Measured Currents in JET Limiters During Disruptions

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ABSTRACT

Structures mounted inside a tokamak must be able to withstand the electromagnetic forces which arise during disruptions of the plasma. This paper reports on halo current measurements in the JET tokamak during disruptions.

A toroidally distributed array of current sensing tiles reveal that in many disruptions a high degree of toroidal uniformity exists. However in exceptional disruptions the halo current measured at different toroidal positions varies by more than a factor of 2. This latter class of disruption has been observed to result in an asymmetric displacement of the vacuum vessel.

The total halo current is estimated to be up to 15% of the initial plasma current. The halo current width for a particular disruption is estimated to be 8cm.

INTRODUCTION

Elongated tokamak plasmas are susceptible to an axisymmetric instability in which the plasma undergoes a basically vertical motion [1]. A loss of feedback control of the plasma vertical position causes an uncontrolled vertical displacement and will result in a disruption. Alternatively the disruption of the plasma due to other causes will generally result in a loss of vertical stability.

The local changes in magnetic field due to the change in plasma vertical position and plasma current induces currents in the vessel structure. This gives rise to eddy current forces. Forces on vessel components may also arise from currents flowing between the plasma and the vessel, outside the confinement region [2]. This attached current (halo current) tends to be much larger than the scrape off layer currents flowing in a stable plasma [3], probably due to the same large field changes which drive the eddy currents in disruptions. The segment of the halo current flowing in the vessel produces a force on the wall. An opposite restoring force is experienced by the plasma.

Evidence of halo current [3, 4, 5, 6] includes 1) measured difference in toroidal field just inside the top and bottom of the vessel, indicating a net radial current in the plasma, 2) the motion of the vertically unstable plasma which seems to indicate an extra stabilizing force at work, and 3) measurement of the current collected by vessel wall tiles. In addition in JET [6] and JT-60 [7] there is circumstantial evidence of halo currents based on observed damage to in-vessel components.

METHOD OF MEASUREMENT

Fig. 1 shows a cross section of the JET vessel. The mushroom tiles occupy 56 toroidal positions and 2 poloidal positions. Instrumented mushroom tiles are located at 8 toroidal positions, and 2 poloidal positions (Fig. 2). The instrumented tiles are electrically connected to the wall through a 4.65mΩ resistance. The measured resistive voltage drop used to deduce the current is on the order of 10V. Inspection of the mushroom tile current signals during poloidal and toroidal field changes without plasma indicate that the signals are robust against pick-up due to stray loops.

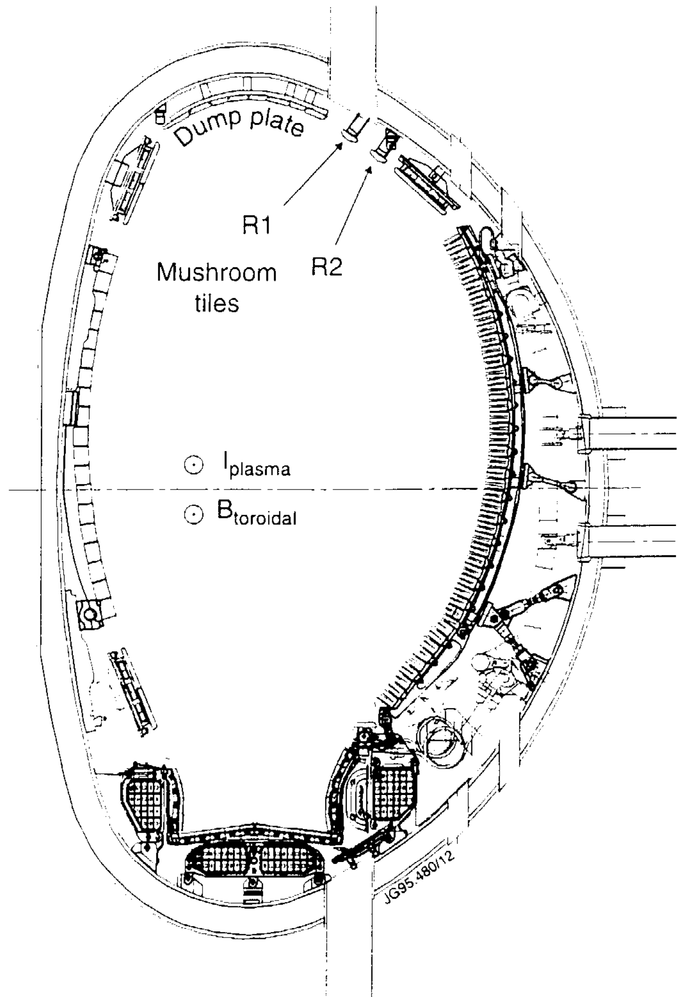

Fig. 1 Cross section of the JET vessel. R1 & R2 denote the two different mushroom tile poloidal positions.

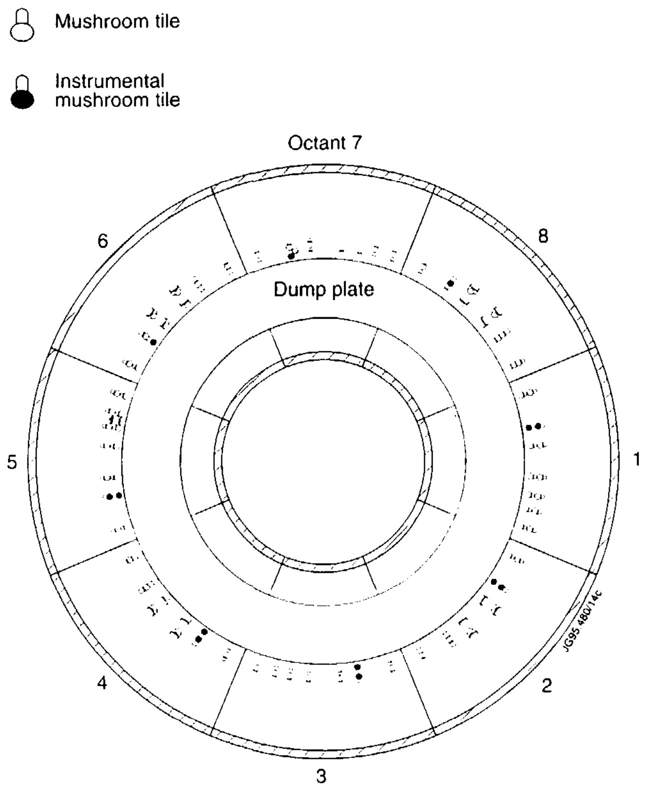

Fig. 2 View from below showing the toroidal distribution of the mushroom tiles.

RESULTS

Fig. 3 shows traces for all the instrumented mushroom tiles for a 3MA plasma which ended in disruption. Also shown are the plasma current and the radial and vertical position of the plasma current centre. In this case, the plasma underwent a significant vertical movement before the plasma current decay. It is this category of disruption which was observed to result in the largest mushroom tile currents.

The mushroom tile current is positive (i.e. into the wall) which is consistent with a halo current flowing along field lines in the same direction as the plasma current. The mushroom tile was usually measured to be in this direction when the plasma moved upward in the disruption. When the plasma moved downward, there was generally no signal on the mushroom tiles.

The dashed lines in Fig. 3 show that the currents in the R1 and R2 rows of tiles are synchronized within their own row, but not with one another. This indicates an axisymmetric motion of the plasma in which the region where the halo current intercepts the wall sweeps over the R2 row, and then the R1 row.

It is difficult to assess the toroidal symmetry of the measured halo current at any single instant because of the fluctuating signals. Fig. 4 shows the integrated mushroom tile signals mapped out according to the toroidal and radial position. For the 3 positions out of 16 (2 rows × 8 octants), where no signal was available, an estimate based on the value from the

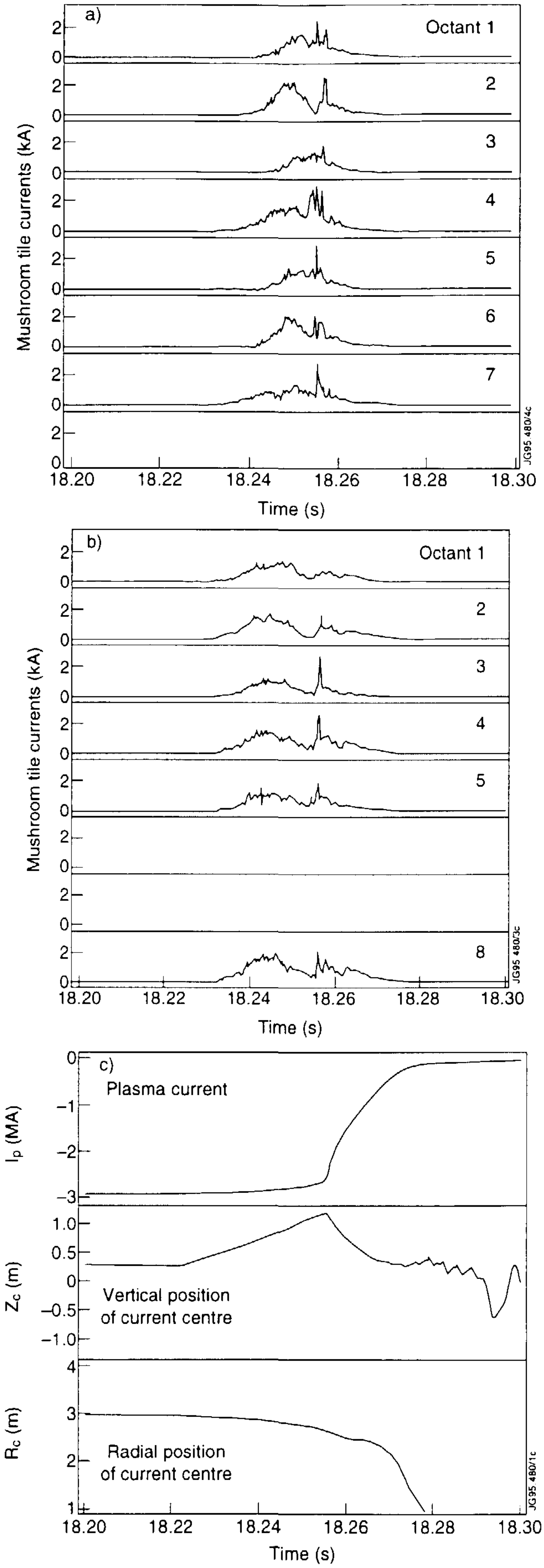

Fig. 3 The measured current collected by a) the 7 mushroom tiles at poloidal position R1 and b) the 6 mushroom tiles at poloidal position R2. Also shown is c) the plasma current and the position of the plasma current centre during the disruption of pulse No. 34250.

same octant scaled by the averaged R1 vs. R2 signal is shown. This disruption was typical of the majority of disruptions in that there seemed to be more current collected on the even numbered octant positions. This systematic toroidal asymmetry is not believed to be a result of asymmetric halo current, but due to asymmetric shadowing of the tiles. If the halo current is flowing along field lines in a vertically displaced plasma, then look at the ceiling of the torus (Fig. 2), current would approach a mushroom tile flowing counter-clockwise with a radially inward twist. The tiles at the toroidal position just before the mushroom tiles are laid out in a slightly different way in the odd octants than the even octants. The data suggests that the layout of the tiles in the even octants shadows the instrumented tiles to a higher degree than in the odd octants. Typically the current collected in the even numbered octant positions is 50% higher than in the odd positions.

Apart from this systematic asymmetry the majority of disruptions show a high degree of toroidal uniformity (within ~ 20%).

There are, however, exceptional cases in which there is a pronounced toroidal asymmetry. The example in Fig. 5 is typical of the observed asymmetry; the integrated mushroom tile current varies approximately sinusoidally with toroidal position, with a period of unity and a zero offset. In this example, the measured currents were originally symmetric, but then dropped to zero at different times for the different positions. Other cases exist, however, where the mushroom tile currents are asymmetric throughout the disruption and the integrated current is negative in some octants.

The disruptions where the halo current is observed to be non-uniform are consistently associated with toroidally asymmetric displacement of the vacuum vessel [8] which indicates the presence of asymmetric forces. It was also observed that the average integrated halo current tended to be highest during these asymmetric disruptions, although the plasma current was not higher in these disruptions.

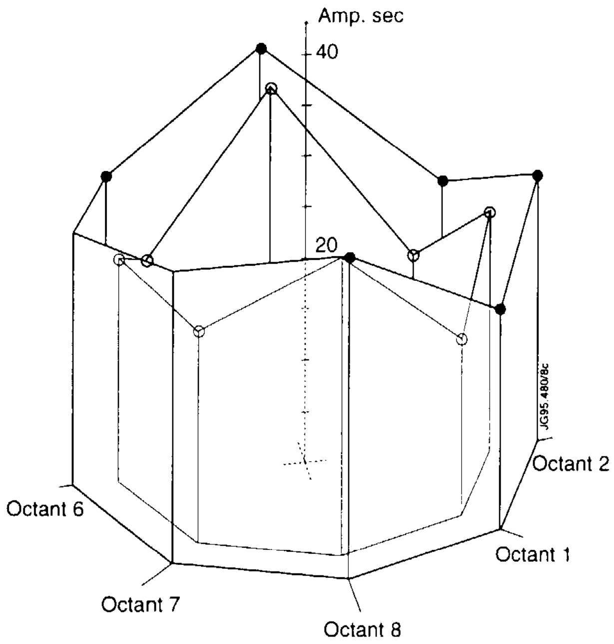

Fig. 4 The time integrated mushroom tile currents for pulse No. 34250 mapped out toroidally.

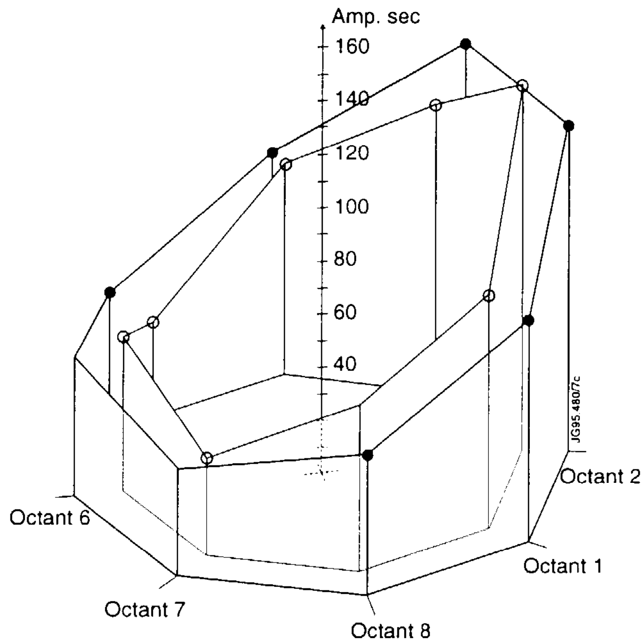

Fig. 5 The time integrated mushroom tile currents for pulse No 34078 mapped out toroidally.

ESTIMATE OF THE HALO CURRENT WIDTH

Fig. 6 shows the average measured halo current per tile for the toroidally symmetric disruption illustrated in Fig. 3. The region where the current is attached to the walls sweeps across row R1 then row R2.

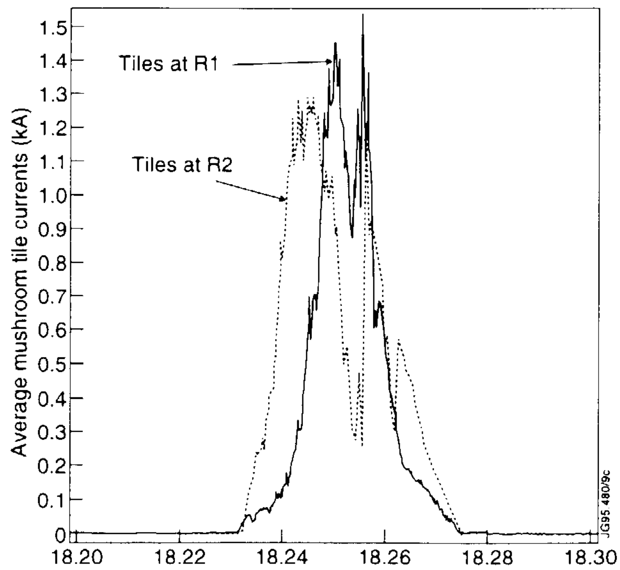

Fig. 6 The mushroom tile currents at poloidal positions R1 and R2 averaged over the different toroidal positions.

If the poloidal extend, $\Delta\ell$, of this region is assumed to remain constant during the sweep, knowing the distance between rows R1 and R2 gives $\Delta\ell \simeq 0.34$m. This will be larger than the halo current width, d, since the current is impinging on the wall at a small angle. Because of the systematic difference in the current measured at even and odd numbered octants, we know that row R2 must at least partly shadow row R1. From this, the maximum width of the halo current is then estimated to be d ~ 0.08m. It should be noted, however, that the width d may have been larger during a later phase of the disruption, specifically when the plasma reaches its maximum vertical displacement. Furthermore, it might be that the width is larger in other disruptions where circumstances do not allow the width to be estimated.

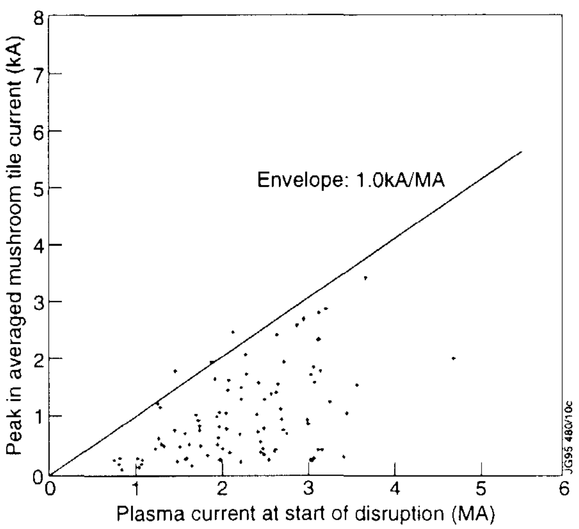

Fig. 7 Peak values of the mushroom tile current averaged over the R1 and R2 sensors.

ESTIMATE OF THE HALO CURRENT MAGNITUDE

In the case of the symmetric disruption in Fig. 3 it was concluded that the poloidal extend of the halo current contact area was of the same order as the poloidal distance between the rows of mushroom tiles. Furthermore it was also concluded that the field lines approached at a shallow angle, such that there is some shadowing of mushroom tiles by one another. Under these conditions, the poloidal component of the total halo current is intercepted by the mushroom tiles. Scaling up the peak, total current measured by $\Delta x/2\pi R$ gives $I_H = 0.19$MA, where Δx is the toroidal arc length between instrumented tiles and the tiles which partially shadow them, and R is the major radius at the tiles. Making the same calculations for many disruptions, should yield values ranging between zero and the maximum poloidal component of the halo current.

Fig. 7 shows the peak value of the sum of the measured currents for approximately 200 disruptions from the 1994/1995 operational campaign. The values fill the region between zero and the envelope shown for two reasons 1) some disruptions at a given plasma current may have an inherently small halo current, 2) In some cases the mushroom tile will not completely intercept the halo current. The limiting envelope, applied to all the mushroom tiles gives $I_H = 18\%$ I_p, where I_p is the value of the halo current just prior to the disruption.

CONCLUSIONS

From a toroidally distributed array of instrumented limiters it was observed that the majority of disruptions lead to a toroidally symmetric (within 20%) distribution of the halo current. However, in exceptional cases there is a marked toroidal variation in the mushroom tile current with mode number n = 1.

During the vertical displacement of the plasma the region of halo current attached to the walls could be seen in some disruptions to sweep past the different poloidal locations of the current collecting tiles. The width of the halo current perpendicular to the poloidal field was estimated to be 0.08m, although it may have been larger during a later phase of the disruption.

Finally, from the sum of the collected current it was concluded the magnitude of the poloidal component of the halo current was $I_H \leq 15\% I_p$ where I_p is the plasma current just prior to the disruption.

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