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Status of the Halo Current Sensor Project for JET-EP

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** See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives",*
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ABSTRACT

Halo Currents (HCs), flowing through plasma and vacuum vessel during plasma disruptive events, induce severe mechanical stresses in the plasma facing components and in the vessel, and are a major concern for present and future fusion experiments like ITER.

The new system of Halo Current Sensors (HCS) designed for JET-EP should help to evaluate HC density distribution, localization and rotation as well as toroidal and poloidal current asymmetries.

The HCS system will include 4 identical mechanical structures each including: 8 Rogowski coils and 2 toroidal pick up coils. The Rogowski coils will measure directly the current flowing through some of the tiles of the upper dump plate. The toroidal field pick-up coils will estimate the total poloidal HC.

The coil assemblies are installed at the top of the vessel close to secondary X point in 4 octants equally spaced along the toroidal coordinate.

In this paper the design and the manufacturing of the HCS system are presented in detail.

INTRODUCTION

During Vertical Displacement Events (VDEs), currents flowing through plasma and vacuum vessel have been recorded in many tokamaks. The so-called Halo Currents (HCs) induce severe mechanical stresses in the plasma facing components and in the vessel. The need to better understand the origin, the distribution and the scaling of HCs is one of the critical points for any next step device, like the ITER project, in particular for the design of the plasma facing components and for a reliable plasma operation at high performances.

In the framework of the enhancements for JET-EP, the implementation of a new Halo Current Sensor (HCS) system was included [1]. This system will allow to evaluate HC distribution, localization and rotation as well as toroidal and poloidal current asymmetries, their nature and correlation with other plasma parameters [2].

The procurement of HCS system is managed by Consorzio RFX, divided in three contracts: coils manufacture, tiles machining and structure manufacture including system integration. The installation, cabling and data acquisition are under the responsibility of JET Operator.

1. SYSTEM DESCRIPTION

The HCS system consists of Rogowski coils and toroidal field pick-up coils [2]. The Rogowski coils will measure the current flowing through some of the tiles of the upper dump plate that protect the vessel close to the secondary X-point of the plasma (fig.1). The toroidal field pick-up coils will estimate the poloidal HC.

The HCS system will include 4 identical mechanical structures each including: 8 Rogowski coils and 2 toroidal pick up coils (fig.2). The coil assemblies will be installed in 4 octants equally spaced along the toroidal coordinate (fig.3).

Each mechanical structure includes one articulated conduit ending with a signal plug (fig.2). The plug is designed to be remotely deployed and fits a socket installed on the vessel wall where the signals, through twisted and shielded cables, are routed to a feedthrough on the inner-top of the vessel.

The Rogowski coils are housed in a groove machined in the Carbon Fibre Composite (CFC) tiles and are designed to collect the current flowing through the tile on its central part (fig.4). The modification significantly reduces the thickness of the CFC tile: an accurate electro-mechanical analysis with a Finite Element code was performed under the specified worst load conditions [3]. The numerical analyses were validated with an experimental campaign on the original and the machined tiles, in order to compare the behaviour and to verify the operational limit of the modified tiles. The results of the analysis and of the experimental campaigns (table 1) indicate a decay in the behaviour of the tiles, as they are machined for the Halo project, but confirm that there is sufficient safety margin on the mechanical resistance.

The system will be remotely installed requiring a design fully compatible with the existing JET remote handling systems. Figure 5 shows a HCS support structure placed on a spare module of the Upper Protection Plate during dimensional control. The modified dump plate tiles will fasten the HCS to the dump plate. The remote operation for the installation has been tested and verified at JET by means of the virtual reality system and physical mock-ups on the In Vessel Test Facility.

An appropriate alumina coating of the Rogowski coils supporting plate was applied on the region outside the probe, to allow a correct halo current path from the CFC tile to the protection plate through the Rogowski coils (fig.6).

2. SENSOR DETAILS

Both sensors are coils wound around a MACOR® core (fig.6 and fig.7). They have to withstand temperature up to 400°C, therefore the windings are made of mineral insulated cables (MICs) with high purity (99%) magnesia between the Chromel active core and the Inconel® external sheath. The cable diameter is 0.65mm and a double layer winding has been foreseen for both type of sensors, to have a sufficiently large effective area, with opposite winding direction. For the Rogowski coils, due to the limited space inside the thickness of the CFC tiles, the collecting area for each turn is $S=0.837 \times 0.537\text{cm}^2$ with a global coefficient of $K=1.8\ 10^{-7}$ Vs/A. For a nominal disruption in JET, a typical average signal of approximately 30mV is expected, with an estimated peak of 100 mV.

Typical pick-up voltage, due to not perfect winding probe and not twisted areas into the plug and the feedthroughs, is estimated to be around 6-7mV.

The Toroidal pick up coils have the same effective area ($S_N=0.05\ \text{m}^2$) as the other ones previously installed in JET, but with a significantly reduced dimension.

Signals from toroidal pick-up and Rogowski coils are recorded by transient recorders, both as voltages and integrated signals. The recordings are made using 16-bit isolating ADCs of JET type UXT1. Sampling rates up to 10ksample/s may be selected and the storage capacity allows this recording rate to be sustained for a whole JET pulse.

The 1kV input insulation protects the electronics; the sensor circuits are earthed at a point close to the ADC inputs that minimizes the interferences.

The toroidal pick-up coils produce substantial signals, and an integrator range of +/-250mVs will be used. For the direct recording the range is +/- 250mV. These ranges are already in wide use at JET.

The Rogowski coils produce relatively small signals and acquisition ranges of +/-2mVs and 250mV. The high integrator sensitivity means that noisy signals are expected, that will need digital processing after the pulse to recover all the data information. Integrator drift could amount to some 10% of the range, but existing software is available to correct its linear component.

For both types of coils, the analogue bandwidth of the conditioning channel is set at 10kHz and the input resistance is 18kΩ.

The mineral insulated cables must be UHV sealed and withstand a voltage up to 800V in DC; the terminations have to be installed in the vacuum vessel, therefore a special termination has been qualified to withstand both the temperature limit and the UHV tightness. An UHV helium leak test is performed, on all the probes, before and after a repeated thermal cycle procedure between 120°C and 350°C. A final insulation test at high voltage is performed at the end of the thermal cycles to verify the integrity of the insulation.

The MIC terminations are installed inside the plug and the active pins of the plug are directly welded on the MIC terminations.

CONCLUSIONS

The HCS system has been developed, under JET-EP enhancement program, to allow a more detailed study of the HCs flowing in the upper part of the JET vessel.

The development of this project has required in depth studies for the development of critical technologies with extensive qualification and validation test campaigns on different components.

These technology developments had a significant impact on the quality assurance implemented during the manufacturing processes of the components and of the whole system.

The delivery of the HCS system is foreseen on September 2004 and the installation is scheduled on November 2004.

ACKNOWLEDGEMENTS

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REFERENCES

[1]. C. Damiani, "JET enhancements under EFDA", Fusion Engineering and Design, vol.66-68 (2003), p.153-159.

[2]. N. Pomaro, T. Bolzonella, P. Fiorentin, L. Grando, S. Peruzzo, V. Riccardo, P. Sonato, "Proposal for halo current diagnostic system for JET", Review of Scientific Instruments Amer. Inst. of Physics, vol.74, March 2003, p.1567-1570.

[3]. L. Grando, D. Marcuzzi, "Final calculations and considerations on Halo sensors tiles mechanical tests", EFDA document EP-DIA-HCS-T-004, 2003.

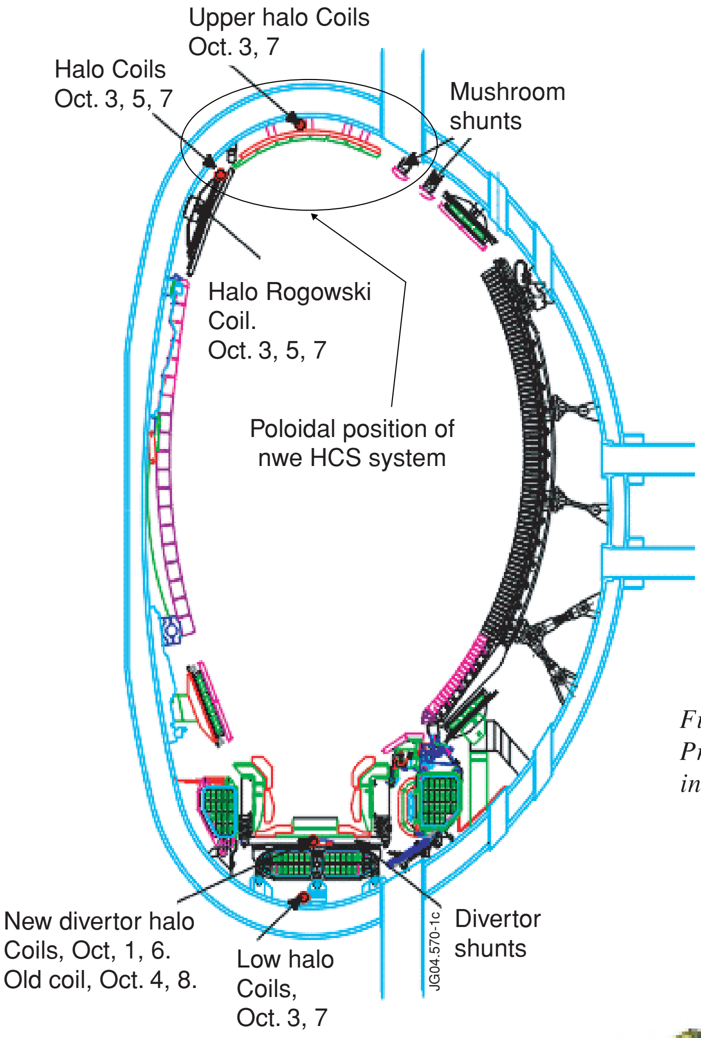

Figure. 1: Poloidal position of the Upper Vessel Protection Plate where the halo sensors will be installed.

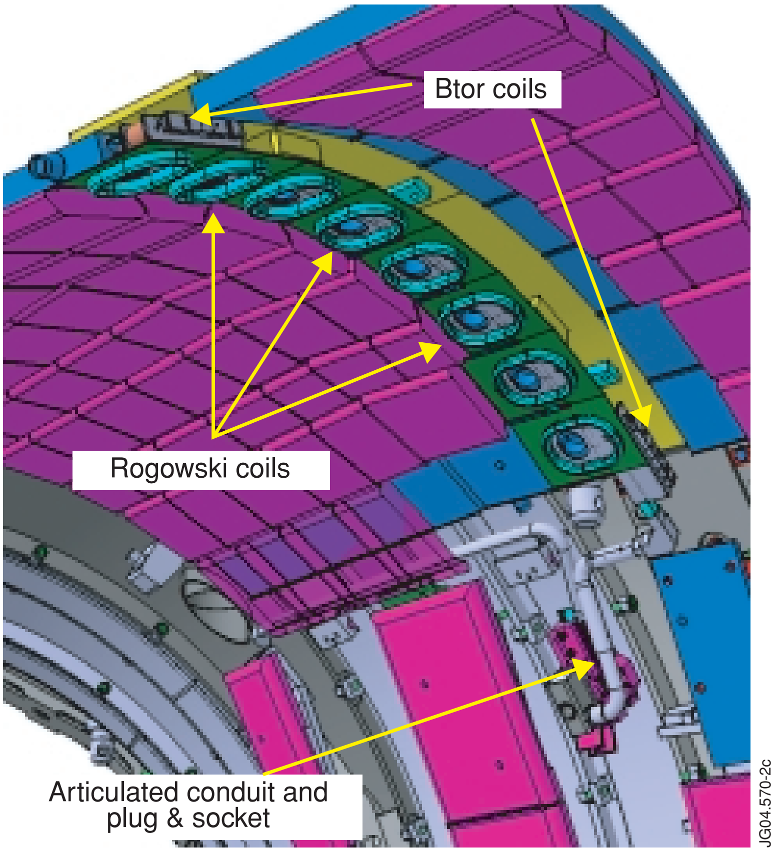

Figure. 2: CAD image of the sensor support structure installed in the vessel with the complete cable conduit up to the port. The CFC tiles have benn removed for clarity.

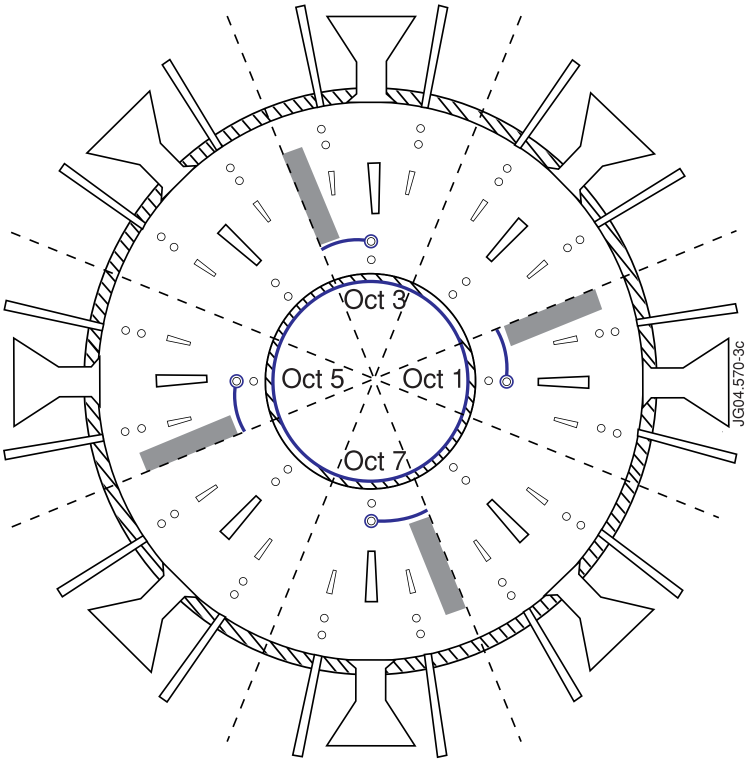

Figure. 3: Toroidal layout of the positions where a set of new probes will be installed.

Figure. 4: One CFC tile with the groove for the Rogowski coil allocation. A detail of the halo sensor support structure where is visible the annular case that houses the Rogowski coil. The area outside the annular case has the alumina coasting preventing the electrical contact of the tile with the structure.

Figure. 5: The first halo sensor support structure installed on one spare protection plate. The support structure is attached to the remote handling tool that will be used for the installation.

Figure. 6: One Rogowski coil with the protecting case. On the right side of the Rogowski coil the winding is intentionally interrupted to show the double layer turns.

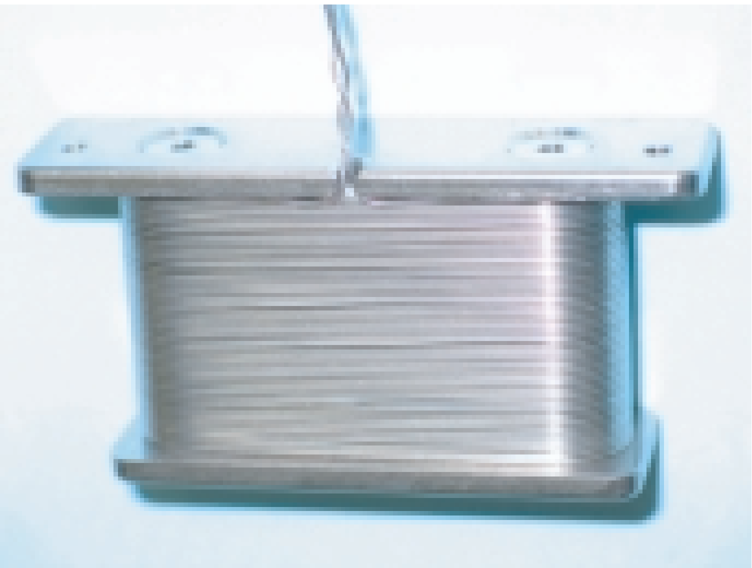

Figure. 7: One toroidal field pick up coil, used to derive the global halo current.