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DISRUPTIONS AND VERTICAL DISPLACEMENT EVENTS IN JET

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Abstract

Major disruptions and vertical displacement events (VDE's) represent a serious problem for the integrity of large devices such as ITER and a reactor. This arises from the localised power deposition on the divertor target and first wall, the production of runaway electrons in the post-disruptive plasma and the substantial forces transmitted to the vacuum vessel by eddy and halo currents. Extensive experiments have been performed in JET to characterise the phenomena associated with disruptions and VDE's and to investigate the underlying physics. In addition, the installation of a disruption feedback stabilisation system based on a set of 4 internal saddle coils driven by high power (3kA/1.5kV), high frequency (0-10kHz) amplifiers has allowed initial experiments on the control of disruptions by suppression of the n=1 mhd precursor. This system has also been used to study fundamental aspects of the physics of error field induced modes, which is of direct application to ITER.

1. VERTICAL DISPLACEMENT EVENT (VDE)

For the Pumped Divertor phase of JET, an improved vertical stabilisation system, designed to stabilise vertical instability growth rates of up to $1000s^{-1}$ was installed. Under quiescent conditions, this has proven capable of stabilising all plasma equilibria used at elongations of up to 1.9. Whilst disruptions are rather frequent, (40 - 60% of the total pulses) high current disruptions and VDE events are relatively rare occurrences (< 10%) of the total number of disruptions. However these kind of disruptions, which produce the largest forces and halo current, are of the highest interest. A major problem relating to control of the vertical position was encountered at disruptions, as was observed in the original JET configuration, and at edge localised modes (ELM's). This loss of control was generally experienced at singular giant ELM's in highly shaped plasmas, which often terminated the long ELM-free H-modes in high fusion performance experiments. At such ELM's, a rapid displacement of the plasma occurred, generally inwards and upwards, and as a result, the plasma usually made contact with the upper inner wall region. The sudden plasma movement led to a rapid rise in the radial field current to the limiting value of 2.5kA on a timescale of ~ 5ms, the upper level of the radial field amplifier was exceeded, and a VDE resulted. Typical traces for a VDE event are shown in Fig.1.

Within a timescale of ~ 100μs the thermal energy is deposited on the target plates as shown by infrared fast camera observations and the plasma moves vertically as shown by magnetic signals (n=0). Langmuir probe observations support the hypothesis of a toroidal SOL current of the order of 10kA, intercepted by the divertor target during ELM's.

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[1] See Appendix to IAEA-CN-64/O1-4, The JET Team (presented by J Jacquinot).

Using a simplified model of the vertical stabilisation it can be shown that such SOL current could produce a sufficiently large amplitude impulse to cause the loss of control with the subsequent VDE.

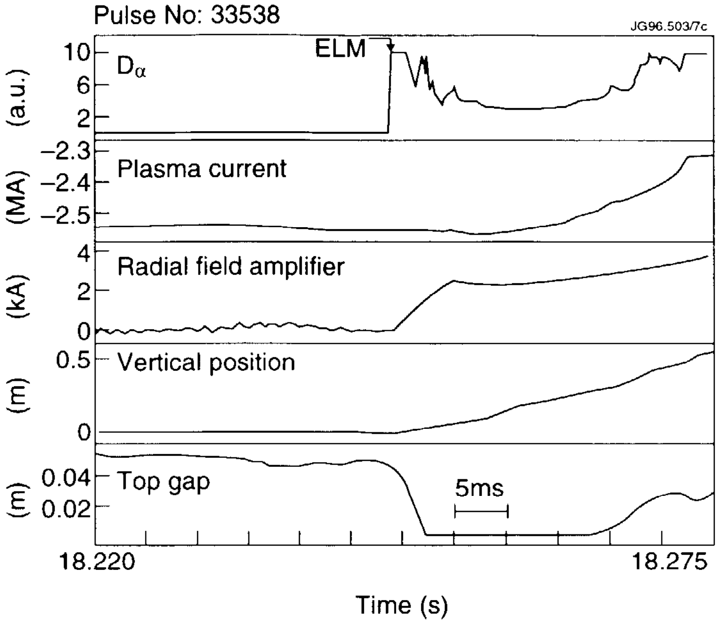

Fig.1 Time evolution of an upward VDE event following a giant ELM. Pulse number 33538.

2. DISRUPTION FORCES

Plasma disruptions produce forces primarily on the vacuum vessel. The study of the dynamic stresses on the vessel for a plasma disruption is performed by a FE shell model representing 180° of the vessel. The input for a disruption is obtained from the strain gauge data taking into account the plasma position signals.

In order to evaluate the forces produced by the plasma in a given configuration an estimate of the disruption dynamics is necessary. However, for the same plasma configuration the disruption dynamics changes considerably leading to a large variation of the forces produced.

2.1 Vertical forces

The vertical forces are generated by the plasma vertical movement during a disruption. They scale with the square of the plasma current as shown in Fig.2. The value of the vertical force therefore depends on the plasma configuration, on the plasma current and on the plasma dynamics. An empirical estimate of the maximum vertical force which can be generated in a given configuration (F number) is calibrated against the forces measured in disruptive plasma pulses [1].

At a comparable plasma current the disruptions which produce the large vertical forces are those caused by VDE, with loss of the vertical stabilisation in which the current movement product $I_p.\Delta Z$ is larger. On the other hand, disruptions in which the control of the vertical position is maintained during the decay of the plasma current, produce small or negligible vertical forces.

The frequency distribution of the vessel forces in the last 2 years of JET operations is shown in Fig.3. The distribution shows the higher forces produced by the downward disruptions despite the stabilisation effects of the currents induced in the divertor coils.

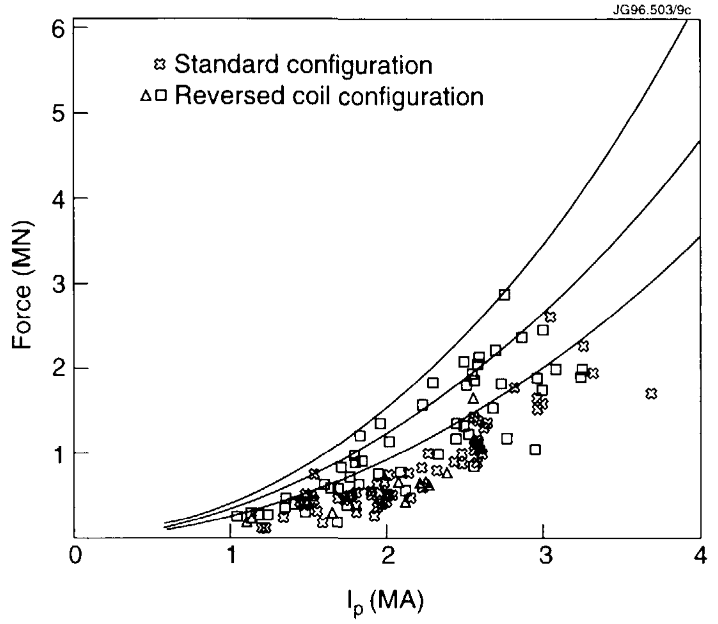

Fig.2 Measured vertical vessel force versus the plasma current prior to disruption.

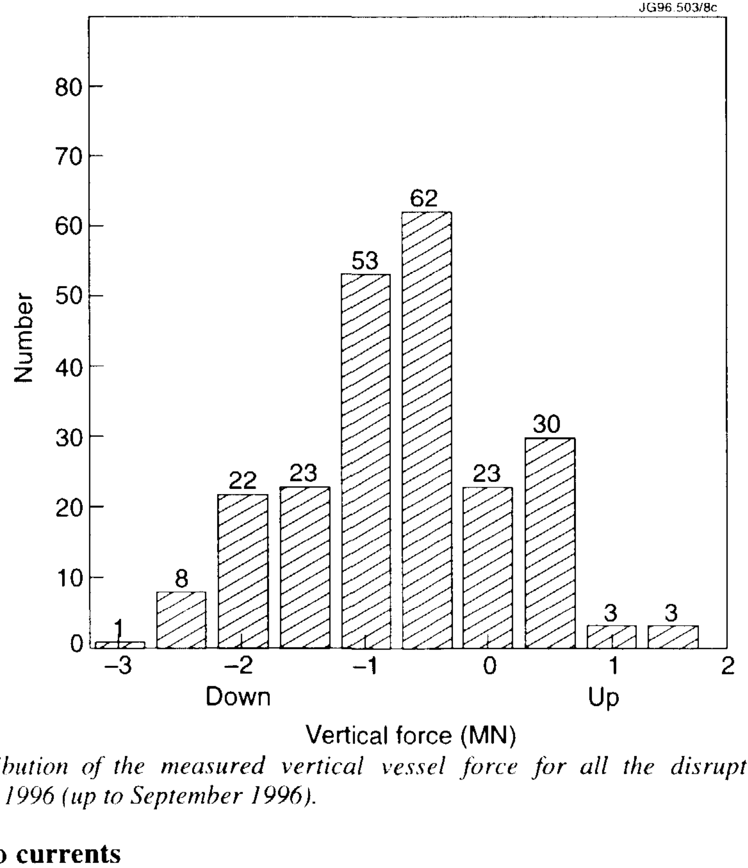

Fig.3 Distribution of the measured vertical vessel force for all the disruptions which occurred in 1996 (up to September 1996).

2.2 Halo currents

The halo currents sensitive diagnostics have been installed in the vacuum vessel: a pair of toroidal field pick up coils located on the top and bottom of the vessel, poloidal current shunts at 2 toroidal positions, a number of poloidally and toroidally distributed shunts on the earthing connections of certain in-vessel components [2]. It has been found that the integrated estimated halo current scales with the measured vertical force.

The total average halo currents was found to be ≤ 20% of the initial plasma current, as shown in Fig.4.

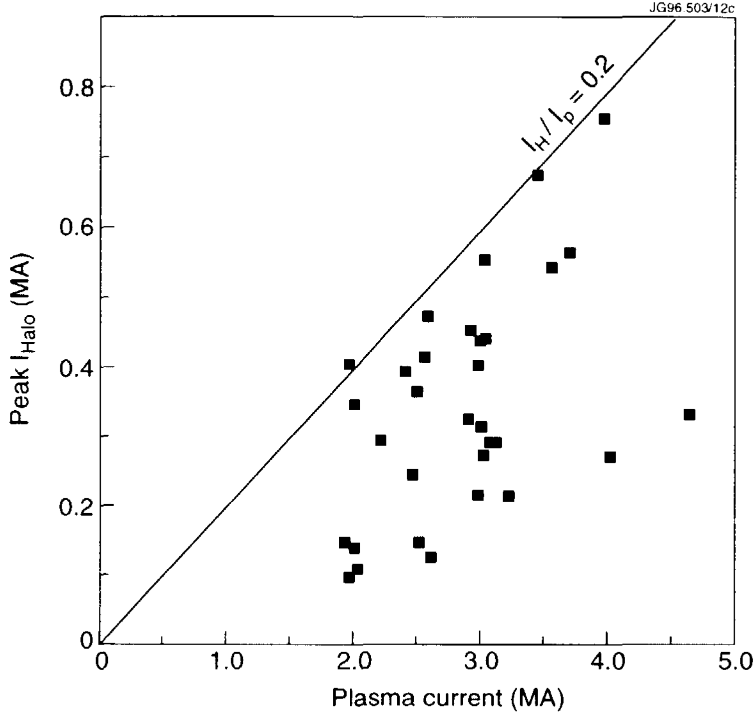

Fig.4 Integrated halo current versus plasma current prior to the disruption.

3. LATERAL DISPLACEMENTS

The vacuum vessel displacements are measured at the ports and the radial displacements are available on four octants at the upper and lower main vertical ports (MVP's) and all eight octants at the main horizontal port (MHP), where also the tangential displacements are measured.

The toroidal distribution of the halo current is given only for upwards disruptions.

Local measurements of intercepted halo currents and measurements of forces on the vessel supports indicate large time fluctuations and toroidal asymmetries of the halo current density in the presence of toroidal asymmetries of the global vertical forces acting on the JET vessel as measured from the 8 instrumented tiles in 8 locations at the top of the vessel. The typical trends are shown in Fig.5.

In the presence of the measured toroidally asymmetric halo currents a net lateral movement of the vacuum vessel was observed. The toroidal distribution of the time integrated halo currents peak was as high as twice the average as shown in Fig.6. The observed lateral movement of the vessel is associated with an apparent asymmetry of the measured plasma current centred at two different toroidal locations. The inferred m=1, n=1 island would be equivalent to a tilting of the plasma with a resulting force which needs to be balanced by other asymmetric toroidal forces such as induced or halo current forces. From the movement of the position of the plasma current centroid the apparent edge safety factor could be evaluated. A correlation has been found between large sideways movements and an estimated value of the safety factor between 1.0 and 1.3. From the vector sums of the average octant displacements, it appears the whole vessel moved approximately by 5.6mm in the direction between octant 5 and 6.

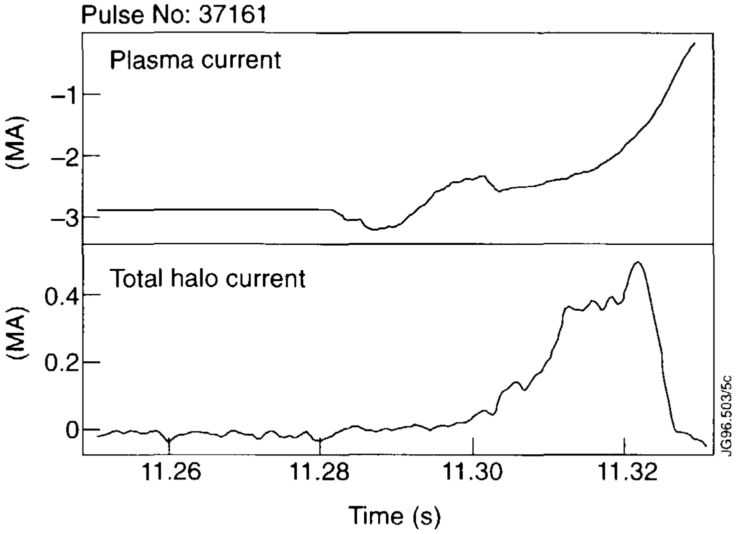

Fig.5 Time evolution of VDE and measured halo current for pulse 37161.

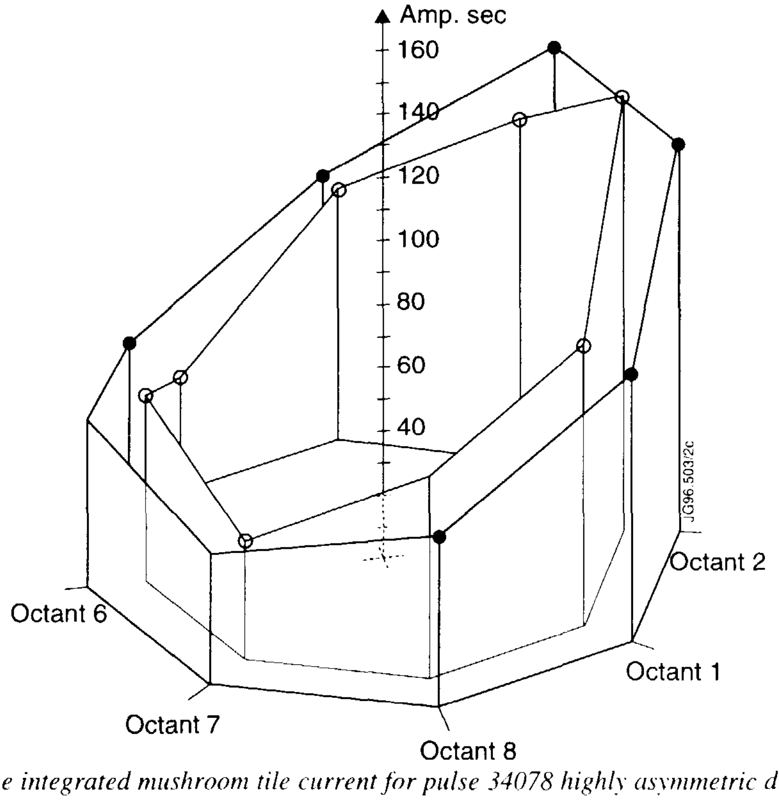

Fig.6 Time integrated mushroom tile current for pulse 34078 highly asymmetric disruption.

4. SADDLE COILS

Experiments on the influence of external error fields on mhd stability have been pursued using the internal saddle coil set [3]. n=1 'locked' modes induced by intrinsic error fields are considered to be significant for ITER since the critical error field threshold is predicted to be very low, $B_r/B_t \sim 2\times10^{-5}$.

Initial experiments have investigated the threshold for the static error field modes. In JET n=1 fields B_r as small as 0.12 mT (B_r/B_t~5 10^{-5}) are sufficient to penetrate (with n_e=1-1.4$10^{19}$m^{-3} q_{95}~3, I_p=1-1.5MA) and generate tearing modes. Figure 7 shows the linear dependence of the penetration threshold with the plasma electron density.

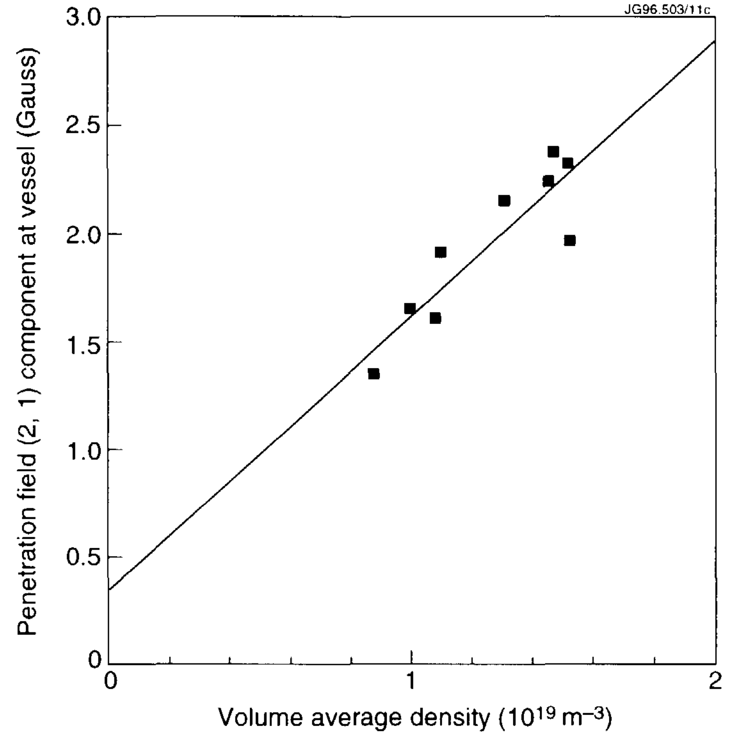

Fig.7 Penetration threshold ($I_{SC}\cdot B_{r21}$) as a function of the average electron density n_e.

Rotating tearing modes have also been generated with the application of a small n=1 field rotating at a frequency close to the plasma rotation frequency.

The considerable scatter of the data shown in Fig.7 appears to depend on the details of the plasma equilibrium.

Magnetic feedback control has been applied in JET to saturated tearing modes. The amplitude and the position of the modes have been measured by four fast pickup coils. The spurious pickup due to the feedback vacuum field and to the ideal MHD plasma response to this field has been measured and compensated in the digital controller. The plasma ideal response is independent of the field frequency and strongly dependent on the plasma configuration and q value. Upon the application of the feedback AC field a modification of the growth rate of the tearing mode has been observed in a few pulses as shown in Fig.8.

It has not yet proved possible to stabilise tearing modes precursors of density limit disruptions because their high instability parameter Δ' and the low feedback gain applied.

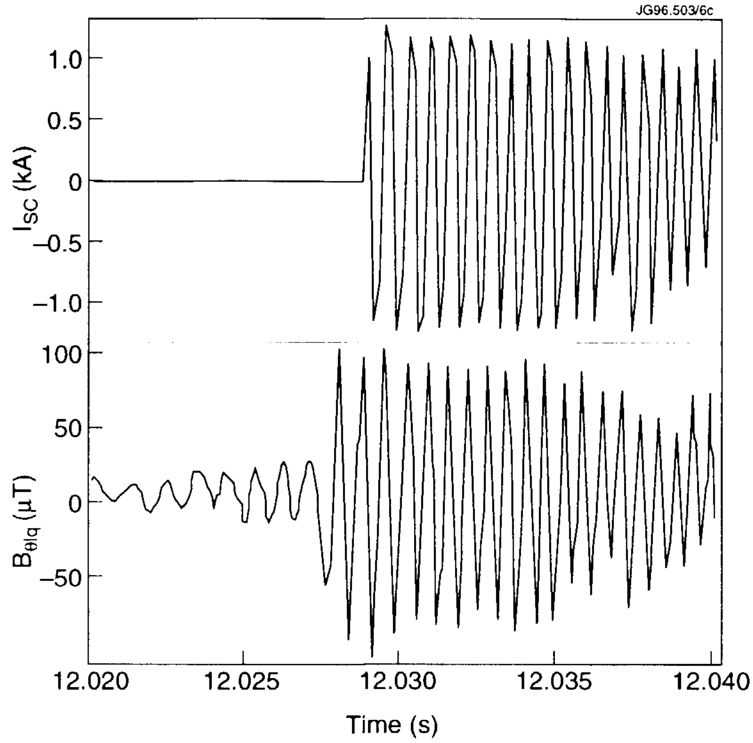

Fig.8 Modification of a tearing mode growth rate at the sudden application of the feedback current (I_{SC}). Feedback started by a trigger on mode amplitude at a field level of ~ 50μT. $B_{\theta lq}$= field at the poloidal limiter (n=1).

CONCLUSIONS

The analysis of the disruption dynamics and vessel forces in JET has shown that the large vertical forces produced by the elongated plasma cause both halo current forces localized on in-vessel components and stresses on the main vacuum vessel. VDE events producing the highest vertical forces cause sideways vessel displacements associated with a tilting of the plasma column. Experimental evidence shows that this event occurs when the limit q is in the region 1-1.3. Loss of control of vertical stabilisation associated with ELM's in shaped plasma produce upward VDE's. Experiments with the lower saddle coils set have measured the threshold for the static error field mode and have been applied to the saturated tearing modes. Systematic measurements of vessel displacements and forces have been carried out.

REFERENCES

[1] NOLL, P., et al., Fusion Technology **15** (1989) 259.

[2] ANDREW, P., et al., in Proc. 16th IEEE/NPSS Symposium on Fusion Engineering **1** (1995) 770.

[3] SANTAGIUSTINA, A., et al., in Controlled Fusion and Plasma Physics (Proc. 22nd Eur. Conf. Bournemouth, 1995), Vol. 19C, Part IV, IV-461.