

Technological choices

The design for outer pick up coils is based on Coated Copper wire wound on a plastic former: Tri axial, coated Cu wire (0.18 mm Cu diameter) on a TORLON 5030: 30% glass fibre reinforced PAI resin plastic former. The Cu coated wire is UHV compatible and certified up to 180°C. (Pending UHV test at baking temperature). The plastic former has high mechanical strength and expansion coefficient similar to Al, it is certified up to 275°C and UHV compatible. A TORLON plate is foreseen to serve as heat shield from the first wall and is still to be designed.

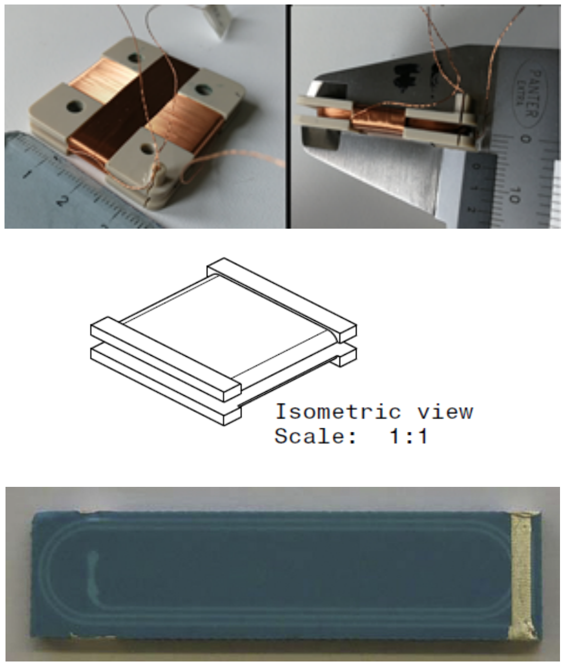

Figure 5. Reduced size mock-up of ex-vessel pick up coils (up), CAD design of coil former for in-vessel pick up coils (mid), picture LTCC coil for TCV (Reprinted from [3,4]).

The inner pick up coils are biaxial (tangential, radial) probes, composed of 0.25mm diameter MIC wire and Macor ceramic former, they are designed to withstand high heat flux and temperature. The MIC cable has a small diameter to avoid damage if bent excessively.

The high bandwidth sensors will be Bi Axial LTCC coils (printed Ag coil on ceramic layers). They are very thin, with good heat resistance and importantly high sensitivity at higher frequencies. In Figure 5 Different examples of external, internal and fast sensors are shown [3,4].

The Non-integrated Magnetic field measurement will be based on Hall Effect probes. These are three axial probes made of doped semiconductor and positioned outside DTT Vacuum Vessel, inside the cryostat, so they need to be compatible with a cryogenic environment. Among their weak points neutron damage can degrade semiconductors, even though doped detectors have improved much in neutron resistance [5].

Plasma current measurements will be based on the measurement of change in polarization of light in presence of longitudinal magnetic field, along an optic fibre wound poloidally around the DTT VV. The fibre will be Ex vessel (unless adequate annealing system for in-vessel fibres is devised) [6].

References:

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