Theory Seminar Discussion, January 09, 2025, PPPL, Princeton NJ, USA

Wall Touching Kink Mode and toroidal asymmetry in current spike measurements in JET disruption*

Leonid E. Zakharov [1], Sergei Gerasimov [2] and JET contributors [3]

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[3] *See the author list of "Overview of T and D-T results in JET with ITER-like wall" by C. F. Maggi et al. to be published in Nuclear Fusion Special Issue: Overview and Summary Papers from the 29th Fusion Energy Conference London, UK, 16-21 October 2023*

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* *The work was partialy funded by the US DoE Grant DE-SC0023274*

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Relevant publications:

1. *S.N. Gerasimov, L.R. Baylor, et al. "'Integration of SPI pellets with plasma on JET and associatred disruptions". 2024 Physica Scripta 99 p.075615 https://doi.org/10.1088/1402-4896/ad55bd*
2. *V. Riccardo, "Timescale and magnitude of plasma thermal energy loss before and during disruptions in JET" 2005 Nucl. Fusion 45 (2005) 1427-1438*
3. *R. Litunovski,"The Appearance and Evolution of toroidal Asymmetries During Plasma Disruptions in Tokamaks". JET Internal Report, Contract No. JQ5/11961 (JET Joint Undertaking, Abingdon, 1995), Pts. 1, 2.*
4. *P. Noll, P. Andrew, M. Buzio, R. Litunovski, T. Raimondi, V. Riccardo, and M. Verrecchia. "Present Understanding of Electromagnetic Behavior During Disruptions in JET". in Proceedings of the 19th Symposium on Fusion Technology, Lisbon, 1996, Ed. by C. Varandas and F. Serra (Elsevier, Am- sterdam, 1996) Vol. 1, p. 751.*
5. *L.E. Zakharov "The theory of the kink mode during the vertical plasma disruption events in tokamaks" Phys. Plasmas 15 062507 (2008)*
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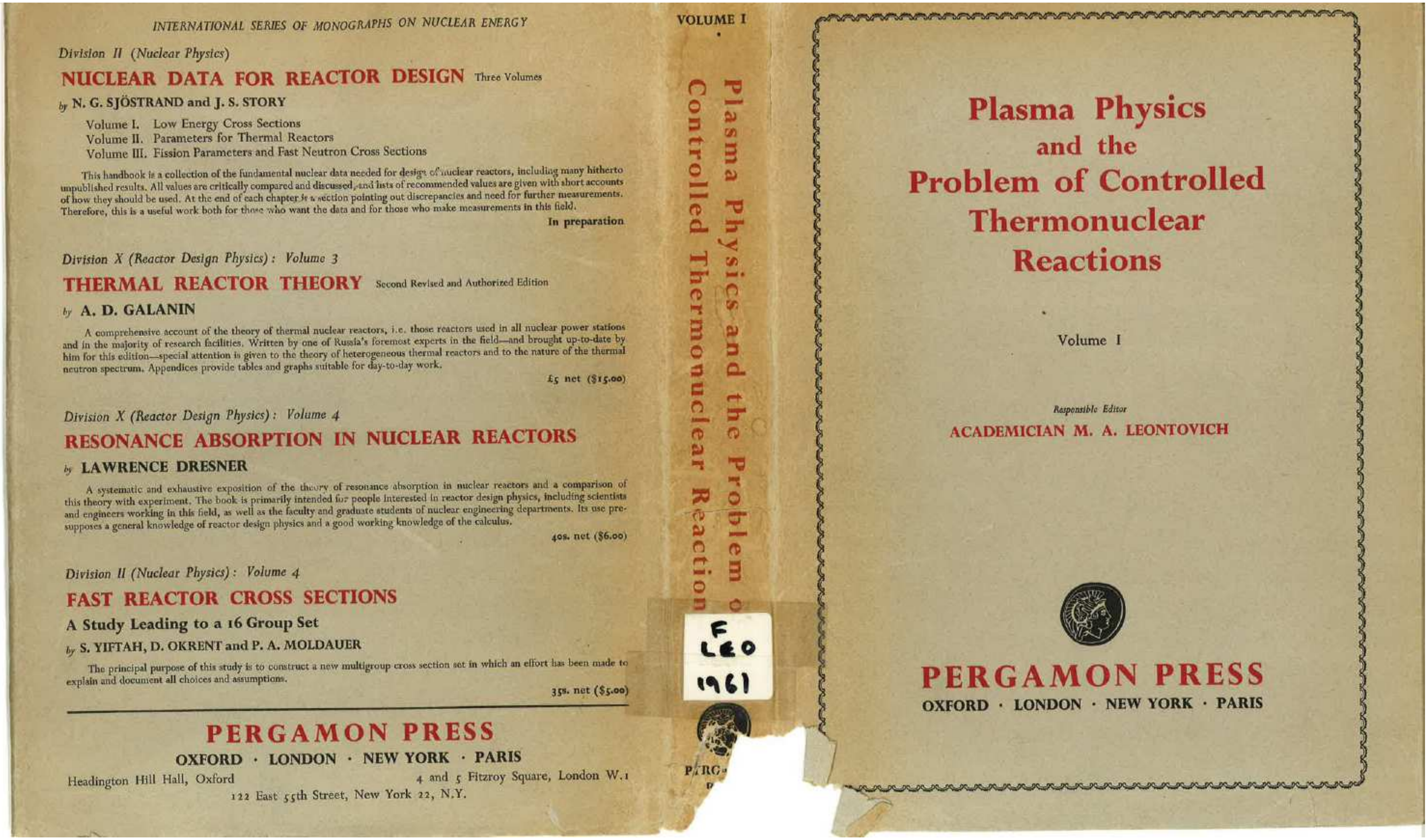
    Physics of Plasmas 22, 060702 (2015); `doi: 10.1063/1.4922663`

1 Shafranov stability criterion $q > 1$, 1952



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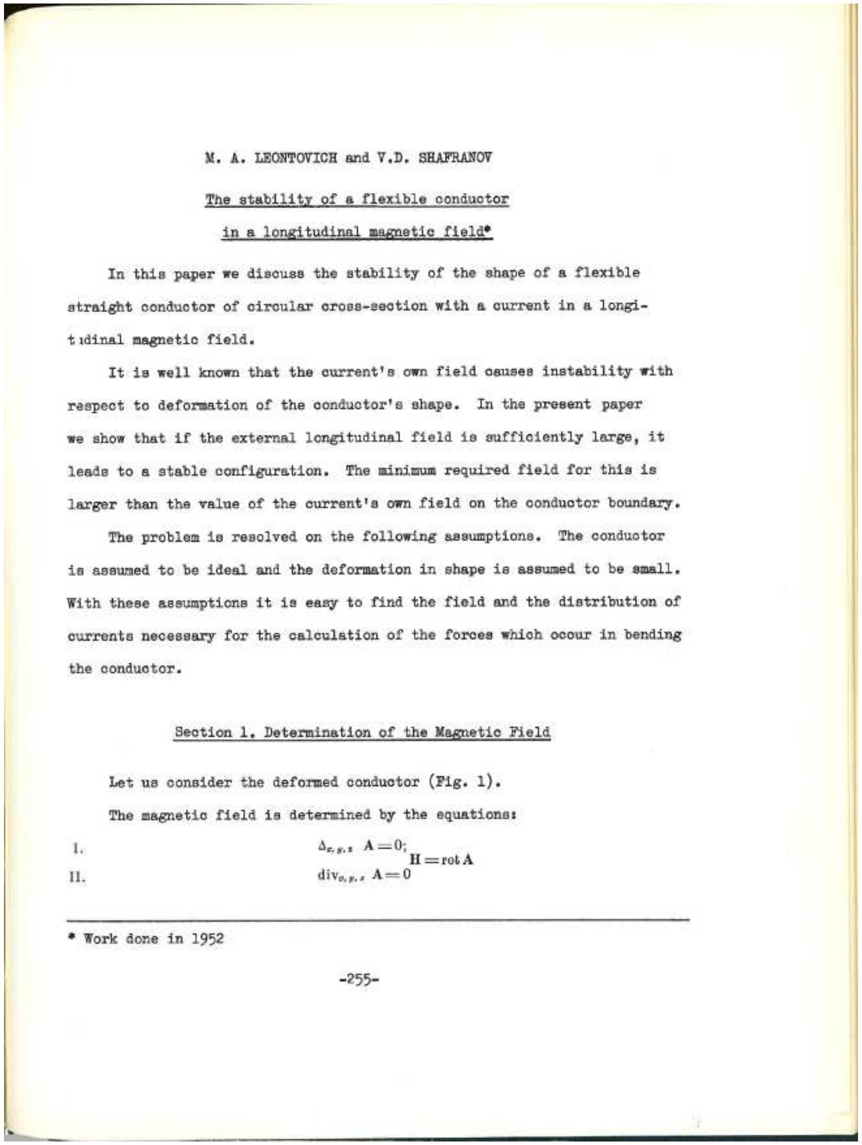
1 Shafranov stability criterion $q > 1$ (cont.)



M. A. LEONTOVICH and V.D. SHAFRANOV

The stability of a flexible conductor
in a longitudinal magnetic field*

In this paper we discuss the stability of the shape of a flexible straight conductor of circular cross-section with a current in a longitudinal magnetic field.

It is well known that the current's own field causes instability with respect to deformation of the conductor's shape. In the present paper we show that if the external longitudinal field is sufficiently large, it leads to a stable configuration. The minimum required field for this is larger than the value of the current's own field on the conductor boundary.

The problem is resolved on the following assumptions. The conductor is assumed to be ideal and the deformation in shape is assumed to be small. With these assumptions it is easy to find the field and the distribution of currents necessary for the calculation of the forces which occur in bending the conductor.

Section 1. Determination of the Magnetic Field

Let us consider the deformed conductor (Fig. 1).

The magnetic field is determined by the equations:

I. $\Delta_{x,y,z}\ \mathbf{A}=0;$

II. $\mathrm{div}_{x,y,z}\ \mathbf{A}=0$

$\mathbf{H}=\mathrm{rot}\,\mathbf{A}$

* Work done in 1952

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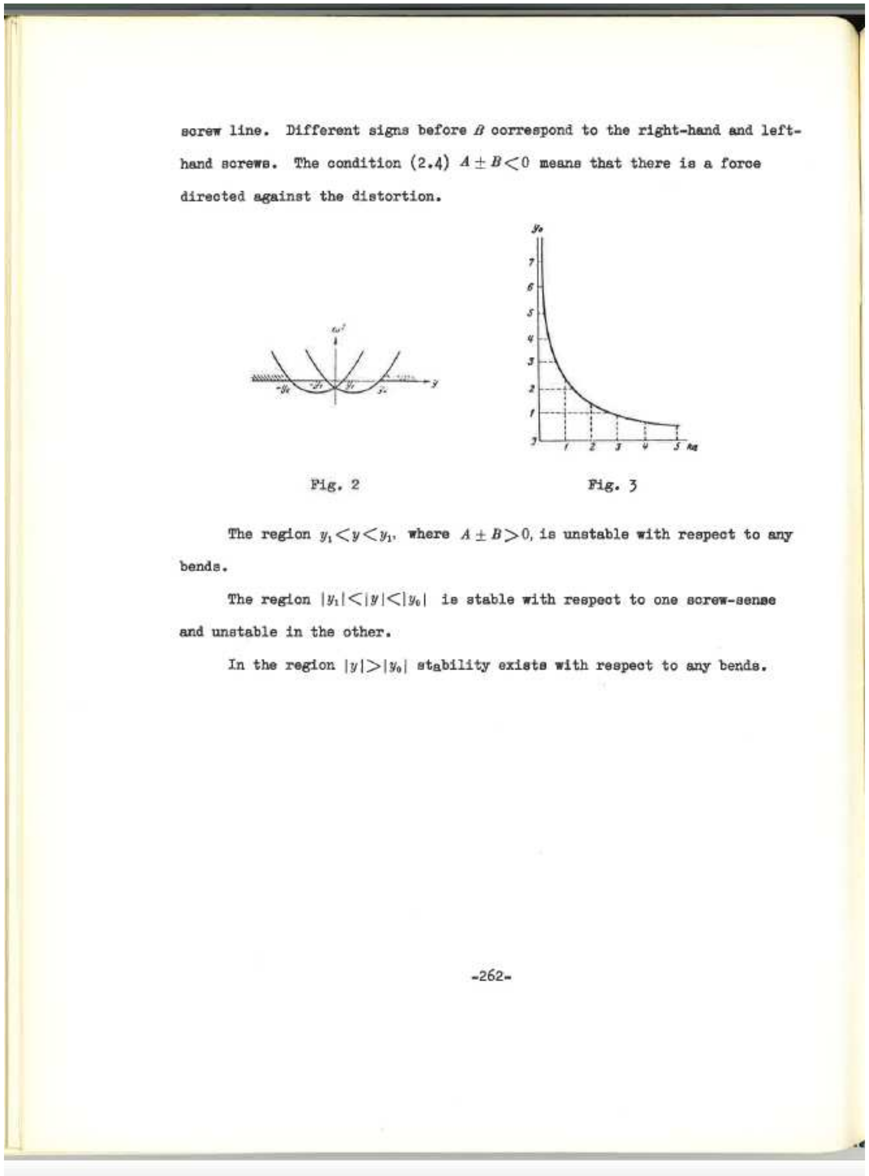

screw line. Different signs before B correspond to the right-hand and left-hand screws. The condition (2.4) $A \pm B < 0$ means that there is a force directed against the distortion.

Fig. 2

Fig. 3

The region $y_1 < y < y_1$, where $A \pm B > 0$, is unstable with respect to any bends.

The region $|y_1| < |y| < |y_0|$ is stable with respect to one screw-sense and unstable in the other.

In the region $|y| > |y_0|$ stability exists with respect to any bends.

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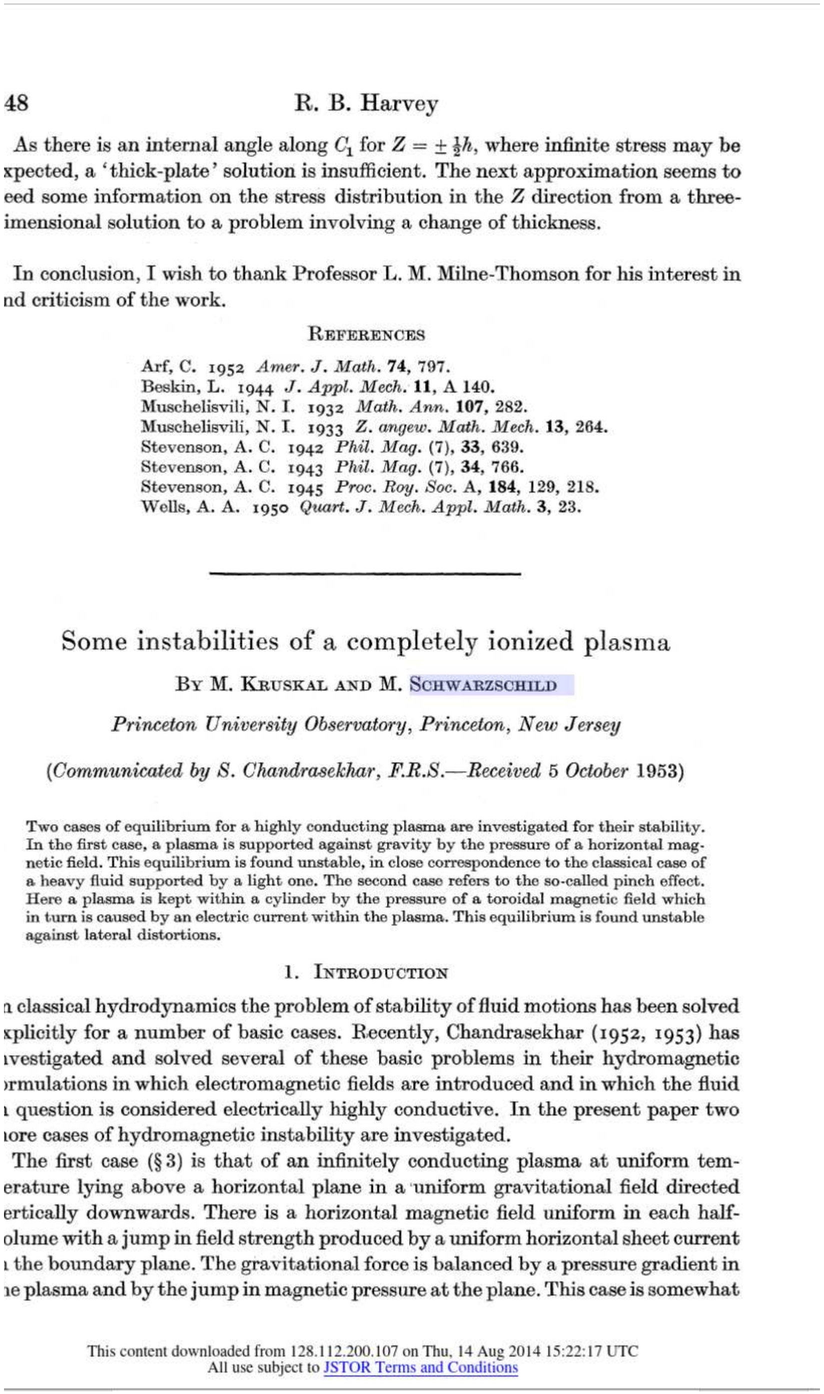
2 M. Kruskal and M. Schwarzschild, 1953



As there is an internal angle along C_1 for $Z = \pm\frac{1}{2}h$, where infinite stress may be xpected, a 'thick-plate' solution is insufficient. The next approximation seems to eed some information on the stress distribution in the Z direction from a three-imensional solution to a problem involving a change of thickness.

In conclusion, I wish to thank Professor L. M. Milne-Thomson for his interest in nd criticism of the work.

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Some instabilities of a completely ionized plasma

By M. Kruskal and M. Schwarzschild

Princeton University Observatory, Princeton, New Jersey

(*Communicated by S. Chandrasekhar, F.R.S.—Received* 5 *October* 1953)

Two cases of equilibrium for a highly conducting plasma are investigated for their stability. In the first case, a plasma is supported against gravity by the pressure of a horizontal magnetic field. This equilibrium is found unstable, in close correspondence to the classical case of a heavy fluid supported by a light one. The second case refers to the so-called pinch effect. Here a plasma is kept within a cylinder by the pressure of a toroidal magnetic field which in turn is caused by an electric current within the plasma. This equilibrium is found unstable against lateral distortions.

1. INTRODUCTION

n classical hydrodynamics the problem of stability of fluid motions has been solved xplicitly for a number of basic cases. Recently, Chandrasekhar (1952, 1953) has nvestigated and solved several of these basic problems in their hydromagnetic ormulations in which electromagnetic fields are introduced and in which the fluid n question is considered electrically highly conductive. In the present paper two ore cases of hydromagnetic instability are investigated.

The first case (§ 3) is that of an infinitely conducting plasma at uniform temerature lying above a horizontal plane in a uniform gravitational field directed ertically downwards. There is a horizontal magnetic field uniform in each half-olume with a jump in field strength produced by a uniform horizontal sheet current n the boundary plane. The gravitational force is balanced by a pressure gradient in e plasma and by the jump in magnetic pressure at the plane. This case is somewhat

---

where p^1, B_z^1, E_z^1 are constants. The other independent solutions of equations (25) and (26) are excluded because they become infinite at $r = 0$ and $r = \infty$ respectively. The surface equations now give three independent linear homogeneous relations among p^1, B_z^1 and E_z^1, and the condition that these have a non-trivial solution is

$$\frac{\rho_0 r_0^2 \eta \omega^2}{2p_0\zeta}\frac{J(\zeta r_0)}{J'(\zeta r_0)} = \eta r_0 + \frac{k^2}{\eta^2}\frac{H(\eta r_0)}{H'(\eta r_0)} + \mu_0\kappa_0 r_0^2\omega^2\frac{H'(\eta r_0)}{H(\eta r_0)}, \tag{30}$$

TABLE 2

	exact solution in terms of $B_z^1 = \frac{p_0 B_0 k\zeta}{\rho_0 r_0 \omega^2 \eta}\frac{J'(\zeta r_0)}{H'(\eta r_0)}$ $E_z^1 = \frac{p_0 B_0 \zeta}{\rho_0 \omega}\frac{J'(\zeta r_0)}{H(\eta r_0)}$	approximate solution for $\mu_0\kappa_0 \approx 0$ and $\lvert k\rvert r_0 \ll 1$
	plasma	
p	$p_0 J(\zeta r)$	$\frac{1}{2}\lvert k\rvert p_0[1+2L/\gamma]^{\frac{1}{2}} r$
ρ	$\rho_0 J(\zeta r)/\gamma$	$\frac{1}{2}\lvert k\rvert \rho_0[1+2L/\gamma]^{\frac{1}{2}} r/\gamma$
v_r	$-p_0\zeta J'(\zeta r)/\rho_0\omega$	$-\frac{1}{2}[p_0(1/L+2/\gamma)/2\rho_0]^{\frac{1}{2}}$
v_θ	$-\mathrm{i}p_0 J(\zeta r)/\rho_0\omega r$	$-\frac{1}{2}\mathrm{i}[p_0(1/L+2/\gamma)/2\rho_0]^{\frac{1}{2}}$
v_z	$-\mathrm{i}kp_0 J(\zeta r)/\rho_0\omega$	$-\frac{1}{2}\mathrm{i}k[p_0(1/L+2/\gamma)/2\rho_0]^{\frac{1}{2}} r$
	vacuum	
B_r	$-\mathrm{i}\mu_0\kappa_0\omega E_z^1 H(\eta r)/\eta^2 r - \mathrm{i}kB_z^1 H'(\eta r)/\eta$	$-\frac{1}{4}\mathrm{i}B_0 r_0[1+2L/\gamma]^{\frac{1}{2}}/\lvert k\rvert L r^2$
B_θ	$kB_z^1 H(\eta r)/\eta^2 r + \mu_0\kappa_0\omega E_z^1 H'(\eta r)/\eta$	$-\frac{1}{4}B_0 r_0[1+2L/\gamma]^{\frac{1}{2}}/\lvert k\rvert L r^2$
B_z	$B_z^1 H(\eta r)$	$-\frac{1}{4}kB_0 r_0[1+2L/\gamma]^{\frac{1}{2}}/\lvert k\rvert L r$
E_r	$\mathrm{i}\omega B_z^1 H(\eta r)/\eta^2 r - \mathrm{i}kE_z^1 H'(\eta r)/\eta$	$\frac{1}{2}\mathrm{i}kB_0 r_0[p_0(1/L+2/\gamma)/2\rho_0]^{\frac{1}{2}}$ $\times[Lr_0^2/r^2+L+\ln(r_0/r)]$
E_θ	$kE_z^1 H(\eta r)/\eta^2 r - \omega B_z^1 H'(\eta r)/\eta$	$\frac{1}{2}kB_0 r_0[p_0(1/L+2/\gamma)/2\rho_0]^{\frac{1}{2}}$ $\times[Lr_0^2/r^2-L-\ln(r_0/r)]$
E_z	$E_z^1 H(\eta r)$	$\frac{1}{2}B_0 r_0[p_0(1/L+2/\gamma)/2\rho_0]^{\frac{1}{2}}/r$
	boundary surface	
j_r^*	$-\mathrm{i}kp_0 B_0\zeta J'(\zeta r_0)/\mu_0\rho_0\omega^2$	$-\frac{1}{4}\mathrm{i}kj_0^*[1+2L/\gamma]^{\frac{1}{2}}/\lvert k\rvert L$
j_θ^*	$-B_z^1 H(\eta r_0)/\mu_0$	$\frac{1}{4}kj_0^*[1+2L/\gamma]^{\frac{1}{2}}/\lvert k\rvert L$
j_z^*	$kB_z^1 H(\eta r_0)/\mu_0\eta^2 r_0 + \kappa_0\omega E_z^1 H'(\eta r_0)/\eta$ $+p_0 B_0\zeta J'(\zeta r_0)/\mu_0\rho_0 r_0\omega^2$	$\frac{1}{4}\lvert k\rvert j_0^* r_0[1+2L/\gamma]^{\frac{1}{2}}$
ϵ^*	$\mathrm{i}\kappa_0\omega B_z^1 H(\eta r_0)/\eta^2 r_0 - \mathrm{i}k\kappa_0 E_z^1 H'(\eta r_0)/\eta$	$\frac{1}{2}\mathrm{i}k\kappa_0 B_0 r_0[p_0(1/L+2/\gamma)/2\rho_0]^{\frac{1}{2}}$ $\times[Lr_0^2/r^2+L+\ln(r_0/r)]$

where J' and H' are the derivatives of J and H. If we normalize by taking $p^1 = p_0$, then B_z^1 and E_z^1 are determined by these relations. Their values are given in table 2 at the head of a column. The remainder of this column contains the exact solution expressed in terms of B_z^1 and E_z^1; $\hat{\mathbf{B}}$, $\hat{\mathbf{E}}$, $\hat{\mathbf{j}}$ and $\hat{\epsilon}$ all vanish in the plasma and are therefore not listed in the table.

We now neglect terms which have the light velocity in the denominator, such as the last term of the second equation (28) and the last term of equation (30). Thus, equations (28) give $\eta = \lvert k\rvert$ and equation (30) gives

$$\frac{\rho_0 r_0^2 \lvert k\rvert \omega^2}{2p_0\zeta}\frac{J(\zeta r_0)}{J'(\zeta r_0)} = \lvert k\rvert r_0 + \frac{H(\lvert k\rvert r_0)}{H'(\lvert k\rvert r_0)}. \tag{31}$$

It can be proved that, for any fixed value of $k \neq 0$, the left-hand side of this equation varies monotonically from 0 to ∞ as ω^2 goes from 0 to ∞ through real values; since

3 Shafranov's model of the tokamak plasma

1. ***M.A Leontovich, V.D. Shafranov (1952)***
   "The stability of a flexible conductor in a longitudinal magnetic field" ***Plasma Physics and the Controlled Thermonuclear Reactions. Responsible Editor Academician M.A. Leontovich***
   Pergamon Press. Ozford, London, New York, Paris, V.2, 1960
   (English Translation)

2. ***M. Kruskal and M. Schwarzschild (1953)***
   "Some instabilities of a completely ionized plasma"

   Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 223, No. 1154 (May 6, 1954), pp. 348-360
   The Royal Society
   `http://www.jstor.org/stable/99560`

Shafranov model of tokamak plasma:
Dynamically, tokamak plasma behaves as a flexible super-conductor

3 Shafranov's model of the tokamak plasma (cont.)

Why Shafranov's model of flexible super-conductor describes the real plasma?

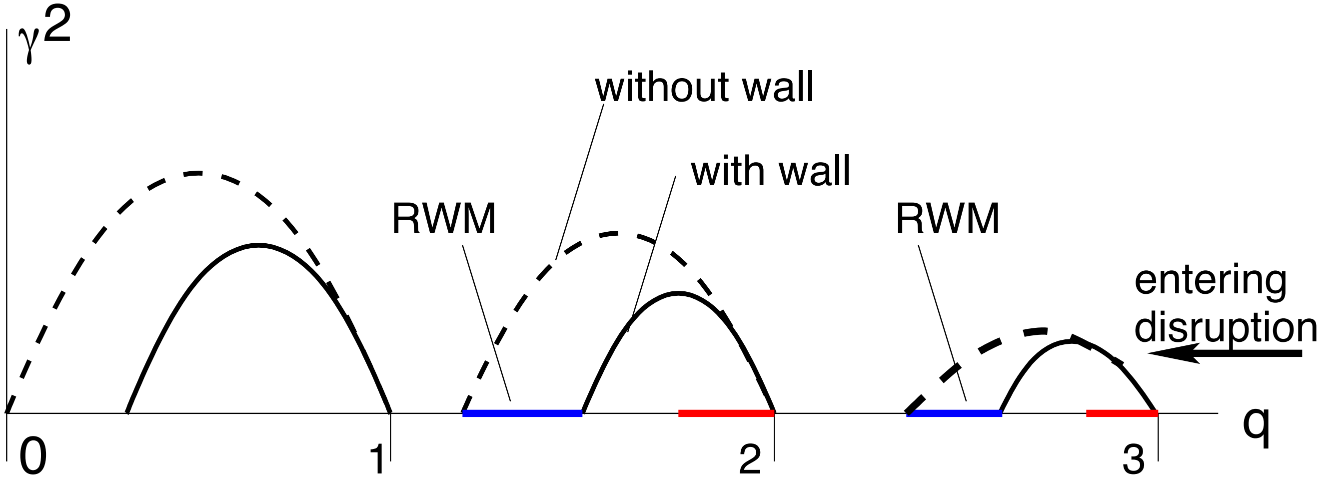
Oleg Pogutse expained this to me in the mid 1970s:

Huge parallel electron thermal conduction $\chi_{\|,e} \simeq \infty$ suppresses the normal component of magnetic field in plasma perturbations (Kadomtsev, Nedospasov, 1959)

Tokamak plasma exisits excliusively due to excitation
of virtual surface currents in plasma dynamics.
Its macroscopic dynamics is, in fact, fast equilibrium evolution
under frozeness conditions into magnetic field.
(plasma inertia plays no role)

4 Shafranov's stability diagram

Resonant free boundary kink mode initiates the disruption. Wall plays no role.



When $q(a,t)$ is going down toward $q = m$, the kink mode excited with no effect of the shell. The kink mode grows at a fast, MHD, time scale, leading to disruption.

The resonant Fourie harmonics of the kink mode does not produce perturbations of $\tilde{\vec{B}}$

$$\tilde{B}_{normal,m^*/n^*} = \mathrm{B}\cdot\xi_{m^*/n^*} = 0. \tag{4.1}$$

The resonant harmonic is almost "invisible" in tokamaks.

Its surface perturbation ξ_{m^*/n^*} can touch the wall

5 Tokamak stability and equilibrium

Simple “straight” model of tokamak plasma equilibrium with helical symmetry

$$\Delta\bar{\Psi}^* = -j(\bar{\Psi}^*) - 2\frac{nB_s}{mR} \tag{5.1}$$

The corresponding perturbed Grad-Shafranov equation

$$\begin{aligned} &\bar{\Psi}^* = \bar{\Psi}_0^*(\rho) + \bar{\psi} = \bar{\Psi}_0^*(\rho) + Y(\rho)\cos(m\theta - n\phi), \\ &\Delta\bar{\psi} = -\frac{dj(\bar{\Psi}_0^*)}{d\bar{\Psi}_0^*}\bar{\psi} \end{aligned} \tag{5.2}$$

leads to the energy principle

$$W \propto \int \left\{ \rho Y'^2 + \frac{m^2}{\rho}Y^2 + \frac{j'R}{B_s(\mu - n/m)} \right\} d\rho \tag{5.3}$$

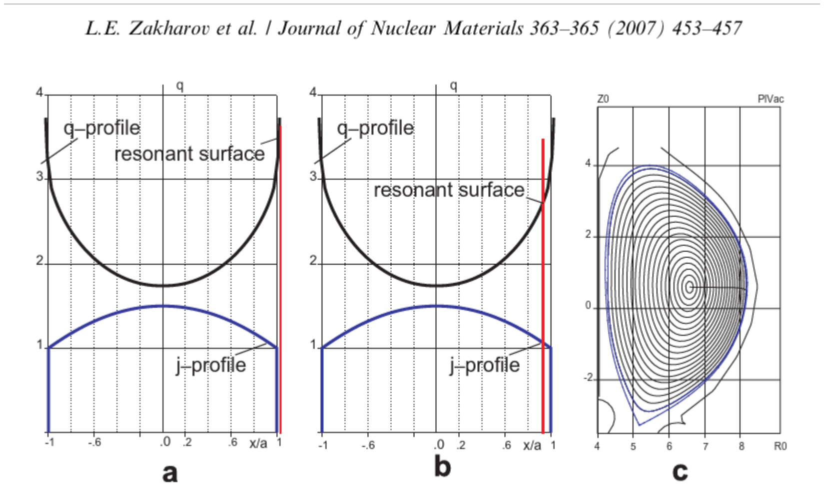
which covers stability of both kink and tearing modes in the main tokamak approximation.

It reflects the tokamak physics much better than the Kruskal-Oberman energy principle for the ideal MHD.

The tokamak plasma can be stable not because of ideal electrical conductance. It is exists and can be stable due to extremely high electron thermal conductace along the magnetic filed lines.

Tokamak plasma behaves like a flexible superconductor even without supeconductivity. It is guided by the GSh-like equilibrium equation even in the case of disruptions.

6 Entering disruptions


L.E. Zakharov et al. / Journal of Nuclear Materials 363–365 (2007) 453–457

(a)* $q_a < \frac{m}{n}$ *kink unstable

(b)* $q_a < \frac{m}{n}$ *tearing stable

(c)* $q_a < \frac{m}{n}$ *for all* m*’s. Stabilized by Li

Principle of successive current layers.

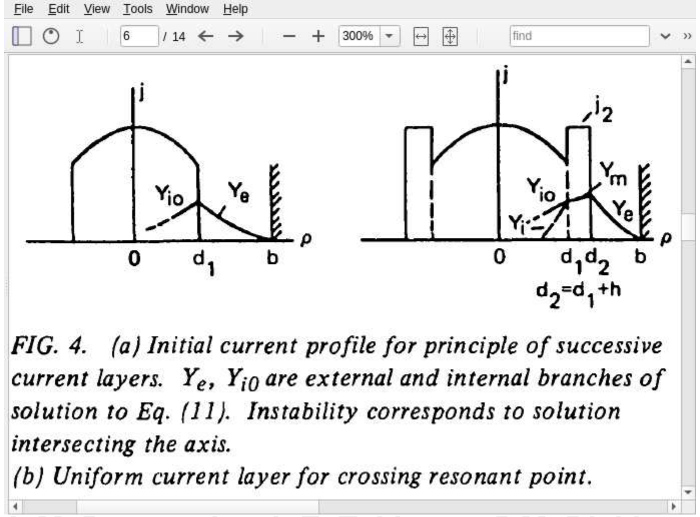


FIG. 4. (a) Initial current profile for principle of successive current layers. Y_e, Y_{i0} are external and internal branches of solution to Eq. (11). Instability corresponds to solution intersecting the axis.
(b) Uniform current layer for crossing resonant point.

L.M. Bogomolov, L.E. Zakharov, P.M. Blekher
“Stability conditions for kink and tearing modes in tokamaks”,1987 Nucl. Fusion v.27 p.241
`http://iopscience.iop.org/0029-5515/27/2/005)`

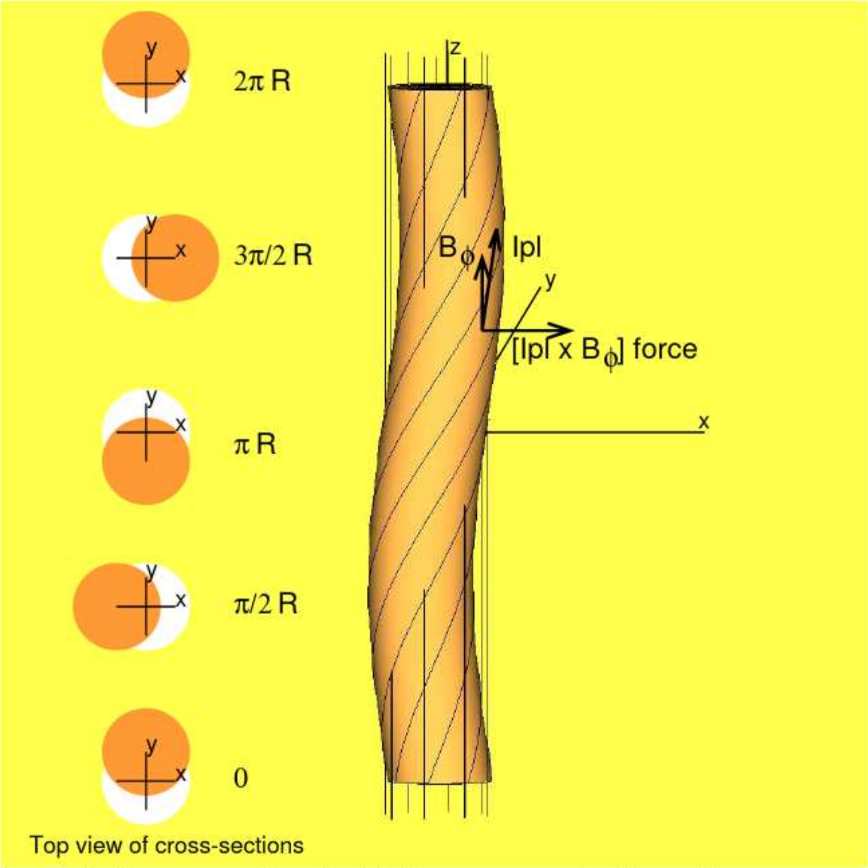
Plasma stability is very sensitive to the current density between the major resonant surface and the SoL

In the unpredictable SoL pushes plasma edge current density toward the resonant surface, e.g., $q = 3, 4$

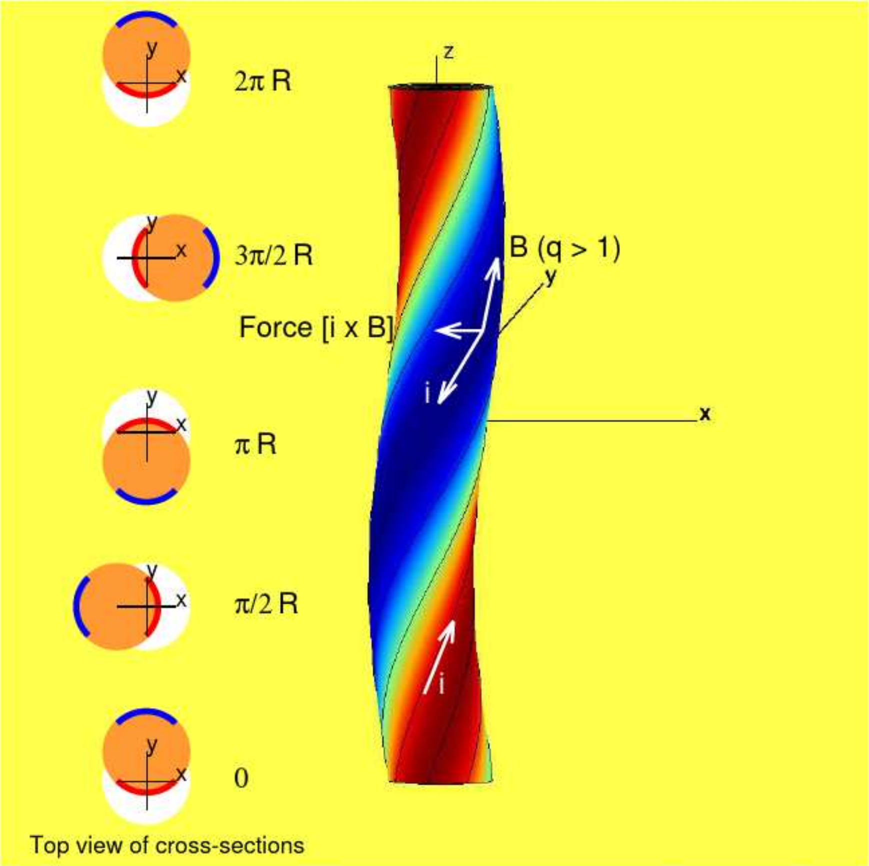
- ***initially plasma could be even more stable***
- ***after pushing*** j_{pl} ***inside*** $q = 3, 4$***,***
  the stable tearing mode is being converted into a fast kink mode and in a disruption

Kink modes and surface currents

Surface currents $\vec{\imath}_{11} = i_{11}\cos(\omega-\varphi)(\vec{e}_\omega + \frac{a}{R}\vec{e}_\varphi)$ are excited in order to eliminate the normal component of magnetic field.



Toroidal magnetic field lines punch the plasma surface



surface currents: blue ones are opposite to plasma current, reds are in the same direction

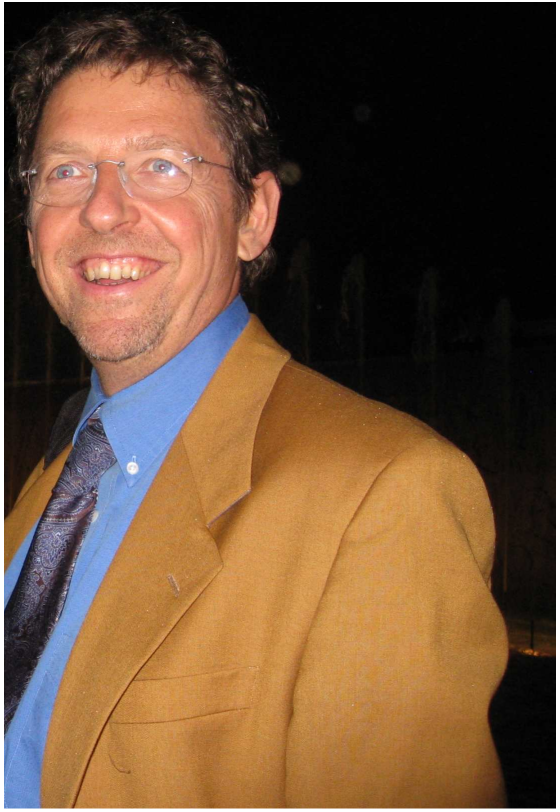
Magnetic field of the surface currents provides equilibrium in the core.
Surface currents stabilize the mode at $q > 1$

7 Wall Touching Kink Mode

***WTKM** was introduced in 2007 as a response to the alarming situation in ITER with sideways forces scaled from JET.*

- ***has given the scientific basis to Noll's engineering group explanation of sideways forces discovered on JET in 1996***
- ***has introduced a new important MHD phenomena associated with kink mode instability***
- ***has justified the Noll's formula for scaling of sideways forces and its applicability to ITER***
- ***has explained toroidal asymmetry in $I_{pl}(\phi)$ measurements with 100 % consistency in $I_{pl}(\phi)$-signal asymmetry and with conflict the wrong sign of the effect from the halo current ideology***
- ***has explained the negative voltage spike in tokamak disruptions***
- ***has suggested itself as the external driver of the thermal quench of the core electron temperature***

Giulio Sannazzaro



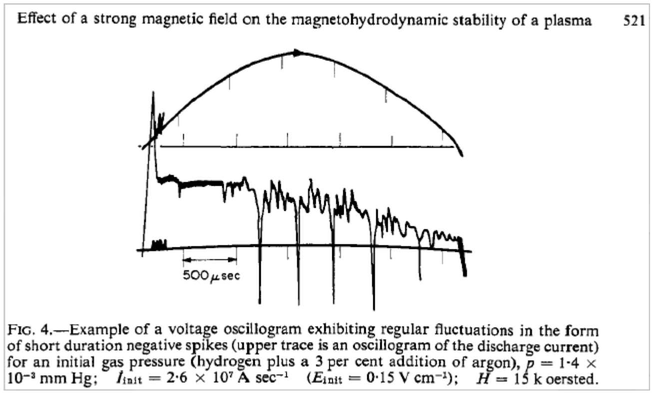
- ***In ≃1994 told Piter Noll to activate the second set of Mirnov coils***
- ***In ≃2007 alarmed ITER on sideways forces (now in ITER IO)***

Here we present specific data on current spike asymmetry and on fast thermal quench on JET.

8 WTKM and disruptions

There is no tangible progress in understanding tokamak disruptions since 1962, when it was discovered by Gorbunov and Razumova on TM-2 tokamak.

E.P. Gorbunov and K.A. Razumova (1962)
‘EFFECT OF A STRONG MAGNETIC FIELD ON THE MAGNETOHYDRODYNAMIC STABILITY OF A PLASMA AND TH7E CONFINEMENT OF CHARGED PARTICLES IN THE TOKAMAK MACHINE”
Plasma Physics (Journal of Nuclear Energy Part C) 1964. Vol. 6. pp. 515-525.
Perpamon Press Lid. Printed in N. Ireland



Effect of a strong magnetic field on the magnetohydrodynamic stability of a plasma 521

FIG. 4.—Example of a voltage oscillogram exhibiting regular fluctuations in the form of short duration negative spikes (upper trace is an oscillogram of the discharge current) for an initial gas pressure (hydrogen plus a 3 per cent addition of argon), $p = 1{\cdot}4 \times 10^{-3}$ mm Hg; $\dot{I}_{init} = 2{\cdot}6 \times 10^7$ A sec^{-1} ($E_{init} = 0{\cdot}15$ V cm^{-1}); $H = 15$ k oersted.

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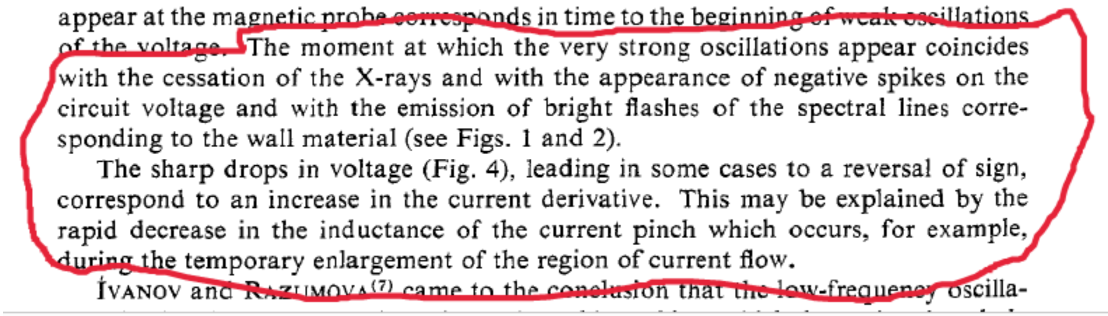
Negative voltage spikes discovered



appear at the magnetic probe corresponds in time to the beginning of weak oscillations of the voltage. The moment at which the very strong oscillations appear coincides with the cessation of the X-rays and with the appearance of negative spikes on the circuit voltage and with the emission of bright flashes of the spectral lines corresponding to the wall material (see Figs. 1 and 2).

The sharp drops in voltage (Fig. 4), leading in some cases to a reversal of sign, correspond to an increase in the current derivative. This may be explained by the rapid decrease in the inductance of the current pinch which occurs, for example, during the temporary enlargement of the region of current flow.

IVANOV and RAZUMOVA$^{(7)}$ came to the conclusion that the low-frequency oscilla-

Together with discovery of disruptions, a nonsense was introduced

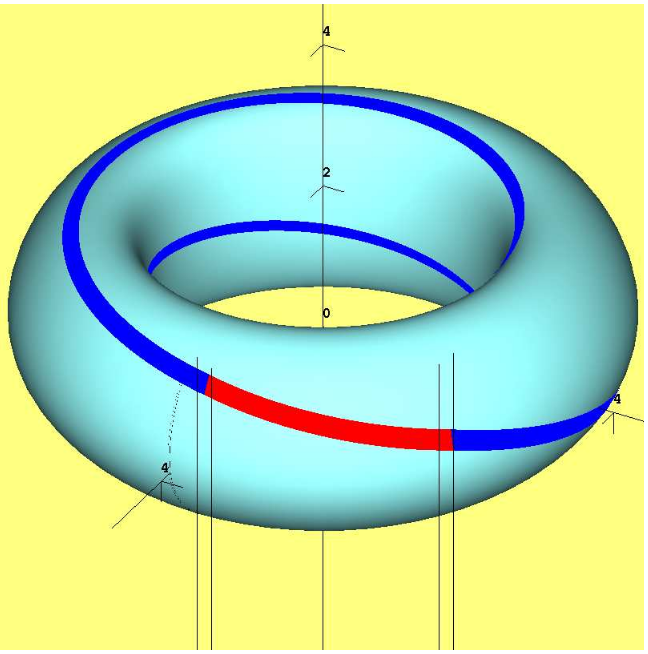
- ***The effect is obviously inductive but puzzling in its sign. Shafranov’s model was ignored.***
- ***The surface currents are “dipole” in nature, like $\cos(n\theta - n\phi)$***
- ***7 At the leading edge their direction is opposit to the bulk plasma current (LZ, 1978).***
- ***The surface currents are big independent of q value (even in the case of $q = m/n$).***
- ***Wiht $q \simeq m/n$, then the main Fourier harmonic m/n is invisible in Mirnov loops***
- ***Plasma is free to touch the wall by a resonant perturbation***

9 Electric circuit of Hiro currents expalains both voltage and current spikes

WTKM touches the wall locally in ϕ and shares its negative surface current with a part of the wall (through Be-ribs on JET).

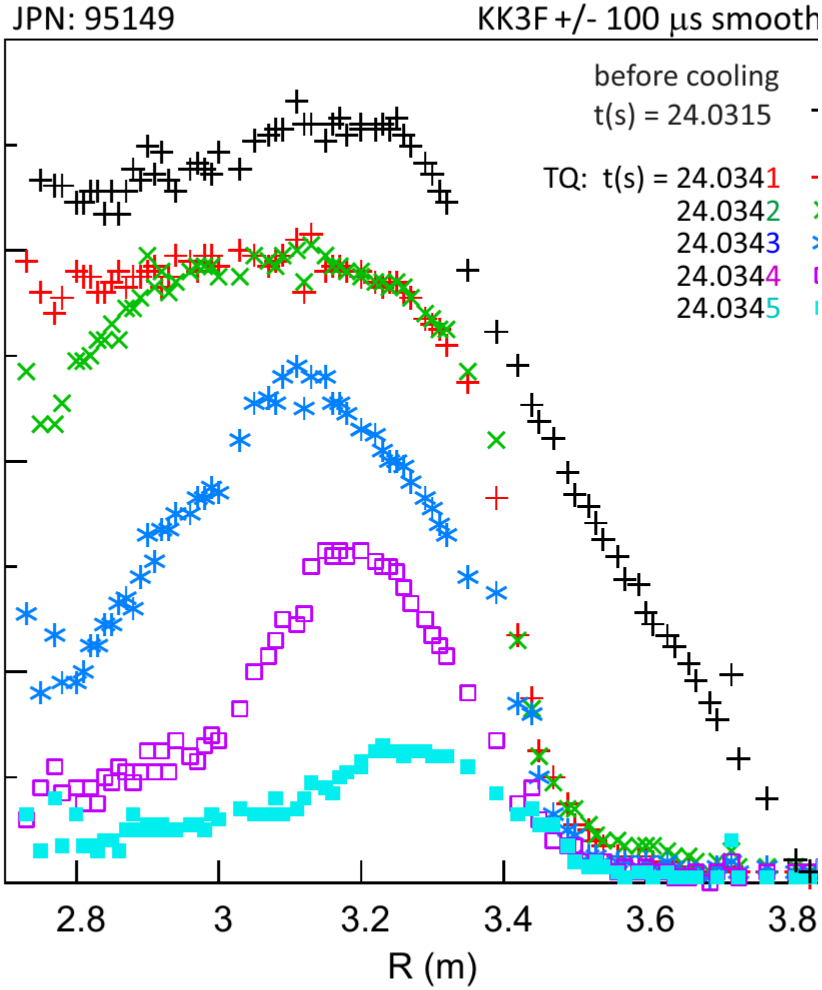
I called these shared current "Hiro" currents. (My friend Hiro Takahashi bothered me for long time with his SoL currents in DIII-D).

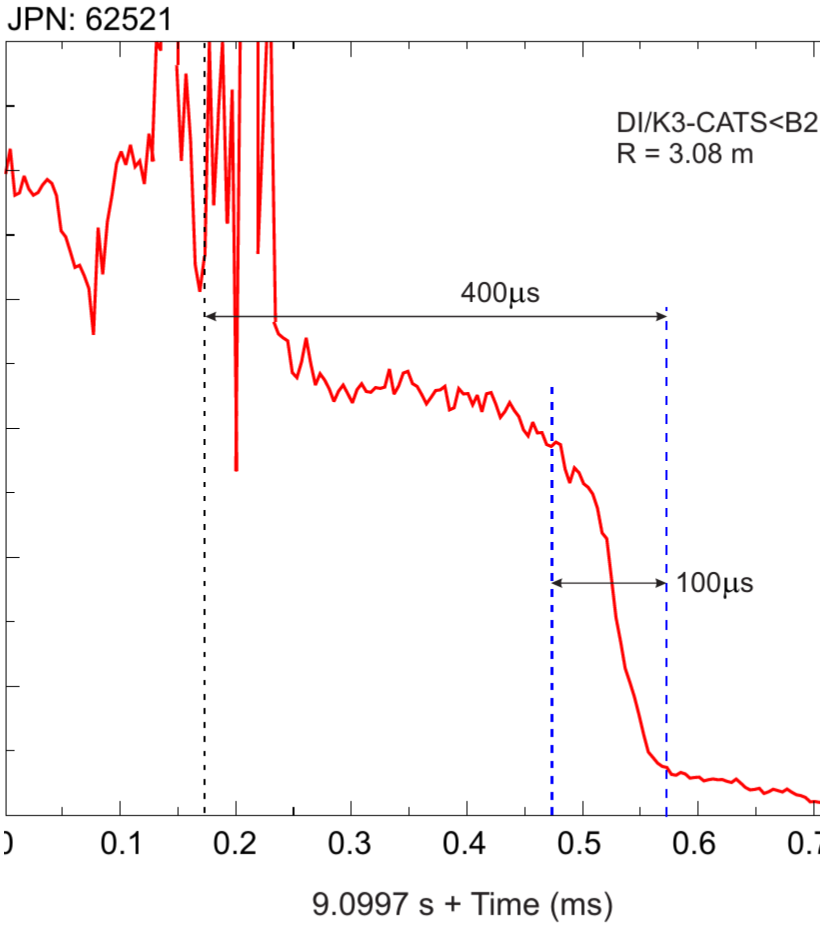
Disruption is the inductive effect. It generates a large negative Voltage spike in order to drive the necessary Hiro currents across the contact resistance.



- ***Due to large contact resistance, Hiro currents decay faster than their positive counterpart at the free plasma surface. This explains the temporary current spike on Rogowski coil.***
- ***The current spike signals consist of a toroidally symmetric part, and the additional asymmetric excess in the zones where Hiro currents flow in the vessel.***
- ***JET with its 4 sets of Mirnov loops has beautiful data on plasma current spike asymmetry in disruptions.***
- ***The asymmetric excess in the current spike signals cannot be bigger than $1/m$ (as representing a contribution of a single turn in the Hiro current circuit).***

11 Ultrafast collapse of Te in the plasma core





JPN 95146 (2019))

2005 V. Riccardo Nucl. Fusion 45 (2005) 1427, fig.7

Both examples with $\simeq$ 100's μs TQ indicate a strong external drive of the confinement loss. It cannot be associated with fantasies of "internal reconnections"

12 Thermal quench on JET is driven by the WTKM

JET data are consistent with the properties of WTKM

- ***It is the free boundary kink MHD mode, the fastest macroscopic instability in tokamaks***
- ***Its wall touching spot is always 3-dimensional (especially in the real in-vessel geometry).***

  As such it produces the full 3-D spectrum of MHD perturbations with no delay in propagation to the entire core and drives the fastest possible destruction of magnetic confinement

- ***WTKM always drives currents in the wall opposite in direction to the plasma current, thus automatically generating the negative Voltage spike as an inductive MHD effect***

  The following decay of these Hiro currents is indicated by temporary enhancement of I_{pl} measurements.

- ***The resonant harmonics of plasma displacement $\xi_{m^*n^*}$ in WTKM is not noticeable on MHD signals due to***

$$\tilde{B}_\perp = (\vec{B}\cdot\nabla)\xi_{m^*n^*} \propto \mathcal{O}(\xi^2) \simeq 0$$

and can be easily enough for touching wall

The m/n=1/1 WTKM drives huge Noll's forces on tokamak vessel in AVDE.

All (m$>$1)'s are weaker but certainly sufficient for generating the Te collapse in the core and generate very visible inductive effects like negative voltage spikes.

13 Summary

- ***Introduced in 2007, WTKM is perfectly consistent with the Voltage and Current spikes in tokamak disruptions which remained the embarrassing puzzles to the fusion community for 62 (!) years.***
- ***The excitation of Hiro currents, opposite to the plasma current, overlooked by the community (while known to me since 1978), explains the "mysterious" signs of the voltage and current spikes. The present community cares more about 'the 'electricity to the grid" rather than on measuring the disruption MHD signals like JET did.***
- ***The WTKM nature of tokamak disruptions indicates the high sensitivity of plasma stability to the near boundary layer (between low-m resonant surfaces and SoL), which is unpredictable due to the unpredictable PSI.***
- ***On JET, WTKM is the primary driver of the Thermal Quench (the collapse of electron temperature in the deep plasma core)***

This understanding makes the disruptions
unavoidable in the current high recycling regime
unless plasma performance is significantly reduced
(as it was wisely utilized in JET DTE2, DTE3 experimental campaigns of 2021, 2023)

In contrast, the low (50% and upto 10% feasible) recycling regimes
with suppressed plasma edge cooling, core fueling by NBI, and elimination of PSI
make plasma predictable and give a chance for disruption avoidance.
But this is a totally different story.

13 Summary (cont.)