EFDA–JET–CP(10)06/08

S.N. Gerasimov, T.C. Hender, M.F. Johnson, L.E. Zakharov
and JET EFDA contributors

Scaling JET Disruption Sideways Forces to ITER

Scaling JET Disruption Sideways Forces to ITER

S.N. Gerasimov[1], T.C. Hender[1], M.F. Johnson[1], L.E. Zakharov[2]
and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]*EURATOM-CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK*
[1]*Princeton Plasma Physics Laboratory, James Forrestal Campus, Princeton, NJ 08543, New Jersey, USA,*
** See annex of F. Romanelli et al, "Overview of JET Results",*
(Proc. 22[nd] IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).

Preprint of Paper to be submitted for publication in Proceedings of the
37th EPS Conference on Plasma Physics, Dublin, Ireland.
(21st June 2010 - 25th June 2010)

INTRODUCTION

A key feature of disruptions during VDE is toroidal variations in the measured plasma current and first current vertical moments, Fig.1. These asymmetries can lead to significant sideways forces as seen on JET [1,2]. The observed asymmetries are a long lasting n=1 variation of the plasma current (I_p) and its first current (vertical) moment (Miz) and have been interpreted as kink mode m/n=1/1 [1], Fig.2.

1. DIAGNOSTICS

Unique JET magnetic diagnostics (in-vessel pick-up coils and ex-vessel saddle, 5kHz sampling rate, Fig.3, Fig.4a) have allowed the comprehensive analysis of the asymmetrical disruptions on a large database. The present database includes 4457 disruptions (I_p^{dis} >1MA) out of which 3503 are recorded (from 1994 onwards) using two (3&7) opposite octants and 954 disruptions (from 2005 onwards) are recorded using 4 octants, each separated by 90^o.

2. PHASE RELATIONSHIP OF IP AND MIZ ASYMMETRIES

Figure 1 shows the typical waveforms (I_p, ΔZ vertical displacement, I_p and Miz asymmetries) during an I_p current quench. The measured plasma current is greater where displacement is also greater [1,2]. Specifically, the toroidal asymmetry in plasma currents corresponds to negative currents (in respect to direction of plasma current) flowing in the vessel, Figure 4(b). The I_p and Miz asymmetries phase diagram confirms that this is correct for the total database without exceptions, Fig.5. The sign of observed asymmetry corresponds to the so called Hiro currents that were introduced by the Wall Touching Kink Mode (WTKM) theory [3]. The WTKM provides an explanation of the long lasting kink mode m/n=1/1 and the polarity of the measured plasma current asymmetries during VDE, Figure 4(b) and Figure 6.

3. PLASMA CURRENT ASYMMETRIES

The maximum observed normalized plasma current asymmetry $A_p^{asym} = I_p^{asym} / I_p^{dis}$ (where I_p^{dis} = $\sqrt{(I_{p7} - I_{p3})^2 + (I_{p5} - I_{p1})^2}$ and I_p^{dis} is pre-disruptive plasma) reaches 23% of plasma current before disruption, Figure 7. The points have been ordered using the 2 octant data (red) and then the 4 octant data (blue) was plotted in the same (red) order. The blue and red points coexist for 4 octant data only. To avoid noise contributing to the results, the presented analysis has been performed for a time window, where the first and the last time points satisfy the condition: I_p^{asym} >0.5% $|I_p^{dis}|$ and $|I_p|$ >10% $|I_p^{dis}|$ and for the first and last 1ms window $|I_p^{asym}|$>10kA.

4. ROTATION

Mode frequencies, which are close to the structural natural frequencies of the components, can cause major dynamic amplification of the loads. On JET, the mode rotation shows significant scatter in respective magnitudes, frequencies and directions. Fig.8 shows the number of turns calculated for four different time windows specified by condition $A_p^{asym} > 0.5\%$, 1%, 2% and 5% for first and last window time points. The rotations are in the range from −2 turns to +8 turns for the entire 4 octant database, where plasma current and the toroidal field are in the anticlockwise direction. The rotation frequencies are also spread in a wide range (Fig.9), which may lead to dynamic amplification of the structural forces. The physical processes leading to these rotation variations are not presently understood.

The A_{4oct} (or A_{2oct}) = $\int I_p^{asym}\, dt/I_p^{dis}$ integral characterizes the severity of asymmetry during the plasma current quench.

5. SIDEWAYS FORCES AND IMPULSES ON JET

In the WTKM theory the forces come (as it should be) from interaction of the current (having both toroidal and poloidal components) in the wall with the full magnetic field. The theory includes both Hiro currents (explaining toroidal asymmetry) as well as eddy currents in the wall. WTKM, as a linear theory, has a single free parameter, i.e., *the mode amplitude*. Besides this, the theory contains everything concerning plasma description, as well as EMF driving currents in the wall. One of the results of the theory is, that the upper estimate of force is reduced to Noll's formula: $F_x^{Noll} = {}^{\pi}/_{2}\ B_T \Delta M_{IZ}$. The direction of the force also remains as in simple model, Figure 2. The absolute and normalized JET sideways forces calculated using Noll's formula are presented in Figures 10 and 11. The normalised impulse of the sideways forces as a function of the plasma current quench time has been plotted on Figure 12. The 2 octant database can be projected to the 4 octant database, if the mode rotates as a pure sine wave in time then $I_{4oct} = \pi/2\ I_{2oct}$ (generally $\pi/2\ I_{2oct}$ gives a good approximation of the 4 octant data). The current quench time ($\tau_{80\text{-}20}$) extrapolated from time to quench from 80% to 20% of I_p^{dis}. The duration of the mode is always within the current quench duration. The line in Figure 12 corresponds to mode amplitude equal to 10% of plasma minor radius before disruption for the whole current quench duration. This line provides a good boundary for the data.

DISCUSSION OF SCALING JET SIDEWAYS FORCES TO ITER

For the accurate calculation of the sideways forces an appropriate wall model linked to kink mode evolution is needed. Together with a simple adiabatic shrinking of the plasma cross-section, this would automatically determine the evolution of mode amplitude as well as the forces. This is not available today or in the near future. Thus we rely on Noll's formula, as a conservative (upper estimation) of the sideways forces, which can be denoted from [3]. Extrapolating sideways forces to ITER based on the Noll's formula, assuming similarity in mode amplitude, would suggest an order of magnitude increase over JET. Separately, the question of scaling of the sideways force impulses (including mode duration, rotation and particularly dynamic amplification of forces) needs to be resolved in the future.

ACKNOWLEDGEMENT

This work was carried out within the framework of the European Fusion Development Agreement and was partly funded by the United Kingdom Engineering and Physical Sciences Research Council under grant EP/G003955 and by the European Communities under the contract of Association between EURATOM and CCFE. Work partly funded by UK EPSRC and EURATOM, and conducted under the EFDA. The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work is also supported by US DoE contract No. DE-AC02-09-CH11466.

REFERENCE

[1]. P. Noll, et al, in Proceedings of the 19th Symposium on Fusion Technology, Lisbon, 1996 , Vol. 1, p. 751.

[2]. V. Riccardo, et al, Nuclear Fusion, Vol. **40**, No. 10 (2000)

[3]. L. Zakharov, Physics of Plasmas **15** (2008) 062507.

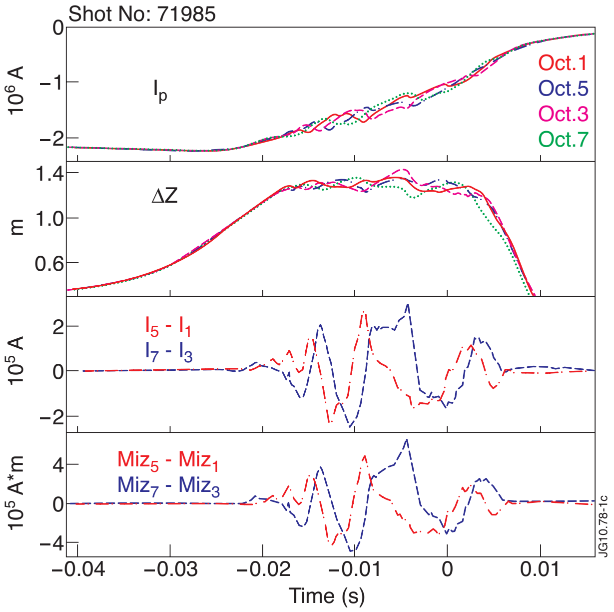


Figure 1: Waveforms of the measured asymmetries.

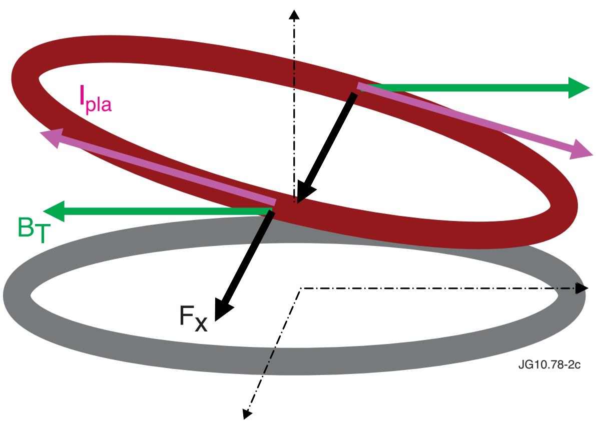


Figure 2: m/n=1/1 mode leads to sideways, simple model [1].

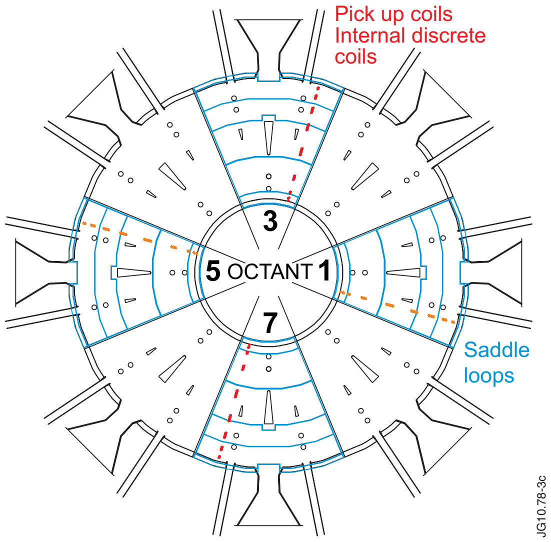


Figure 3: Plan view of JET vessel, showing the locations of the pick-up coils and saddles.

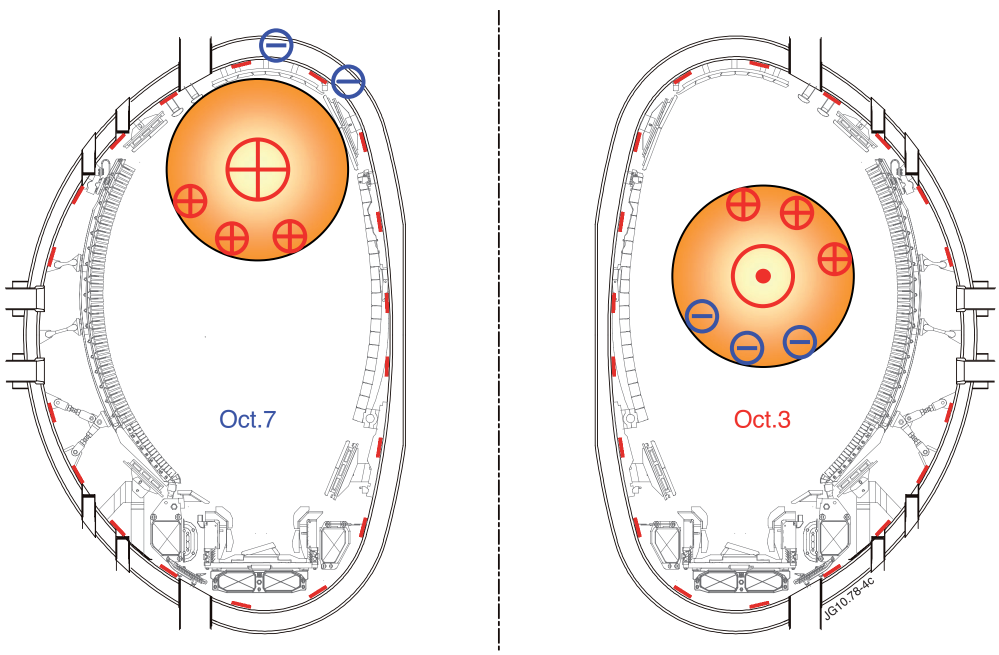
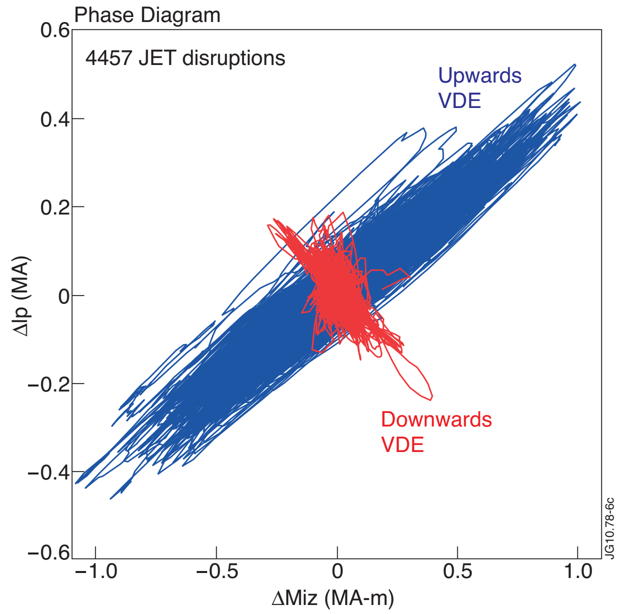


Figure 4: JET vessel cross-section:
(a): showing the locations of the pick-up coils.
(b): polarity asymmetry explanation: current from plasma flows on vessel in Octant 7 and not Octant 3.



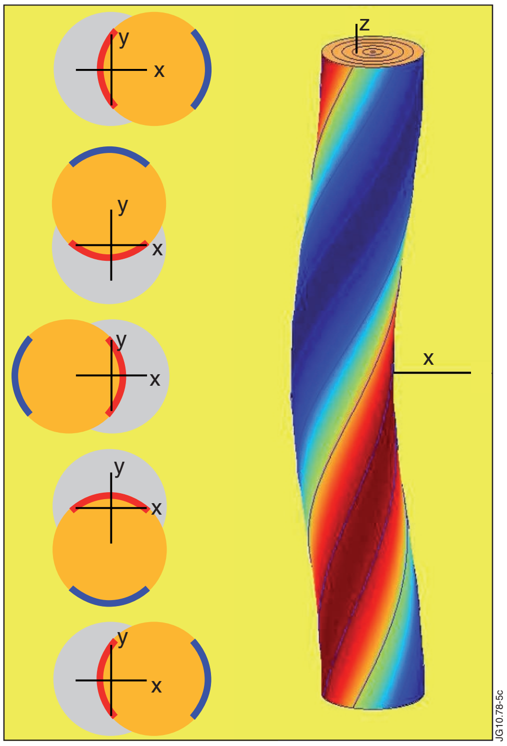
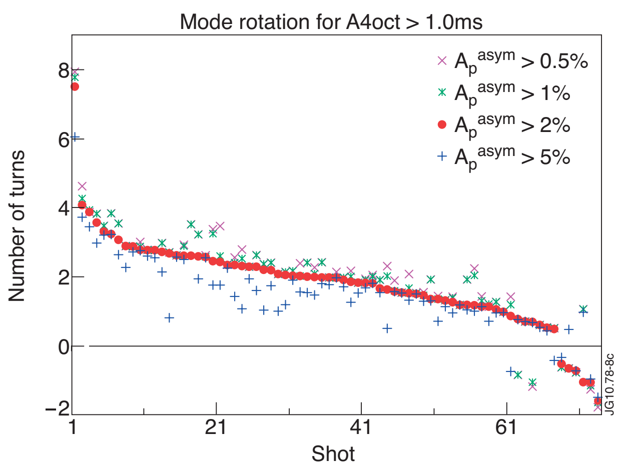


Figure 5: Phase relationship of the I_p and Miz asymmetries: greater displacement leads to greater measured I_p. The downwards VDE trajectories are orthogonal to upwards VDE trajectories because of the displacement polarity.

Figure 6: The bulged outer surface always carries the negative (blue) current, opposite to I_p! The bulged inner surface always carries the positive (red) current.



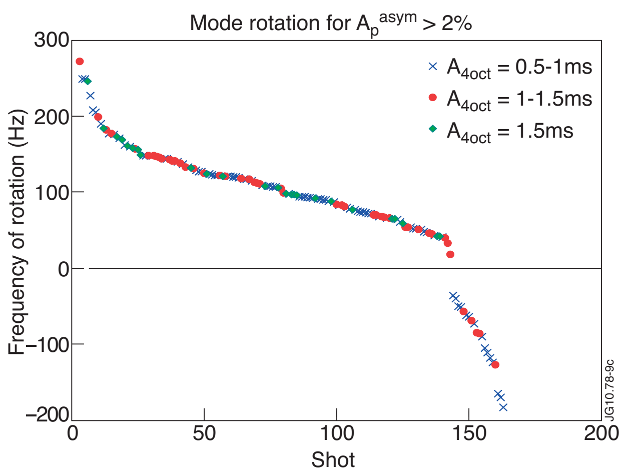


Figure 8: The number of turns calculated for 4 octant databases.

Figure 9: The rotation frequency for the shots with A_p^{asym}> 2% differentiated by A_{4oct}.

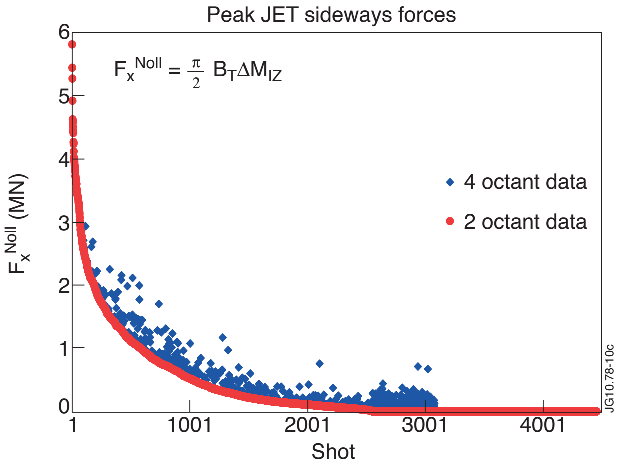


Figure 10: The JET sideways forces for entire databases.

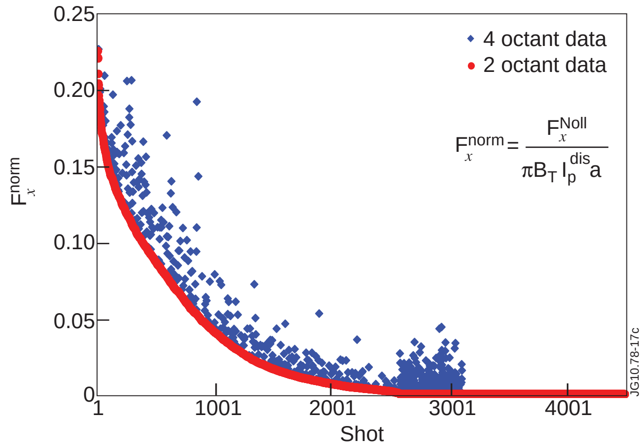


Figure 11: Normalized JET sideways forces.

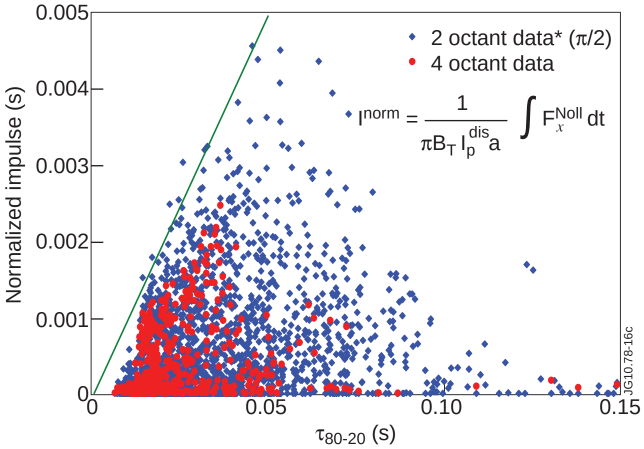


Figure 12: JET normalized sideways force impulse versus the current quench time. The green line is the mode amplitude (current centroid) = 0.1a