Wall Touching Kink Mode during a disruption[1]

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Contents

1 Incompleteness of tokamak MHD

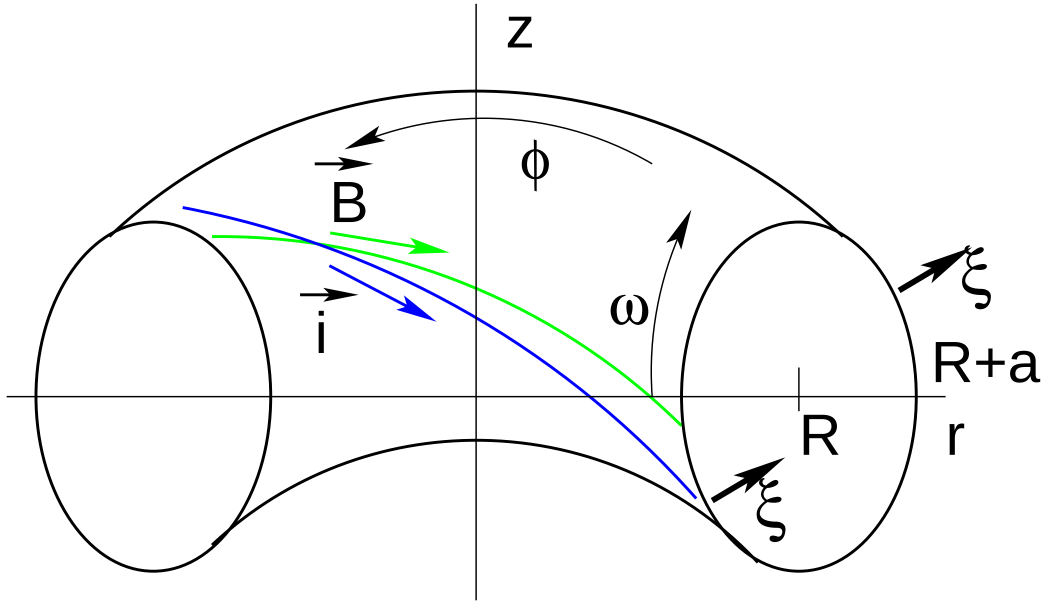
I will give you a sense of a fundamental effect, i.e., the electric contact of the plasma with the wall, which was missed in the tokamak MHD for 57 years, (if counting from the derivation by V.D.Shafranov, 21 year old that time, of stability criterion

$$q > 1, \tag{1.1}$$

which soon after this gave birth to tokamaks as fusion devices).

2 The basics of the kink mode 1/1

Deformation of the plasma surface generates the surface current



$$r = R - \rho\cos\omega,$$
$$z = \rho\sin\omega,$$
$$\rho = a + \xi(\rho,\omega,\varphi), \quad (2.1)$$
$$q = \frac{aB_\varphi}{RB_\omega},$$

Its value is determined by the condition of absence of normal component of B

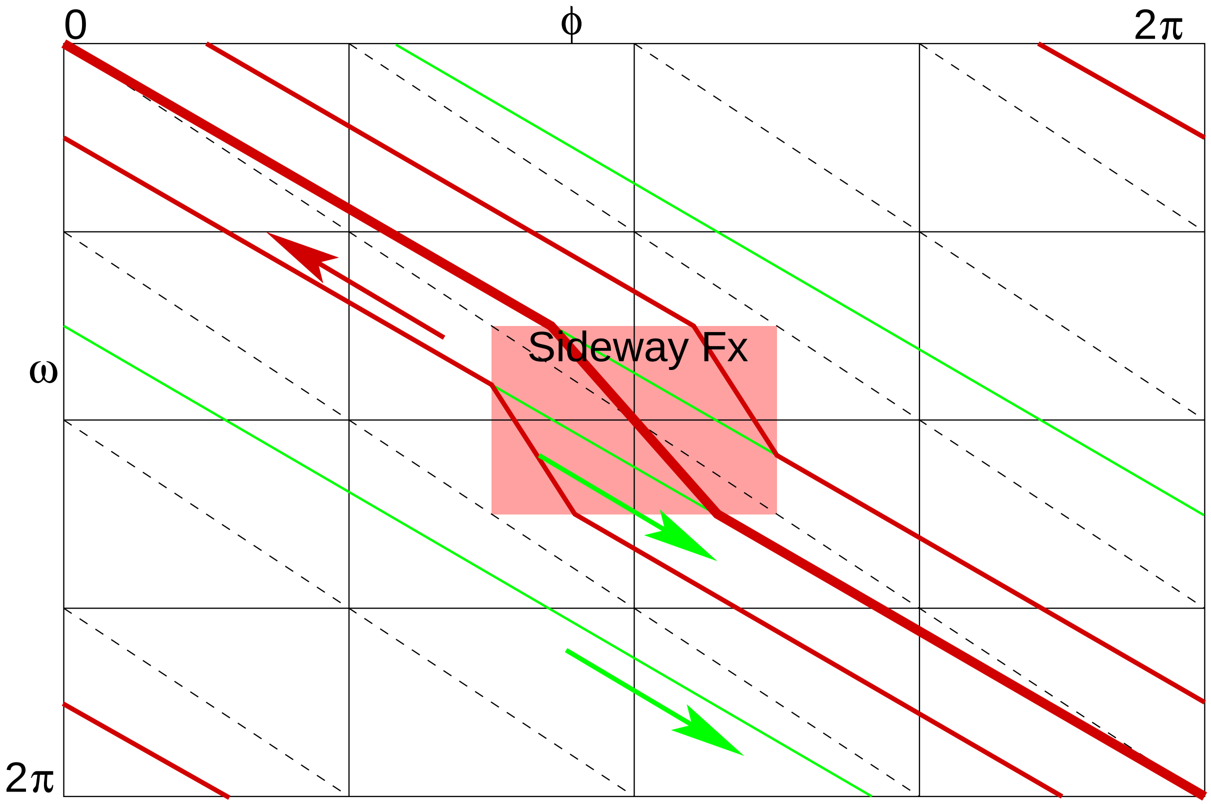
$$\overrightarrow{\mathrm{B}}\cdot\nabla\rho = 0, \quad \overrightarrow{\mathrm{i}}(\omega,\varphi) = -\frac{1}{a}I'_\omega\overrightarrow{\mathrm{e}}_\varphi + \frac{1}{R}I'_\varphi\overrightarrow{\mathrm{e}}_\omega. \quad (2.2)$$

For marginally stable perturbation $\xi(\rho,\omega,\varphi)$ *inside the plasma perturbation the only force acting on the plasma is the surface force* $\overrightarrow{\mathrm{i}}\times\mathrm{B}$*, which is stabilizing if*

$$q > 1, \quad (2.3)$$

3 Wall Touching Kink Mode (WTKM)

Electric contact with the wall makes plasma unstable



The surface current, excited by the mode, finds a way to make plasma unstable

Electromagnetic pressure is applied to the in-vessel conductors

Electric contact with the wall gives much more freedom for plasma perturbations

Energy Principle for ideal WTKM

WTKMs can be described by the same formalism as ideal MHD modes. WTKM are insensitive to non-ideal effects.

$$W_{WTKM} \equiv \underbrace{W_{BFKK}}_{conventional} + \underbrace{\frac{1}{2}\int_{wet-zone} \vec{\xi}_n \cdot (\overrightarrow{\tilde{\mathrm{i}}} \times \overrightarrow{\mathrm{B}}) dS}_{virtual\ work\ against\ the\ wet\ surface} . \qquad (3.1)$$

If the plasma test perturbation satisfies the equilibrium conditions, the W_{WTKM} *is reduced to*

$$W_{WTKM} = -\frac{1}{2}\int^{*}_{\substack{free\ plasma\\ surface}} \vec{\xi}_n \cdot (\overrightarrow{\tilde{\mathrm{i}}} \times \overrightarrow{\mathrm{B}}) dS. \qquad (3.2)$$

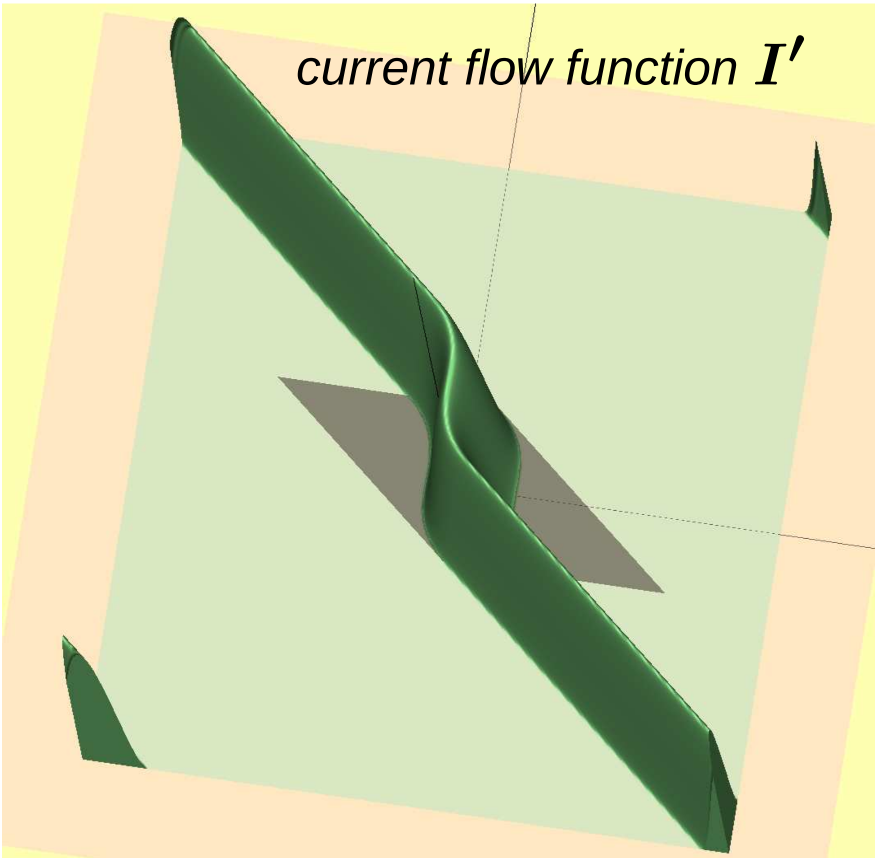
In the presence of the wet-zone (with an electric contact between the plasma and the wall) it is always possible to create a test perturbation with

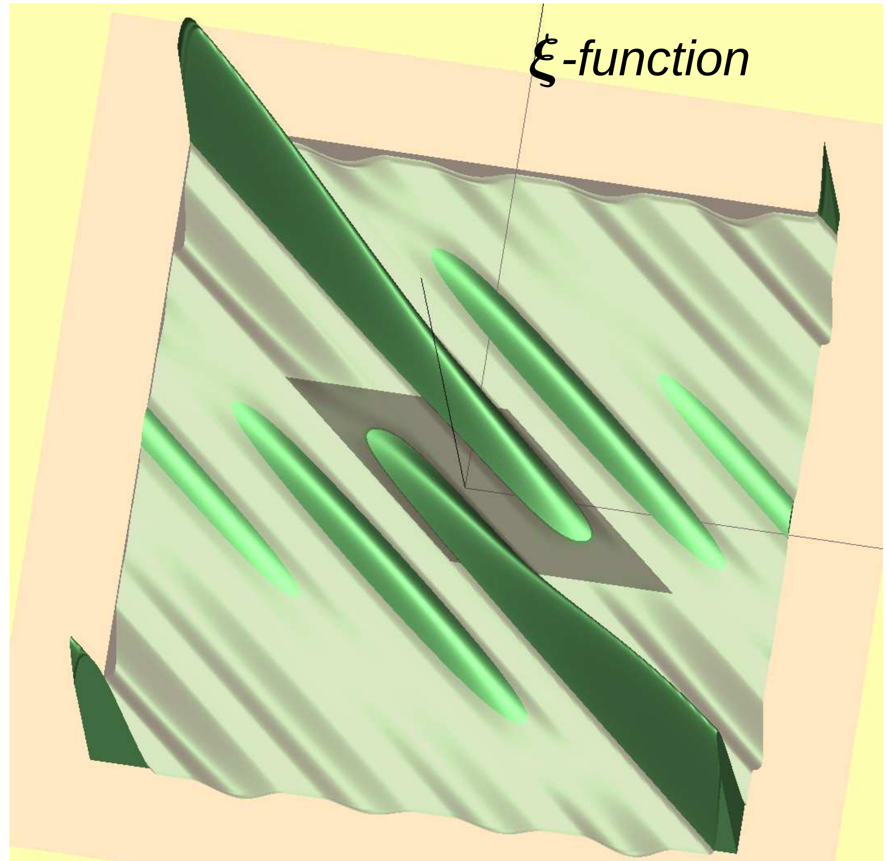
$$\overrightarrow{\tilde{\mathrm{i}}} \parallel \overrightarrow{\mathrm{B}}, \quad W_{WTKM} = 0. \qquad (3.3)$$

In MHD, the existence of a marginally stable test perturbation is equivalent to the ideal instability.

Surface current and displacement

An example of marginally stable test perturburbation (for a flat current distribution)

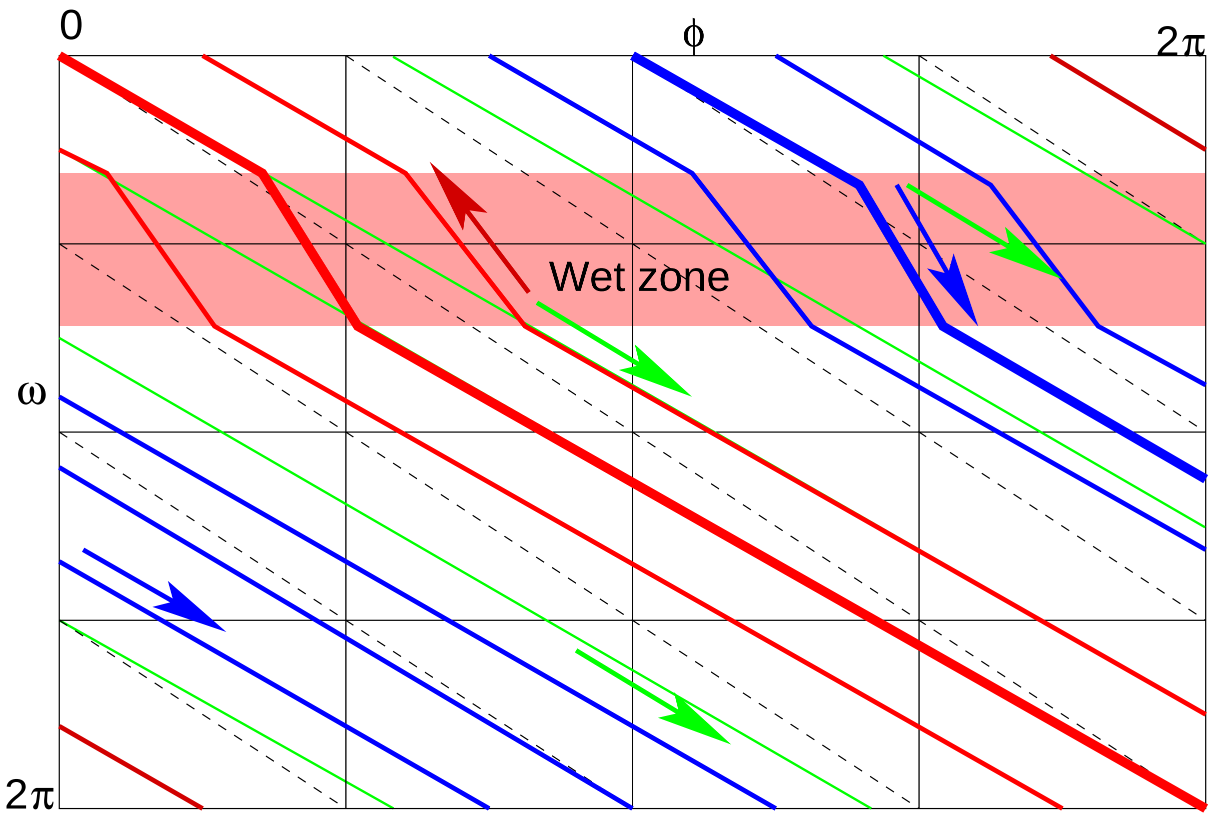




Many surface kink modes (128x128) are involved

WTKM during vertical disruption

On JET the vertical disruption event creates a wet-zone and excites the m/n=1/1 mode at $q > 1.5$

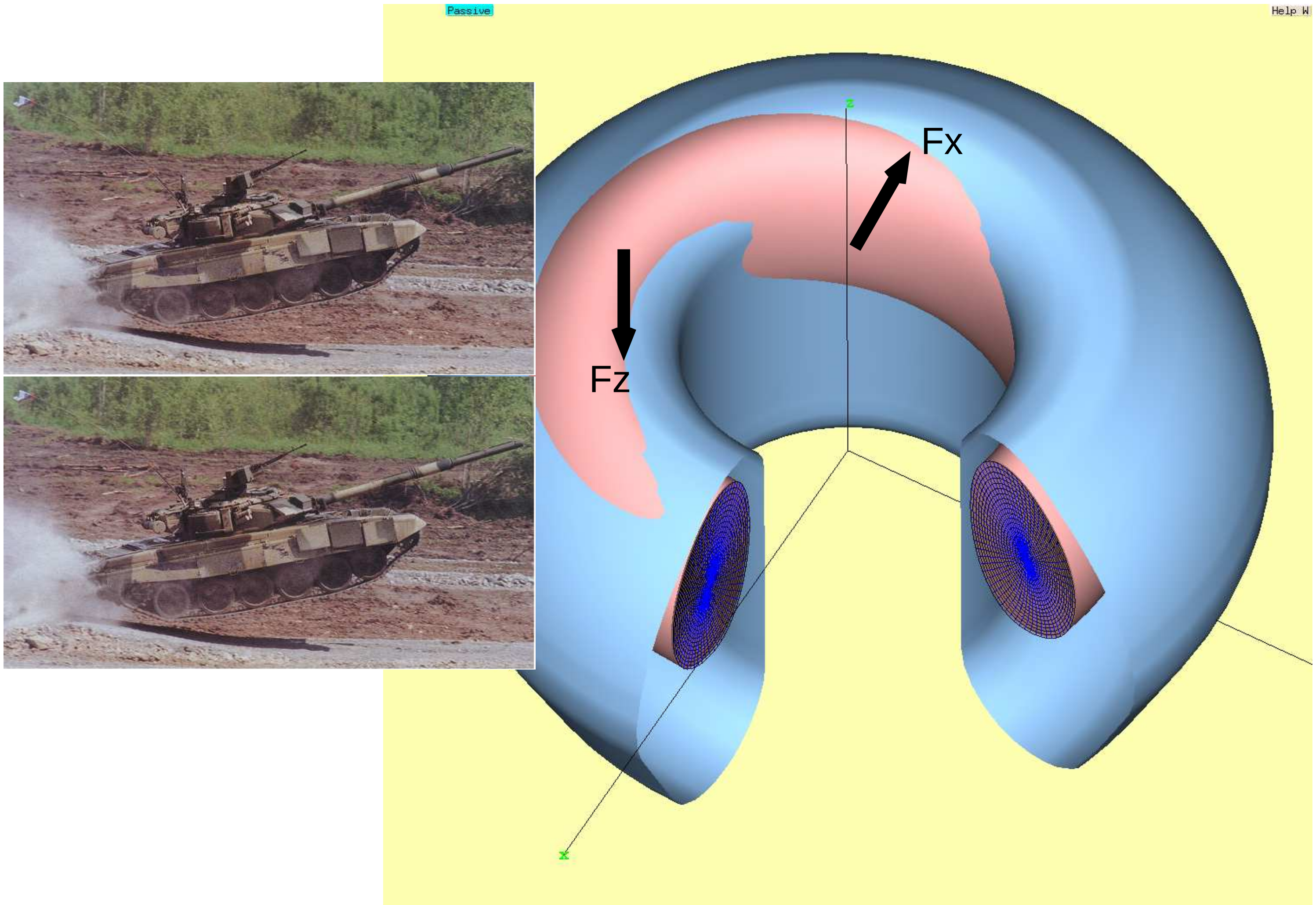


Depending on the position of the wet-spot a troublesome sideway force F_x can be generated

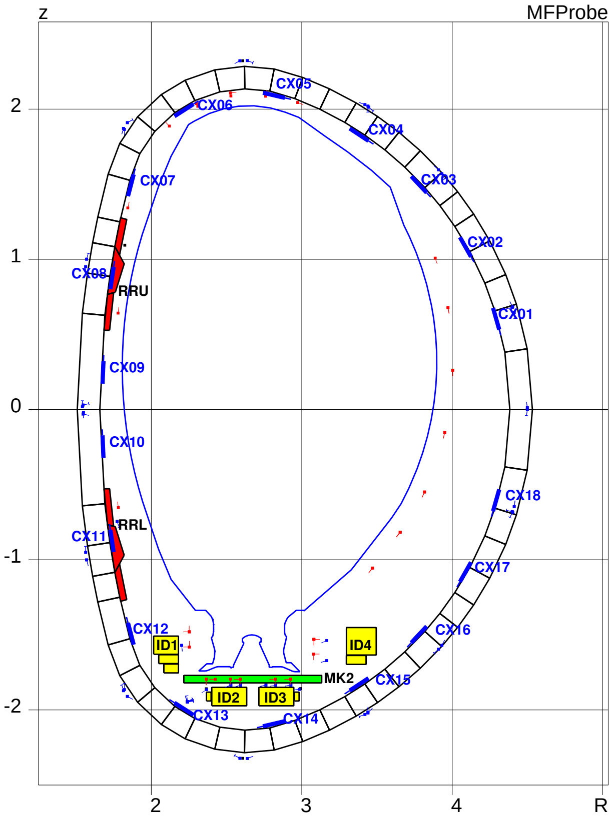
$$F_x = \pi I_{pl} B_\varphi (1 - q)\xi_{11}, \quad (3.4)$$

Sideway force is a concern for ITER

The sideway force impulse $\simeq 2MN \cdot sec$ *in ITER is equivalent to the impulse of two 50 tonne tanks T-90S at the speed of 72 km/hour.*



4 Comparison with JET data



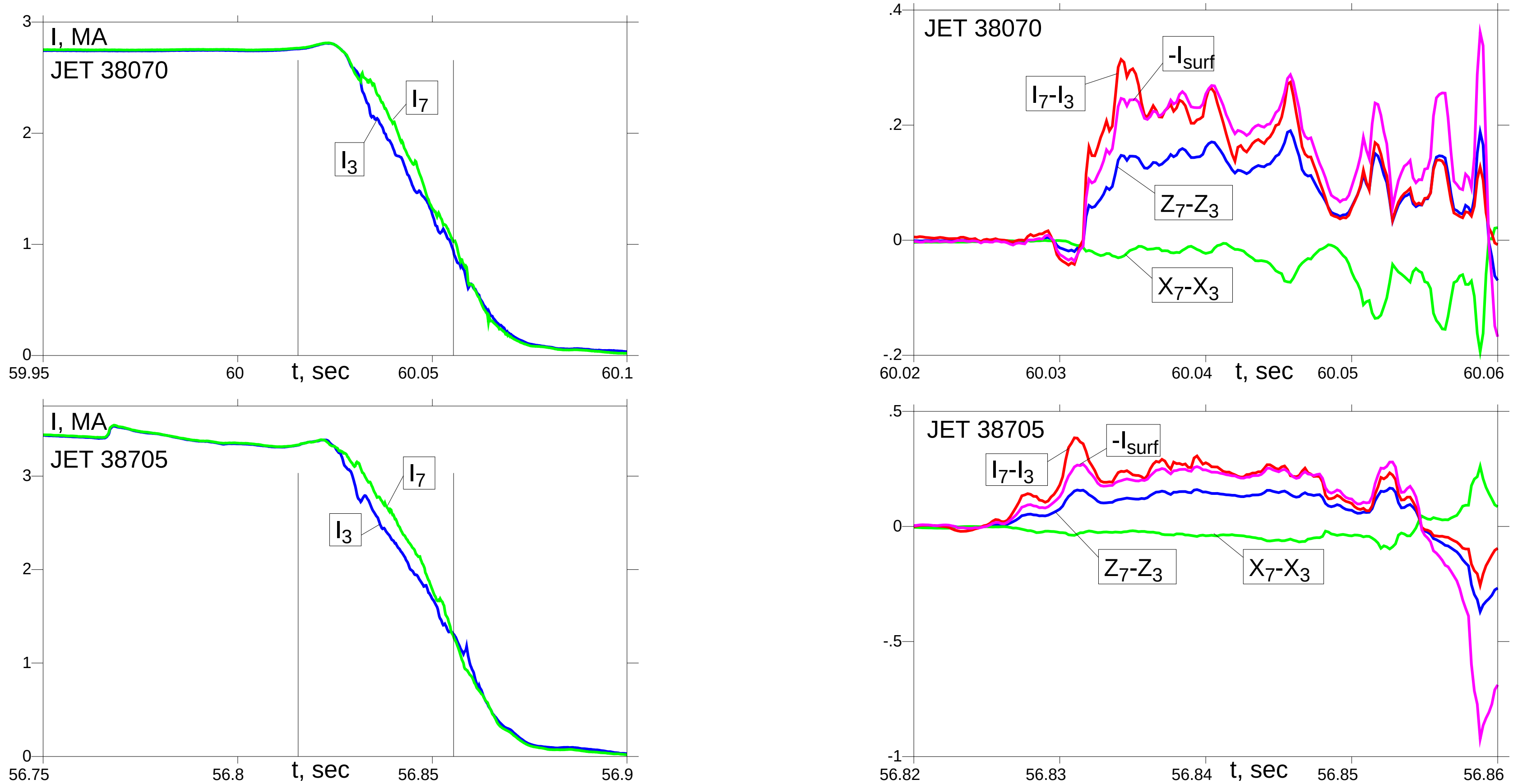
ESC numerical model of JET vacuum vessel.

$$
\begin{aligned}
I_{3,7} &= \sum_{i=1}^{i\le 18} B_i^{3,7} L^i - \sum_{k=1}^{k\le 4} I_{Dk} T^k - I_{MK2} \\
&\quad - I_{RRU} - I_{RRL}, \\
I_{RRU} &= \frac{V_{RRU}}{Res_{RRU}}, \quad I_{RRL} = \frac{V_{RRL}}{Res_{RRL}}.
\end{aligned}
\tag{4.1}
$$

Here, $B_i^{3,7}$ are the probe signals, and V_{RRU}, V_{RRL} are voltages along the restraining rings, and $Res_{RRU,RRL}$ are their resistances.

$$
\begin{aligned}
Z_{3,7} &= \frac{1}{I_{3,7}} \sum_{i=1}^{i\le 18} \left(B_{3,7}^i - \sum_{k=1}^{k\le 4} B_{Dk}^i I_D^k - B_{RRU}^i I_{RRU} - B_{RRL}^i I_{RRL} \right) L^i z^i, \\
R_{3,7} - R_0 &= \frac{1}{I_{3,7}} \sum_{i=1}^{i\le 18} \left(B_{3,7}^i - \sum_{k=1}^{k\le 4} B_{Dk}^i I_D^k - B_{RRU}^i I_{RRU} - B_{RRL}^i I_{RRL} \right) L^i \frac{{R^i}^2 - R_0^2}{2R_0}.
\end{aligned}
\tag{4.2}
$$

WTKM gives right asymmetry in I_{pl}



(a) *(b)*

(a) Plasma currents $I_{3,7}$ *(4.1) in octants 3,7 on JET during the disruptions. (b)* $Z_7 - Z_3$ *and* $R_7 - R_3$ *(4.2),* $I_7 - I_3$ *and its prediction* $-I_{surf}$ *from the present theory.*

$$I_{surf} \equiv 2ai_\varphi = -a\xi_{11}\frac{4B_\varphi}{R_0\mu_0}, \quad \xi_{11} \simeq \frac{Z_7 - Z_3}{2}, \quad a \simeq Z_{top} - Z_7. \qquad (4.3)$$

“Hiro” rather than “halo” currents

Application of WTKM theory to JET discharges 38070, 38705 has shown unambiguously that the surface currents excited by the 1/1 mode (named as “Hiro” currents) rather than “halo” currents are responsible for asymmetry in measurements and associated effects.

5 Summary

Studies of WTKM is an excellent topic for numerical projects within CEMM

1. *Calculation of the sideway forces is of high importance, urgency (and visibility) for ITER, reduced essintially to the ideal MHD inside a specific geometry of the wall. Both eddy currents and electric contact should be taken into account.*
2. *In the form of "Takahashi Kink Modes" the WTKM modes are always present in the scrape of layer of the plasma as the dominant effect determining the edge MHD activity and the width of the edge temperature pedestal, thus, giving a new understanding of the plasma edge.*

   (on Hiro currents and Takahashi Kink Modes see LZ's TTF-08 poster and his web-page)