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Modelling and analysis of the JET EP2 neutral beam full energy ion dump curved end plate

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HIGHLIGHTS

- Following the JET curved FEID end plate failure a new plate has been designed.
- Worst case incident power density due to molecular ions has been modelled.
- Current plate's thermal behaviour has been analysed using new surface TCs.
- New design boasts greatly improved cooling performance as modelled in ANSYS.
- Slotting arrangement introduced to decrease stresses and improve fatigue life.

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ABSTRACT

This paper describes enhanced modelling of the power loading on the current JET full energy ion dump (FEID) curved end plate, and the new end plate design with improvements to the power handling capabilities and additional features to improve fatigue life. Monte-Carlo simulations of each of the nine residual ion components which are intercepted by the plate shows a peak power density of 20 MW/m^2 and compares well with recently installed fast thermocouple measurements. Analytical calculations and simulations with the Charged Particle Optics (CPO) code are used to investigate the potential for movement of the residual ion focus due to space charge effects. Cooling performance is significantly enhanced by improved water channel flow which is both modelled and confirmed by experiment. Fatigue life, calculated from ANSYS modelling is improved using a slot arrangement to relieve stresses created from focussed heat load distribution.

1. Introduction

Neutral beam injection systems have proved themselves as the most effective form of auxiliary heating in tokamak plasmas. In positive ion based systems once the beam is neutralised there are many residual ion components which must be intercepted by suitable ion dumps. A particular challenge for ion dump design occurs when the dump must be placed close to a focus point as is the case for the curved end plate of the JET NBI full energy ion dump. Molecular ion species, though of low power, are focused 30 cm in front of this plate.

As part of the EP2 upgrade to increase neutral beam power and duration, the ion source configuration was changed from Supercusp 130 kV/60A configuration to Chequerboard 125 kV/65A [1]. This allowed for significant increase in neutral beam power but also lead to a fourfold increase in molecular residual ions. The curved FEID end plate was re-designed as an actively cooled element using swirl tubes. Following a failure of this plate in 2014 additional analysis was carried out to determine the power loading on the plate and to improve its performance.

2. Current end plate modelling and analysis

2.1. Monte-Carlo simulations

Modelling of the power loading on the curved FEID end plate carried out in support of the EP2 upgrade predicted a peak power loading of 10 MW/m^2. However, this was not done for each individual ion species and did not consider the depletion of the neutraliser target density due to gas heating at high voltages [2]. This increases

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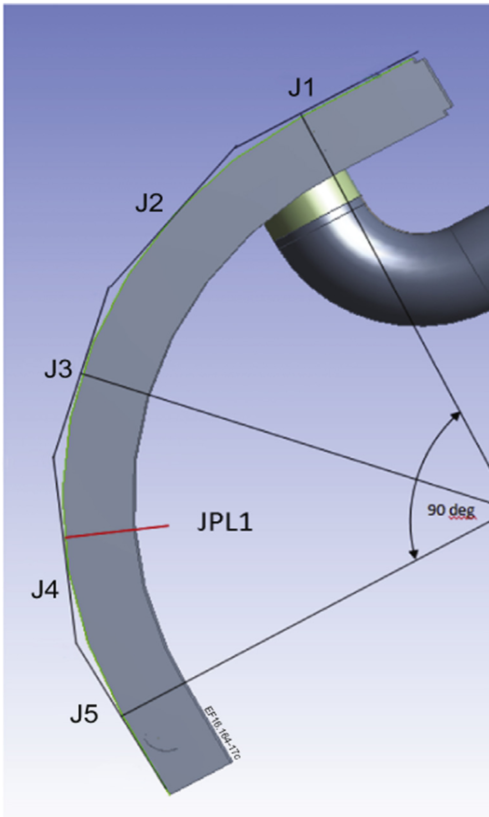

Fig. 1. Curved FEID end plate with the 5 discontinuous plates J1-J5 tangent to the outer face used in MAGNET. JPL1 is the newly installed fast thermocouple.

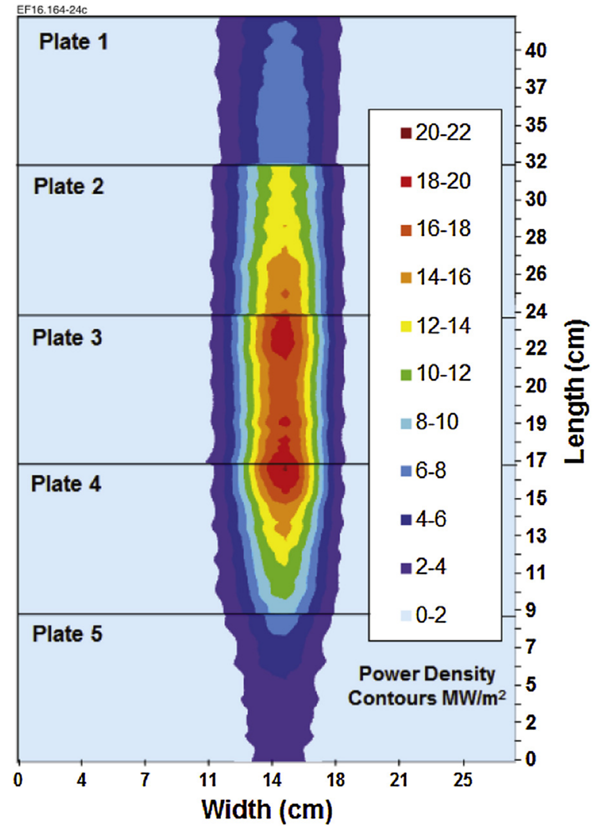

Fig. 2. MAGNET power density profile for the Q1 curved FEID end plate. Peak power density 20 MW/m^2.

the proportion of residual ion species produced in the neutraliser region and thus the power loading on the end plate.

Power loading in the JET beamline is modelled by quadrant using the MAGNET code, a Monte-Carlo simulation programme. Each JET NBI box [3] contains four symmetric quadrants. Each quadrant contains a FEID, curved end plate as shown in Fig. 1, and two Positive Ion Neutral Injectors (PINIs). One on axis (closest to the box central axis) and one off axis (closer to the FEID). The power loading incident on the end plate was modelled for each individual residual ion and re-ionised ion species for the two PINIs operating in 125 kV/65A Deuterium.

The highest peak power density was found to be 20 MW/m^2 on the quadrant 1 (Q1) curved end plate as seen in Fig. 2. The largest contribution comes from the on axis PINI D_2+ full energy ions, followed by D_3+ full energy ions. The off axis PINI, has no residual ion contribution as the full energy ions are bent onto the far side of the FEID. Both PINIs also contribute several MW/m^2 through re-ionisation.

2.2. Charged particle optics

MAGNET does not take into account space charge, which could potentially move the residual ion focus point closer to the end plate and result in a higher peak power density. The CPO code [4] was used to model this effect. CPO was run for the D_2+ residual ion species, as the largest contributor to the power loading. The degree of space charge was varied from 0 to 0.15%, with little change to the focus point of the ions. The 20 MW/m^2 simulated by MAGNET for Q1 is therefore taken as a worst case for the rest of this paper.

2.3. Fast thermocouple measurements

To monitor the temperature of the existing end plates a new fast thermocouple was positioned close to the surface during the 2015 shutdown as shown in Fig. 1. This gives a more accurate reading of the surface temperature in the area of high power loading as given by MAGNET.

Initial analysis was performed using a simple 1D heat transfer model [5] for a copper chrome zirconium plate with temperature dependent conductivity. No cooling of the back surface was assumed, thus only the first 500 ms of pulses were used, as after that the effect of the plate's active cooling is seen. Firstly the thermocouple depth was fitted and averaged over several pulses. This was then input into the model as a fixed quantity and the power density obtained by measuring dT over the linear section of the temperature rise curve.

Fig. 3 shows the power density for Q1, scaled to the MAGNET beam current and extrapolated to 125 kV. At lower voltages the fixed averaged depth was used, but at higher voltages the depth varied enough that it was fitted for each pulse. The 1D power density reaches over 30 MW/m^2 at 125 kV. This is compared to the MAGNET result, which has been scaled with beam current. The ratio of the two power densities is roughly constant over the voltage range, suggesting the neutraliser target depletion applied in MAGNET is largely correct. The thermocouple depth was calculated to be ~7 mm deep, greater than the designed depth of 3 mm. As the drilling has only ±0.5 mm tolerance further analysis was carried out using an ANSYS Workbench model [6].

For the ANSYS modelling of the Q1 fast thermocouple two JET pulses were looked at; #89253 and #89257. In each case the MAGNET power density and the water flow, obtained from an ANSYS CFD model, were scaled so that the modelled thermocouple response