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Status of Design and Manufacture of the Upper Coils and Outer Poloidal Limiter Coils Subsystems for the JET-EP Magnetic Diagnostic

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ABSTRACT.

This paper presents the status of the design and manufacture of the main in-vessel subsystems of the magnetic diagnostics enhancement project for JET. The subsystems are conceived as several sets of pick-up coils supported by mechanical structures attached to existing components of the first wall, to be installed by remote handling. The design constraints and fundamental choices at the base of the project are illustrated. The technological solutions proposed for the construction, presently in progress, are described.

INTRODUCTION

The enhancement project of the JET magnetic diagnostics aims at the design, procurement, installation and commissioning of new sets of magnetic transducers to be installed inside and outside the vessel, in order to significantly improve the current capabilities of the JET magnetics [1]. The in-vessel sensors are grouped in 3 different sub-systems of two field component pick-up coils, to be located as close as possible to the plasma boundary, assembled on rails in order to ease Remote Handling (RH) installation. The 3 sub-systems, Upper Coils (UC), Outer Poloidal Limiter Coils (OPLC) and Divertor Coils (DC), are attached to different structures of the first wall (Fig.1) and replicated for redundancy in 2 Octants (4 and 8 for UC and OPLC, 1 and 2 for DC), for a total of 76 new pick-up coils. This paper focuses on the status of design and manufacture of the first two subsystems (UC and OPLC) performed in close collaboration between the two Associations involved in the magnetics enhancement project, whereas the third subsystem (DC) is managed within the project for the modified divertor (Mark II HD) to be installed during the 2004 Shut-down.

2. DESIGN CONSTRAINTS AND BASIC CHOICES

The design of the UC and OPLC was carried out in order to fulfil the following constraints:

1. Operation and fault condition design criteria for JET in-vessel components [2] (Ultra High Vacuum, temperatures up to 350°C, several scenarios of halo current circulation and time variation of magnetic field);
2. Interface with existing first wall components in a relatively tight geometry;
3. Sharing of a unique feedthrough and minimization of conduits for cable routing;
4. Installation to be carried out completely by means of RH system;

The first two issues called for proper electrical ground connections and electrical breaks on several components and cable shields, in order to minimize the circulation of eddy and halo currents through the structures. Accurate CAD studies and 3D electromechanical f.e.m. analyses were carried out to achieve a design of the support structures with sufficient safety factor even in the worst disruption scenarios. The availability of a unique feedthrough, together with the RH requirements, imposed the set up of several plug and socket assemblies in the system layout. Each plug and socket assembly will be remotely connected and disconnected. In the worst case (UC) the signal cables are interrupted 4 times between the coils and the feedthrough, and this fact represents a matter of concern from the point of view of reliability and immunity to noise of the measurement system. RH installation imposed moreover some technical choices in terms of modular form of the structures and the execution of preliminary tests on mock-ups.

3. UPPER COILS SYSTEM

Each of the two UC assemblies includes a mechanical structure supporting 4 pairs of coils (Top Coil Array), to be fitted in the 100mm gap available between the inter-octant Pump Plates (Fig.2), and a smaller structure supporting 1 pair of coils (Upper Outer Coil Pair) to be attached to the disused Upper Saddle Coils (Fig. 3). The two structures will be installed together, since the 10 twin cables will be collected in a single 20 way RH plug.

3.1 Upper Coils Support Structure

The main components of the UC Support Structures are made of Inconel 600. The Top Coil Array Support Structure will replace a bellow protection plate presently attached to the Dump Plate. Due to RH compatibility, the structure is divided in two parts: a Support Bracket (L shaped), attached to the Dump Plate, and a Support Plate (6mm thick) on which the coils will be welded, and which will be fixed to the Bracket. The Upper-Outer Coils Support is a C-section bar, enclosing the coil pair, with a suitable fixing system to be interfaced to the disused Saddle Coils. To avoid eddy and halo current circulation, the component to be located between the two bars of the saddle coils is isolated by means of alumina coating, whereas the conduit for cables is electrically isolated by means of ceramic spacers. The manufacture of UC Support Structure is presently well advanced (Fig.4) and will be completed within August 2004.

3.2 Upper pick-up Coils

Upper pick-up coils were designed in two different types, one for tangential (poloidal) field measurement and the other for normal (radial) field measurement (Fig. 5). Each type was optimised to fulfil dimensional constraint maximizing the effective magnetic section of the probes. It was chosen to maintain a circular probe winding cross section, as this shape allows the better winding uniformity and the minimal cable curvature, thus improving precision and reliability of the probes. To ease the signal conditioning, the probe magnetic section was made similar to the one of probes previously installed in equivalent positions, and kept around the value of $0.1m^2$, which guarantees an adequate but not excessive signal level. Actual magnetic section of each probe will be calibrated with an accuracy of 0.5% using a precise and stable AC magnetic field source. Probes technology is derived from previous designs: they are realised winding a pair number of layers of mineral insulated cable 1 mm diameter, around an Inconel 600 former. Mineral cable sheath is also in Inconel, insulator is high purity magnesia and the inner conductor is Chromel P. This last material differs from previous designs, which made use of copper, and was chosen to obtain a better mechanical resistance and thermal characteristics more similar to sheath ones, as the analysis of faults occurred on already installed probe suggested a weakness of mineral cables conductors.

Mineral cable terminations were completely redesigned, with specifications and geometrical size similar to previous models but using quite different structure and materials, which allowed a reduced number of rejects and an improved repeatability of vacuum tightness and dielectric strength, also using thin cables where previous designs exhibited poor reliability. This new design was the same originally developed for the new Halo Probes System [3]. To test the vacuum tightness of probe terminations, parameter of paramount importance to preserve JET vacuum level, a computer controlled vacuum oven was realised. Thermal cycles from ambient up to 400°C in UHV on all the production coils are presently in progress.

4. OUTER POLOIDAL LIMITER COILS SYSTEM

Each of the two OPLC assemblies consists of a mechanical structure supporting 7 pairs of coils, that will be fixed to the outer poloidal limiter on the opposite side of a similar structure supporting other existing coils (Fig. 6). Signal cables from the coils (of both OPLC and UC) are routed via a system of fixed and movable conduits and RH plugs and sockets to a new feedthrough and terminated at a nearby socket box. The feedthrough is shared with the supply cables of the Toroidal Alfven Eigenmodes (TAE) antennas. Each TAE antenna will operate between 10500kHz (with transient currents up to 30A), which overlaps with the frequency range of interest to the magnetics project. Careful isolation and screening were therefore taken into account in the design of the feedthrough to minimise RF interference induced from the TAE on the magnetics wiring [4].

4.1 OUTER POLOIDAL ARRAY SUPPORT STRUCTURE

The mechanical support for the sensors consists of a curved and straight mounting beam manufactured from stainless steel 316, which has been lightened by removing excess material. The mounting brackets for the beams will be manufactured from Inconel 625 (higher electrical resistance and stronger than Inconel 600). Electrical breaks have been introduced in to the mounting beams between each of the mounting brackets to prevent halo currents passing through the beams. This eliminates the electrical loop and therefore reduces the forces on the structure. The halo current runs through the Poloidal Limiter at the first wetted support from the bottom and comes back to the plasma at the last wetted support from the top. This still gives a significant radial force of ~5kN (due to the combination of vertical path and toroidal field, and of toroidal path and vertical field).

4.2 OUTER POLOIDAL ARRAY COILS

Each assembly contains 7 fast tangential sensors and 7 slow normal sensors. Each tangential coil shares the same poloidal location with the corresponding normal coil displaced slightly in the toroidal direction. The two types of coils are shown schematically in fig 7. Although a different design and manufacturing technique was used for fast and slow coils the effective area (NA) of the two types of coils is about the same and comparable with that of the Upper and Divertor coils. The construction of the fast tangential sensors consists of a single layer of bare titanium wire wound around a machined ceramic former. The slow normal sensors are constructed from two layers of

1.5mm diameter mineral insulated cable wound around a metallic former. Both sensor types will be protected from the plasma by specific Carbon Fibre Composite (CFC) tile. The magnetic sensors on the outer poloidal limiter assembly measuring the tangential component of the field were optimised to have high bandwidth to satisfy the requirements of MHD analysis. These signals will be digitised at a sampling rate up to 2MHz. Both types of outer poloidal coils and divertor pick-up coils will have their relative sensitivity measured using a Helmholtz pair to generate a spatially uniform AC magnetic field modulated up to approximately 30kHz. The absolute NA of the coils will be established with respect to an accurately manufactured reference coil of known NA. A dedicated measurement of the frequency response up to 2MHz of the fast pick-up coils, including the transmission line (cabling and electronics) from the Torus Hall up to the data acquisition will be performed on site after installation.

5. REMOTE HANDLING ISSUES

The complete UC and OPLC system was designed for remote installation in collaboration with the remote handling team at JET. Each item has been designed to be compatible with the existing remote handling tools where possible, however more than 15 remote handling tools have been designed and manufactured specially for this project. The system has been checked for suitability for remote installation using 3D Catia CAD models and the JET virtual reality system. In addition, a physical mock up was made of the top coil and outer poloidal array and installation trials performed using the MASCOT manipulator in the In Vessel Training Facility (IVTF) at Culham. The most arduous task during the installation process was the installation of the Upper Outer (EQ) Coil, which required the unreeling of 1m of cable wrapped around the EQ coil body in a difficult location near the top of the vessel (Fig.3). The mock up trials showed that this task could be performed using the manipulator as originally designed, however the addition of a second gripper feature considerably improved the installation (Fig.8).

CONCLUSIONS

The design of the Upper Coils and Outer Poloidal Coils subsystems for the JET-EP Magnetic Diagnostic is completed in all the details. The manufacture of the various subcomponents is presently in progress. The assembly and final installation of the systems are scheduled for next autumn, in accordance with the JET 2004 Shutdown.

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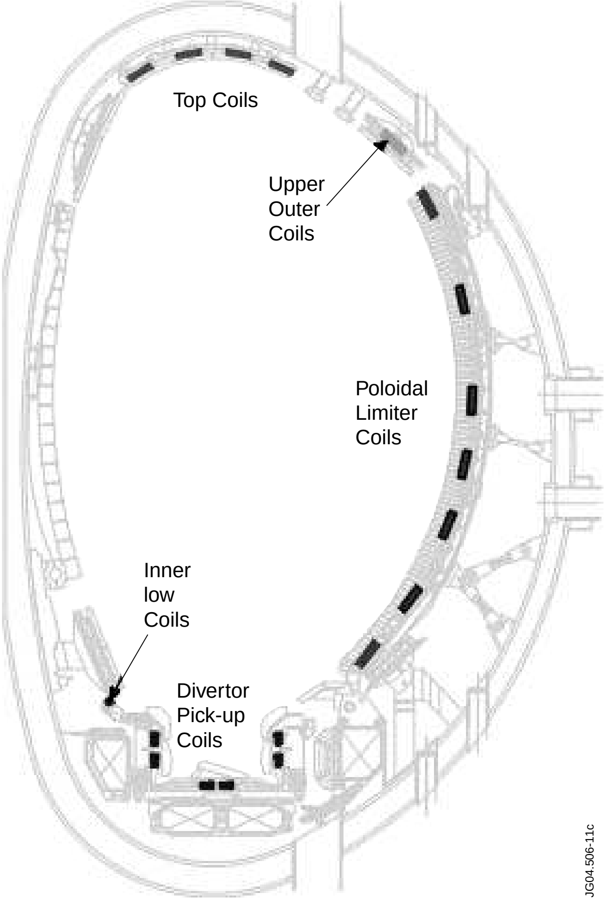

Fig. 1 Poloidal position of the JET EP Magnetic coils.

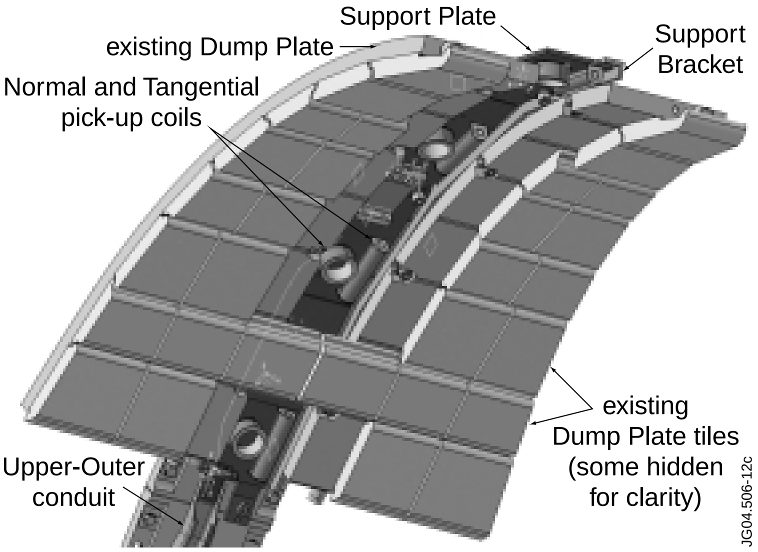

Fig.2 Top Coil Array.

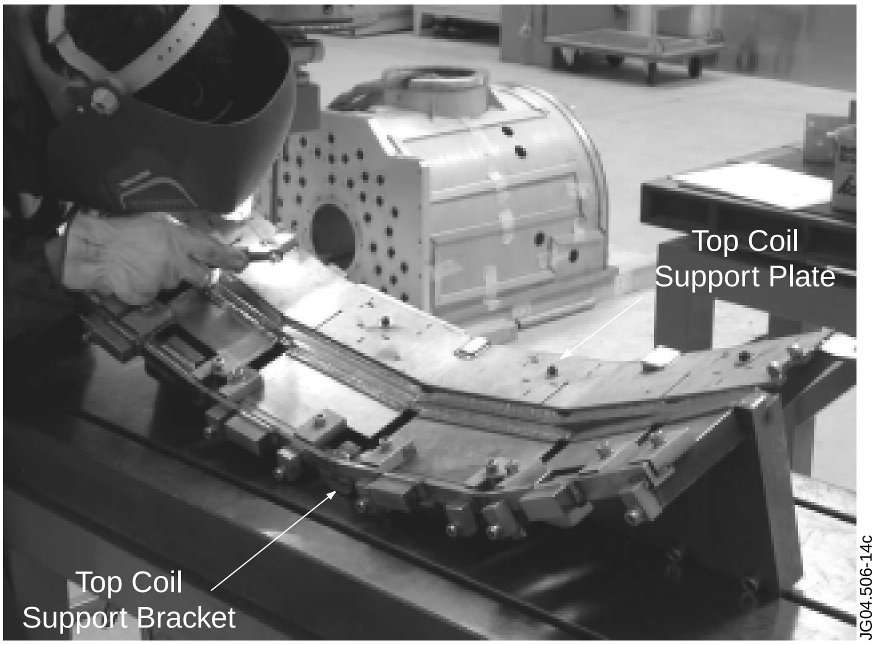

Fig.3 Upper Outer Coil Pair.

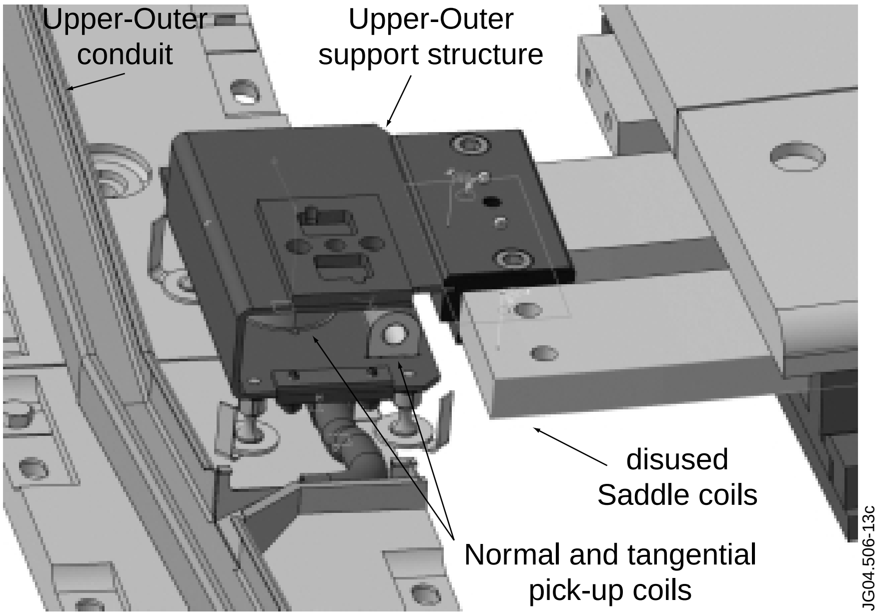

Fig.4 Top Coil Support Bracket and Plate during welding operations

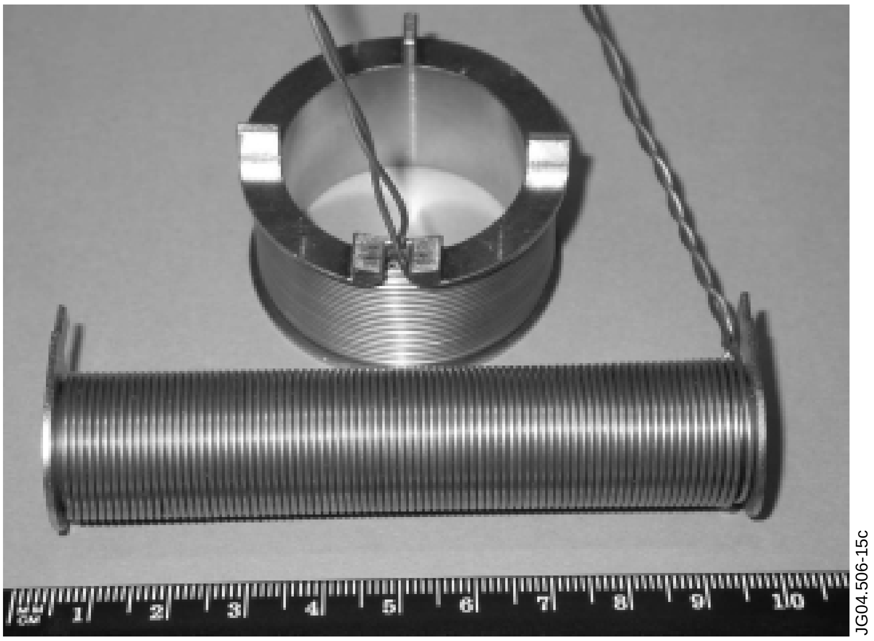

Fig.5 Upper Coils (Normal and Tangential)

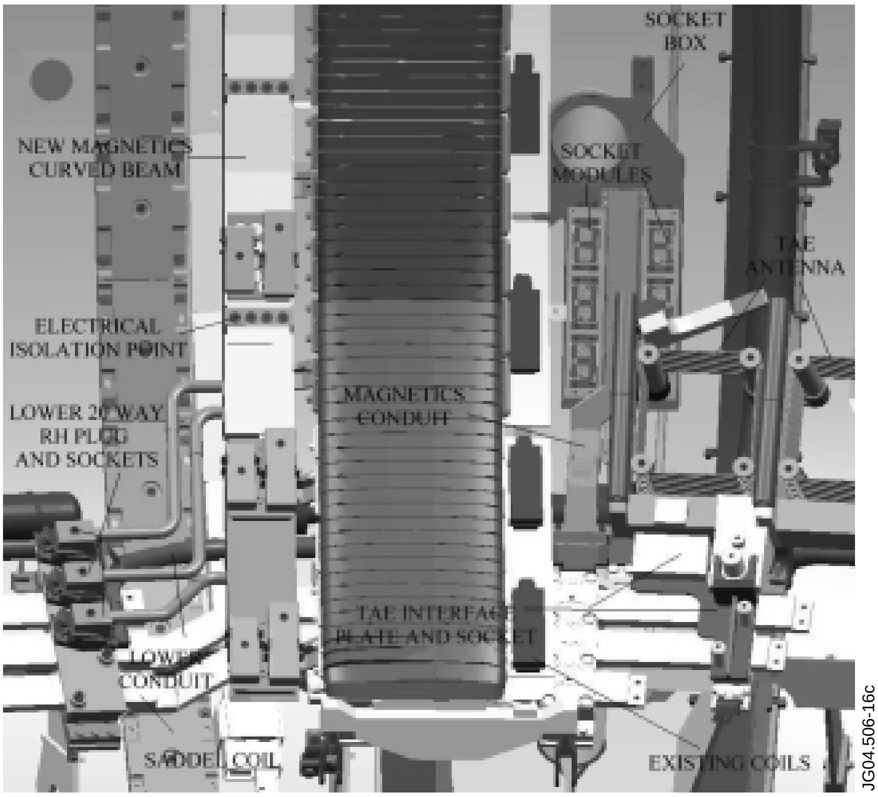

Fig.6 Outer Poloidal Limiter Coil Array

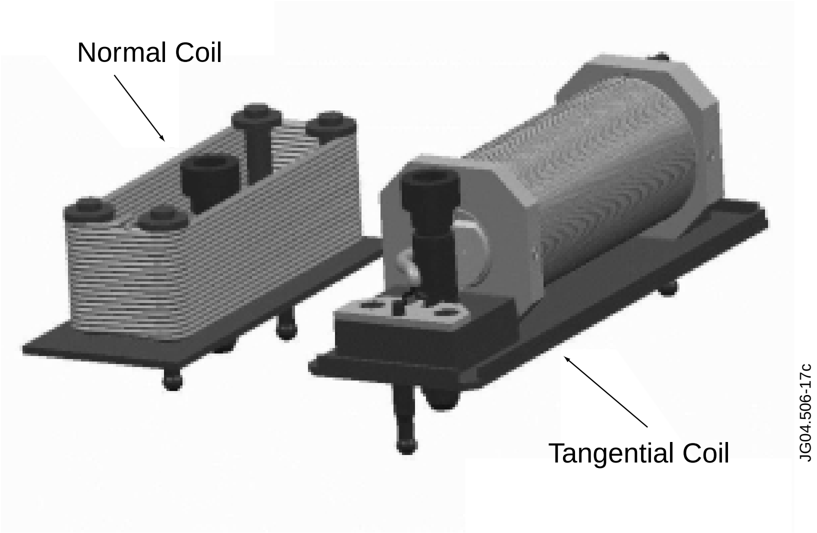

Fig.7 Outer Poloidal Limiter coils (Normal and Tangential)

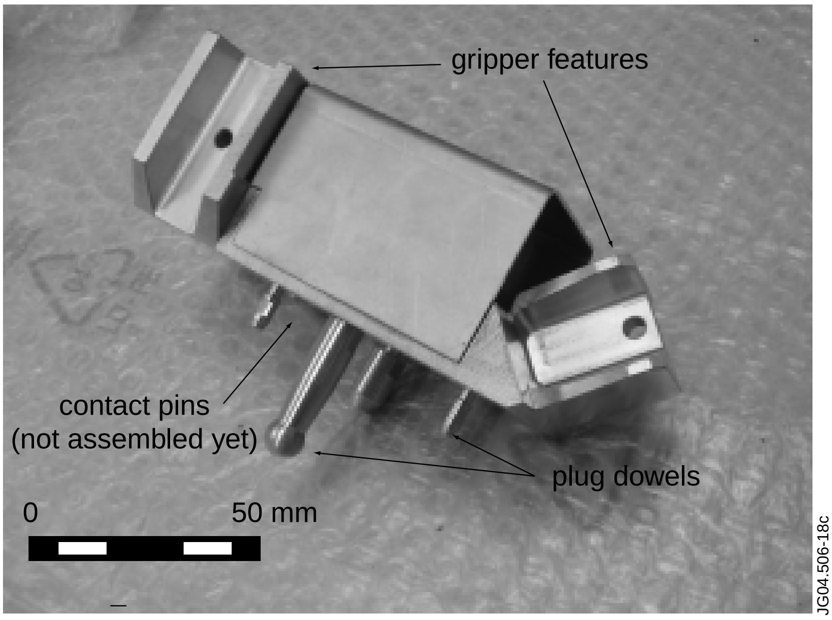

Fig.8 20 way RH plug specially designed for the installation of Upper Coils