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[*] See annex of J. Pamela et al, 'Overview of Recent JET Results and Future Perspectives',
Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).

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ABSTRACT.

During the 2001 shutdown the new halo coils were installed together with other modular based components, in order to minimise the impact on the in-vessel activities. The refurbishment includes two sets of diagnostics: one at the bottom (in the divertor) and one at the top of the vessel. The divertor set consists of two toroidal field pick-up coils, each embedded in a carrier of the septum replacement plate. The top set is integrated with new discrete wall protection plates. It consists of three subassemblies, which can be fully installed or removed by Remote Handling. Each subassembly encompasses a toroidal field pick-up coil and a Rogowski coil embracing the plate support posts. Signals from the three toroidal locations are brought to a single feedthrough by a conduit running 180^{o} in the toroidal direction. The first results (April-May 2002) are presented, and indicate an increased halo current fraction.

1. INTRODUCTION

The primary aim of the refurbishment is to allow the monitoring of disruptions in future JET experimental campaigns. However, the new halo current diagnostics also provide a better characterisation of halo current at JET. In fact, the new top set is favourably placed at the upper inner saddle coils and is exposed to halo current for the whole duration of upward events. This new set provides data on the peak poloidal halo current from three toroidal locations, while in the past at most two were available. In addition, an estimate of the minimum halo current density could be obtained from the Rogowski coils, which for the first time in JET are employed to measure directly intercepted halo. This set of diagnostics will be complemented by a further enhancement to be installed in 2004 [1], as an improved understanding of halo current would help in the design of new plasma facing components and for ITER [2].

The present status of the JET halo current diagnostic system is summarised in Fig.1. Originally JET had two toroidal field pick-up coils at the top and the bottom of the vessel in two locations set 180^{o} apart. When the divertor structure was installed two additional toroidal field pick-up coils were incorporated. In addition a pair of instrumented protection tiles is fitted at the outer top of each octant and two poloidal voltage shunts in the divertor support structure [3]. Now only few of these probes are still working; in particular, only one toroidal field pick-up coil at the top and one at the bottom.

During the 2001 shutdown three Rogowski coils (Fig.2) and three toroidal field pick-up coils (Fig.3) have been installed together with the improved Upper Inner Wall Protection (IUIWP); two toroidal field pick-up coils (Fig.4) in the divertor region, together with the Septum Replacement Plate (SRP).

2. DESIGN

The constraints for the design were set by Remote Handling (RH) installation and by operating conditions: high temperatures (up to $500^{o}C$), high vacuum conditions and disruption loads. In fact, the conduits, and to a lesser extent the coils, are exposed to disruption electromechanical loads [4]; of these the most demanding is the voltage drop at each bellow crossing (25V), which sets the maximum distance between the standard RH conduit supports.

2.1 DESIGN MILESTONES

The conceptual design of the IUIWP coils started in March 2000. Initially four stations were envisaged, but Octant 1 was not easily reachable from either side, while with a relatively small effort the positions at Octants 3, 5 and 7 could be instrumented. The design of a 180^{o} toroidal conduit joining these three locations with the feedthrough located in Octant 7 started in early summer 2000 and was completed in the spring 2001.

The design of toroidal field pick-up coils compatible with the SPR geometry using spare thermocouple wires in two SRP carriers was completed between April and June 2001, the probes procured and manufactured in house on time to be RH installed with the SRP. Just after installation, the signal from one of the SRP coils was found not to be reliable, although the same pair of pins was healthy until the end of the 2001 operation. This significantly reduces the capabilities of the divertor halo system, leaving one working coil suitable for disruption monitoring only.

2.2 TECHNICAL DETAILS

The IUIWP Rogowski coil (Fig.2) is wound on a stainless steel frame 528mm long poloidally and 130mm wide toroidally. The former has a hollow cross section, with a wall thickness of 2mm and external dimensions of 18 x 11.5mm^2. Approximately 750 turns of inconel sheath mineral insulated cable (MIC) are wound on the former and encased. No return loop was included, so the poloidal field pick-up has to be actively removed.

The IUIWP toroidal field pick-up coil (Fig.3) is made of about 110 turns of inconel sheath MIC (outer diameter 1.5mm) wound on a stainless steel cylinder 94mm long, with an external diameter of 18mm and a wall thickness of 1.5mm. The coil is encased in a stailess steel tube 126mm long, with an external diameter of 30mm and a wall thickness of 2mm.

The MIC of the IUIWP coils has a vacuum sealed termination that is connected to a more flexible fibreglass braid insulated copper cable, which runs to the RH plug located in the same octant station. From there, another fibreglass braid insulated copper cable goes to the vessel feedthrough.

The IUIWP halo diagnostic conduit is made of U-shaped inconel 625 tubes with covers. The external cross section is 11 x 20mm^2 and the wall thickness is 0.8mm. Adjacent supports are about 300mm apart and they are RH welded to the bellow protection plates using the same design successfully employed in the installation of the High Field Side Pellet Injector [5].

The SRP toroidal field pick-up coil (Fig. 4) is made of two layers of about 46 turns each. The wire is made of inconel sheath MIC (outer diameter 1mm only). The first layer is wound on an inconel 600 prism with rounded edges, 55mm long and 20mm thick, with a wall thickness of 1mm. A 1mm thick layer of inconel 600 separates the second layer from the first. The coil is inserted in a pocket machined in the SRP carrier and kept in position with pins. The MIC is vacuum terminated and brazed to a fibreglass braid insulated copper cable in the transition box located in a groove at the side of the coil front end. Finally the fibre glass braid insulated cable is connected to one of the divertor structure RH plugs.

3. RESULTS

The poloidal halo current can be estimated from the field measured by the toroidal field pick-up coils once the poloidal field pick-up and the toroidal field contribution due to the external toroidal field current have been eliminated. Similarly, the current collected by the IUIWP tiles can be obtained from the Rogowski coil signal, scaled according to pre-installation tests, once the poloidal and toroidal field pick-up have been removed.

Best fit coefficients to approximate the field pick-up have been computed using the full duration of plasma and dry pulses and requiring that, in absence of a disruption, the halo current was zero. In Fig.5, for Pulse No: 55676 (a 1.8MA deliberate upwards VDE), and in Fig.6, for pulse 55221 (a 2.5MA downwards density limit disruption), the contribution to the local toroidal field due to poloidal halo current (“T3”, top) and the current collected by the IUIWP tile (“R3”, bottom) in Octant 3 are plotted together with the poloidal field components seen by the probes (parallel, “par pick-up”, and perpendicular, “perp pick-up”, to the vessel wall) and the raw signals with only the external toroidal field removed (“raw-tor contr”). In both cases the effect of the poloidal field on the toroidal field pick-up coil is very small, while it is larger on the Rogowski coil signal. The downward event also provides an estimate of the error due to disruption fields for the Rogowski current: ~1.2kA/MA, i.e. 3kA in a 2.5MA disruption; the typical current for a 2MA disruption is 30kA.

As an example the halo current measured by the new probes and the only surviving probe at the top of the vessel are reported in Fig.7 for Pulse No: 55676. There is a correspondence between the toroidal location where the largest poloidal current is measured (“T7”) and where the current intercepted by the Rogowski tile is largest (“R7”). In addition, the poloidal current seen by the old probe (“U3”) is smaller than that seen by any of the new toroidal field pick-up coils. This is typical of most of the disruptions occurred in 2002: in fact, the average ratio between the old probe and the IUIWP probes halo fraction (I_h/I_{p0}) is about 0.6 (Fig.8). Contrary to expectations that a larger number of toroidal stations would have led to an increase in the toroidal peaking factor (TPF), the value for all 2002 disruptions has been less than previously observed. As a consequence the envelope of the (I_h/I_{p0}, TPF) space has moved towards higher halo fractions. One IUIWP toroidal field pick-up coil stopped working properly in the middle of May 2002. This will reduce the value of further VDE tests to complement those carried out during restart before commissioning of the new probes.

CONCLUSIONS

The halo current diagnostic system of JET has been improved, although it remains basic, as a better understanding of the distribution and scaling of halo currents is one of the critical issue in the design of ITER. The refurbished system can validate the findings of the previous system as it includes the same type of probes, only fitted in more suitable locations in the vessel. The improved location could be the reason why, on average, the halo fraction measured by the new probes is higher. However, the available data are very limited and mostly at low plasma current where extreme events are more likely.

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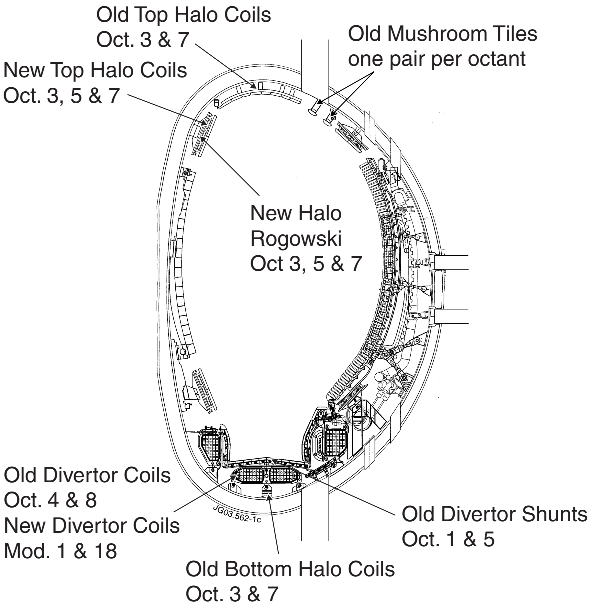

Figure 1: JET cross section with the old and the new halo current diagnostics, probes not working (summer 2002) have been crossed.

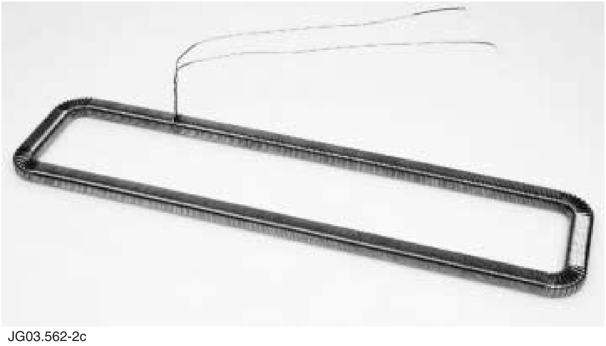

Figure 2: Rogowski coil.

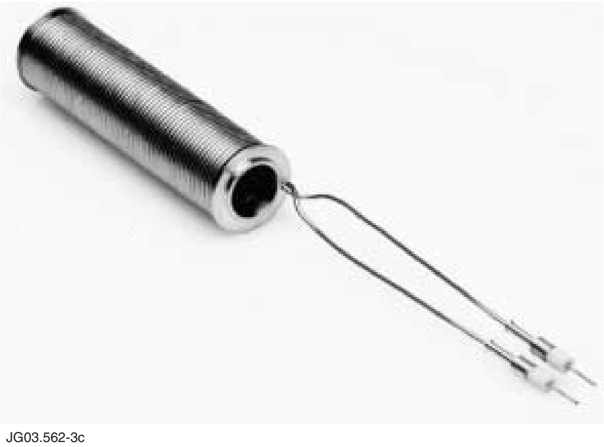

Figure 3: IUIWP toroidal field pick-up coil.

Figure 4: SRP toroidal field pick-up coil.

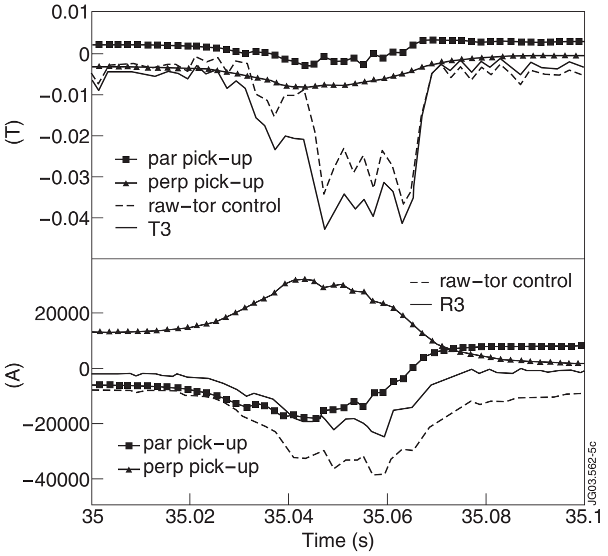

Figure 5: Poloidal field pick-up in the top probes during the (upwards) disruption of Pulse No: 55676. Top: toroidal field pick-up coil, bottom: Rogowski coil.

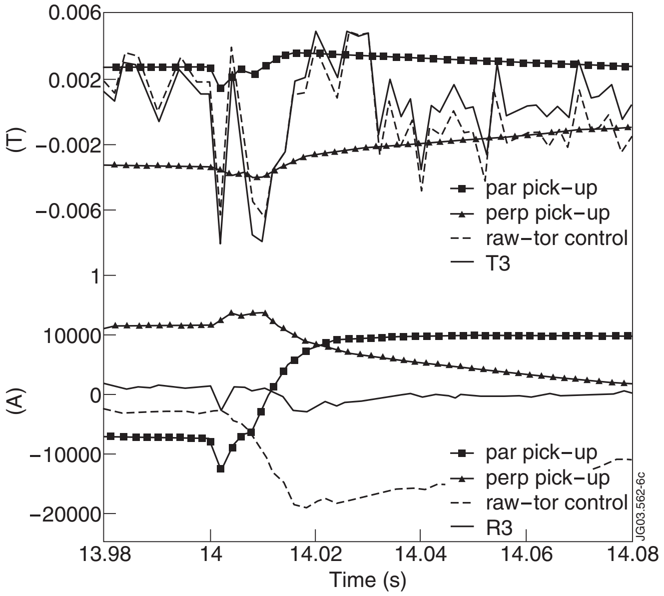

Figure 6: Poloidal field pick-up in the top probes during the (downwards) disruption of Pulse No: 55221. Top: toroidal field pick-up coil, bottom: Rogowski coil.

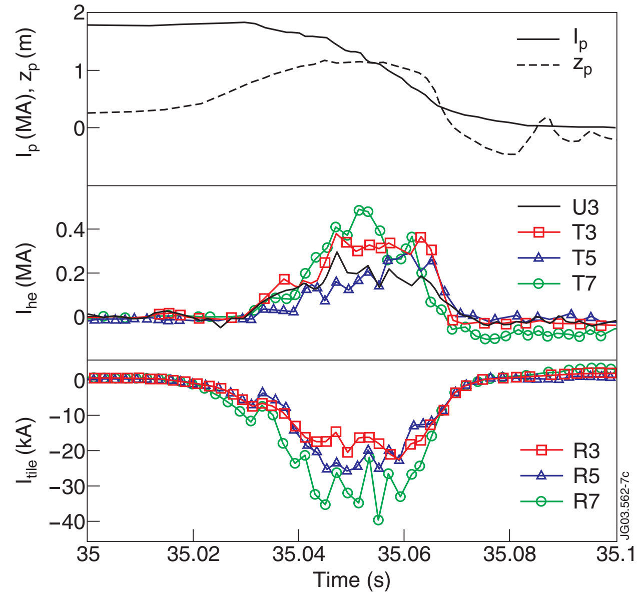

Figure 7: Plasma current and vertical position, halo current at the IUIWP probes during the disruption of Pulse No: 55676.

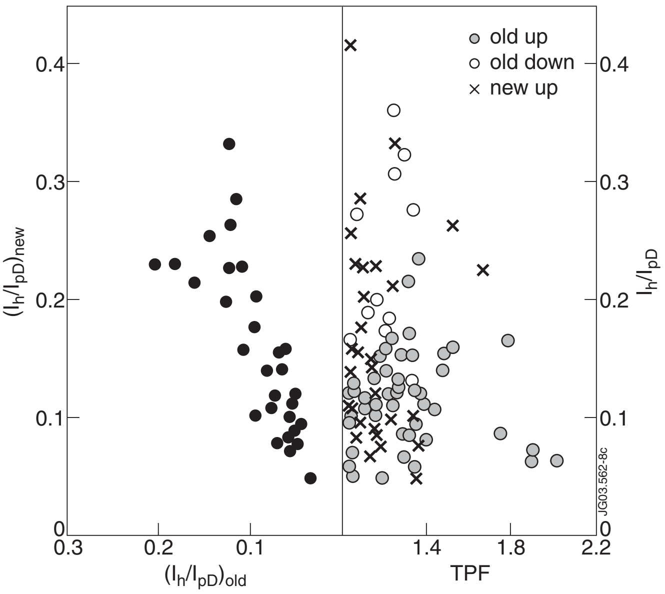

Figure 8: Halo fraction (ratio of maximum poloidal halo current to pre-disruption plasma current) measured by the new probes and by the one surviving old probe (left) and versus the toroidal peaking factor the 2002 (new) data and the 1994-1997 (old) data (right).