The MkII gas box divertor - a new design concept

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1. INTRODUCTION

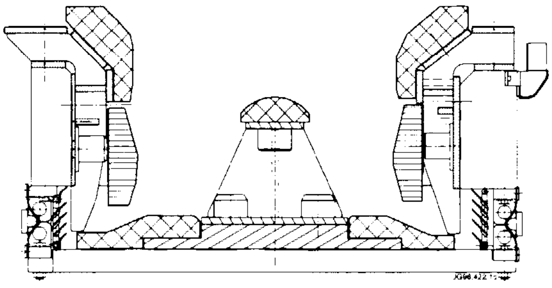

Fig.1: Poloidal X-section of Gas Box Divertor

The Gas Box (GB) Divertor will be the third configuration to be installed in the JET torus since the start of the divertor phase. Details of the MkI [1] and MkII [2] divertors have been reported previously. The design shown in figure 1 is intended to simulate the proposed ITER divertor layout. The main features of the arrangement are:

a) a reduced entrance to minimise the leakage of neutral particles from the divertor region into the main volume and encourage recirculation of impurities and neutrals,
b) a central septum to allow independent control over recirculation of neutral particles along each leg of the divertor;
c) the ability to handle both attached and radiating plasmas.

Detached plasmas that radiate their energy within the divertor volume provide a stringent thermal loading of structural parts.

Divertor physics has had limited success in predicting the effectiveness of the septum or determining a preference for operation on base or side target plates. As a result, maximum flexibility had to be maintained in the design so that additional combinations of components, as shown in figure 2 (a-c), could be tested independently. Further options for the septum were the transparency of the vertical wall and the extent of radial fins to influence neutral particle recirculation. Independent gas feeds to the divertor legs allow fine control of this process.

2. INPUT PARAMETERS

The MkI divertor tested CFC and beryllium targets with the same geometry for both materials. The MkII divertor [2] was optimised for maximum power handling over a wide range of plasma configurations. The GB divertor must accommodate 20MW total conducted power (or 10MW per divertor leg) for:

- attached plasmas with up to 18MW/m^2 deposited locally on target plates and up to 8 MW/m^2 on structural members (figure 3),
- detached, radiating plasmas with 2 MW/m^2 (max) on to all divertor surfaces including the structure.

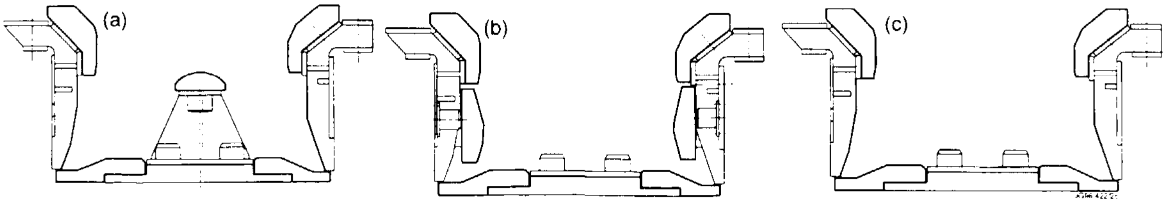

Fig.2(a-c): Options for Divertor Layout.

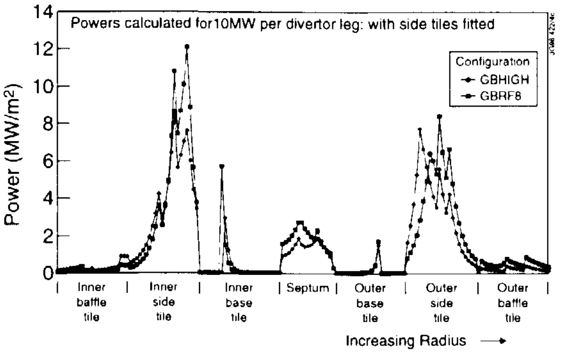

Fig.3: Power Loading over divertor targets.

The principal mechanical loading is due to magnetic forces on the divertor components. These arise from halo currents flowing through the tiles and carriers, then into the support structure (fig. 4). Intrinsic eddy current forces from the rapidly changing magnetic fields appear in the tiles.

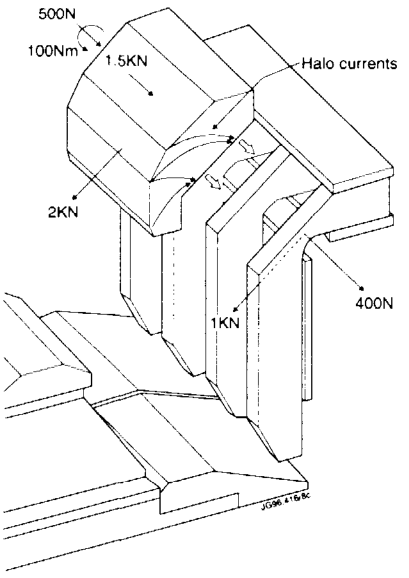

Fig.4: Electro-magnetic forces under halo current.

3. MATERIAL SELECTION

The requirement to accept 2 MW/m^2 anywhere on to the carrier structure led to the decision to use carbon-carbon fibre composite (CFC) plates for all structural members. A structure from metal such as Inconel 600 would distort if 2 MW/m^2 were sustained for 5 seconds. CFC lends itself well to this application, owing to its thermal shock resistance and ability to withstand high temperatures without residual deformation.

Extensive screening tests have been performed during material selection for MkI and MkII divertors. For structural applications a quasi-3D material with nearly isotropic thermal conductivity was chosen. Two grades SEPCARB N11-2 and N11 were selected. The former has high flexural strength but lower thermal conductivity so that use was restricted to areas subject to radiant loads. Structural members that can be exposed to conducted power in some of the options (figure 2) are made from N11 which has the higher isotropic thermal conductivity [3].

Target plates subjected to high heat fluxes on horizontal or vertical plates are similar to those for MkII. A 2D CFC supplied by Dunlop has excellent in-plane conductivity. The transverse direction has low flexural strength so that special fixation methods are used to reduce bending across fibre planes.

4. CARRIER DESIGN

Figure 5 shows a view of the four designs that make up a set. The final assembly has 48 of each design fitted side by side on the divertor support structure.

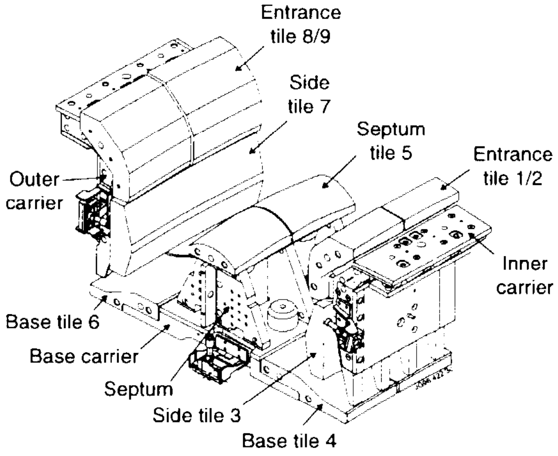

Fig.5: Perspective view of carriers and tiles.

The basic method of joining CFC plates is the barrel nut and bolt shown in figure 6, i.e. an M6 Nimonic 80A countersunk bolt and Inconel 625 barrel nut. Under the assumption of an initial temperature of 200°C and a plasma radiating 10 MW

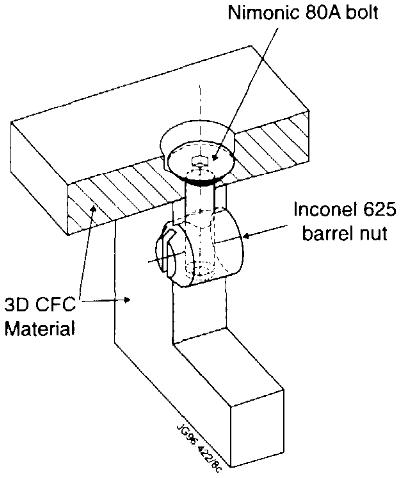

Fig.6: Barrel nut and bolt fixing.

inside each divertor leg for 10 seconds, the worst power loading of 0.7 MW/m^2 on to the ends of an Inconel 625 barrel nut raises the surface temperature to 475°C and a final bulk temperature of 350°C. The surrounding CFC material reaches approximately 450°C. Inconel retains 90% of its yield strength at these temperatures. The problem of seizure between the Nimonic bolts and Inconel nuts is solved by copper plating all bolt threads. Location dowels and anti-vibration nuts by Spiralock are used to ensure alignment and tightness under vibration.

Figure 7 shows the design used for the inner and outer carriers. An arrangement of ribs, webs and plates is used to produce a lightweight, rigid assembly. The target plate tiles are located on to the carriers with alignment dowels and tension bolts loaded with disc springs. Four corner support pads are machined at each tile location to define accurately the tile height with reference to the adjacent tiles for shadowing.

Without the lower side tiles (fig. 2a and c),, radiated power appears directly on the carriers behind the tiles and all exposed metallic components have to be removed or protected with graphite or CFC blocks. The lower ribs on both carriers could be subjected to conducted power up to 8 MW/m^2 while protecting the support structure for certain plasma equilibria. Careful design of the surface slopes and heights is essential.

The manufacturing sequence has to take into account the large number of accurately fitting interfaces that must locate simultaneously to engage all the alignment dowels. A sequence of component and sub-assembly machining has been developed to achieve this task.

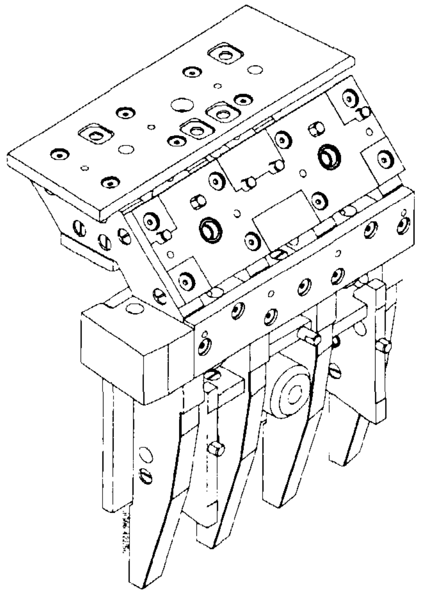

Fig.7: Side Carrier structure.

The base carrier in figure 5 is machined from a single Dunlop 2D tile. The chemical vapour deposition (CVD) process to achieve adequate density in the centre of the 50mm thick tile has proved to be a challenge and multiple oven runs have been required.

The septum in figure 8 is a relatively straightforward structure but one which has to withstand the highest halo current stresses and radiant heat loads.

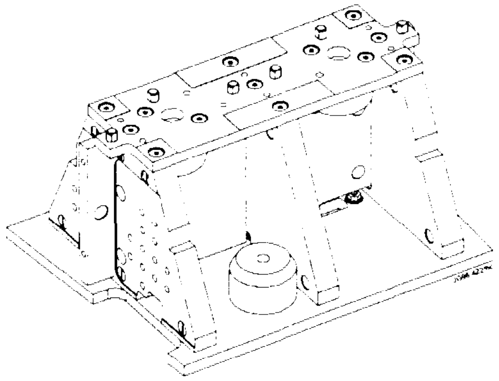

Fig.8: Septum structure.

5. TILE DESIGN

Unlike the tiles in the MkII design [2], shared corner pad support is not used here and each carrier, with its tiles, locates directly on to the support structure. Consequently the build up of tolerances in defining each tile location is larger so that steeper tile angles and shadowing steps are required, resulting in a slightly lower power handling capacity than for MkII.

The orientation of the fibre planes for all except the lower side tiles has been changed from a toroidal to a poloidal plane to improve the spreading of power. A consequence is that all but the side tiles are only half the length of those in MkII.

The surface profile has been designed according to the criteria for MkII [2]. The septum tile surface is bi-directional to receive flux from both toroidal directions.

The method of supporting the tiles mechanically and retaining their integrity against cracking with tie rods is maintained from the MkII. Machining is carried out with ball nosed cutters with vacuum chucks for location.

6. DIAGNOSTICS

The diagnostics may be divided conveniently into three groups - those that measure conditions on the carriers such as thermocouples and Langmuir probes, those that use the carriers as convenient supports such as neutral helium injection and magnetic coils, and those that are mounted independently of the carriers such as bolometers, pressure gauges and µ-wave horns.

Thermocouples are fitted both to tiles and structure with a standard distance of 10mm from plasma facing surfaces. A spring loaded design has been proven in prototype testing.

7. REMOTE HANDLING

Design of the divertor carriers has had to maintain remote handling (RH) capability from the beginning. The side and base carriers have RH lifting points on the top plates while the septum is moved by a special jig locating off the top plate and steps in the ribs. All bolts have been designed for RH operation. Further details are described elsewhere [4].

8. PROTOTYPE TESTING

Thermal and mechanical testing of CFC has been described in [3]. Mechanical testing of a representative septum has been extended to include vibration, pulse and steady state loads. The vibration tests were carried out at 250°C to study the effect upon the copper plated bolts. The top of the septum deflected elastically by 3mm under a 2KN load. After 50 impulses of 1.6KN followed by 80,000 cycles of 900N steady plus 500N cyclic over 10-30Hz, the structure showed no change in compliance. All bolts retained their original tightening torque.

The design of the thermocouple fixing was studied in the neutral beam test bed. Compression springs made from Nimonic 90 do not deteriorate in this environment and the design allows reliable interpretation of the tile surface temperature.

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