Currents during disruptions

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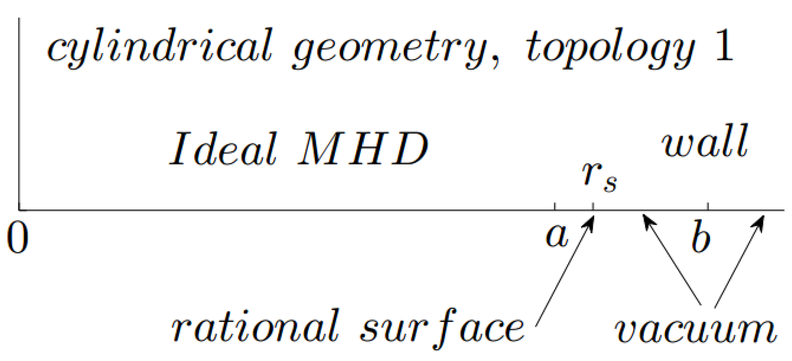
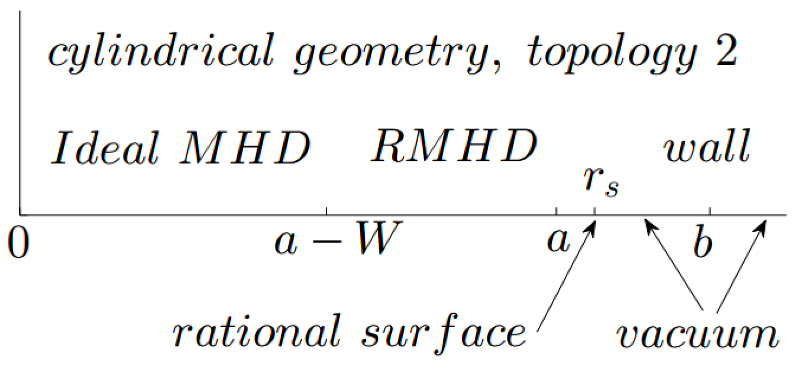
Introduction

Major disruptions and VDEs result in halo and eddy currents flowing in the conducting structures surrounding plasma [1–4]. These currents can produce unacceptable forces on vacuum vessel and in-vessel components, and their careful evaluation is necessary. Recent analytical theory [5, 6] predicts that the ideal plasma surface current can contribute to the halo, especially when the plasma boundary almost coincides with the rational surface. Here we speculate that such a particular case must not be considered in the frame of the ideal MHD, because it leads to a singularity for the plasma displacement. Treating the cold post-disruption plasma edge as a resistive layer we derive a dispersion relation for the growth rate and mode frequency, expressions for the resistive plasma "surface" current and eddy currents in the wall. Our approach has some similarities with that in [7, 8].





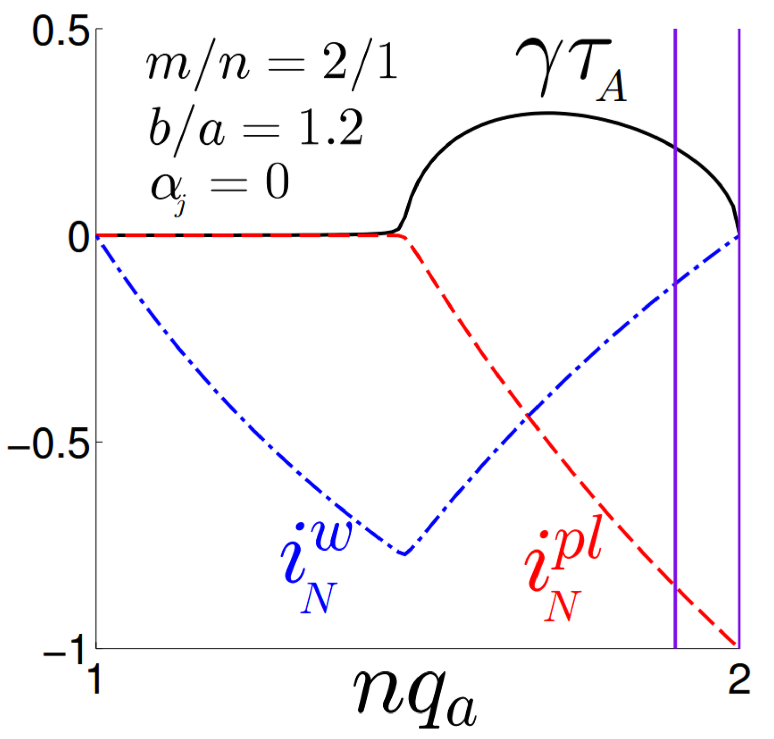


Fig. 1. Normalized growth rate, ideal plasma surface and resistive wall eddy currents vs. edge safety factor for flat current profile.

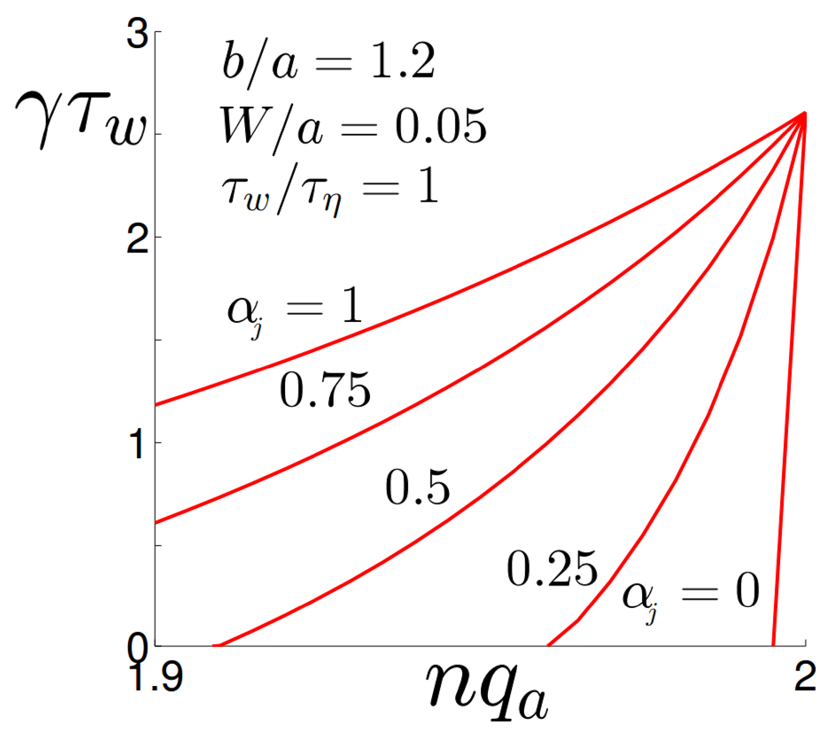


Fig. 2. Normalized growth rate of the locked mode vs. edge safety factor for different current profiles.

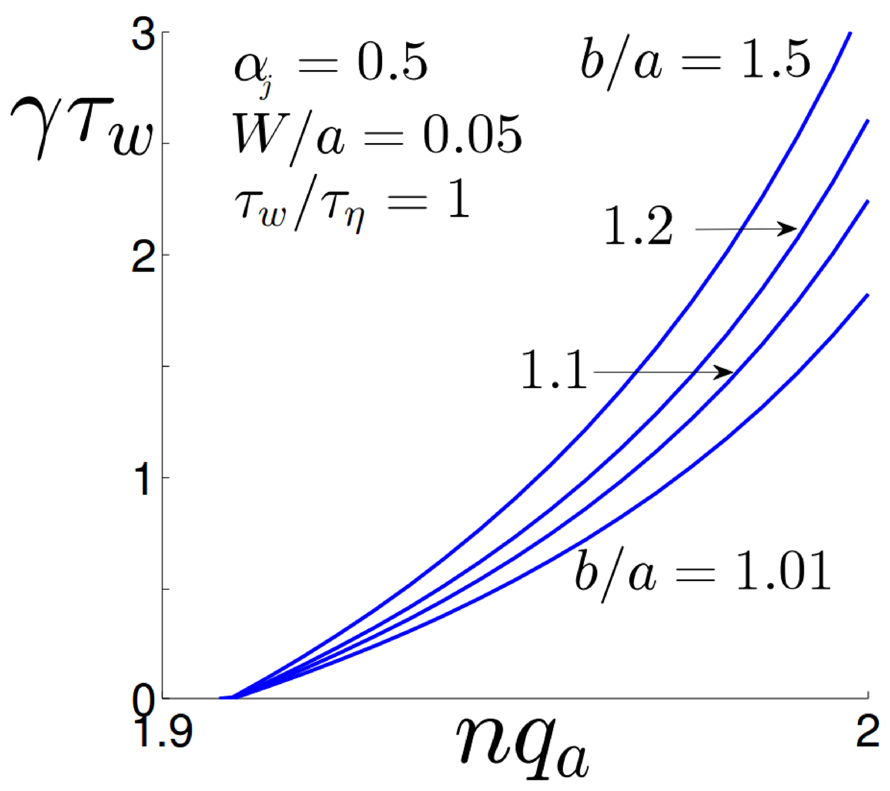


Fig. 3. Normalized growth rate of the locked mode vs. edge safety factor for different wall positions.

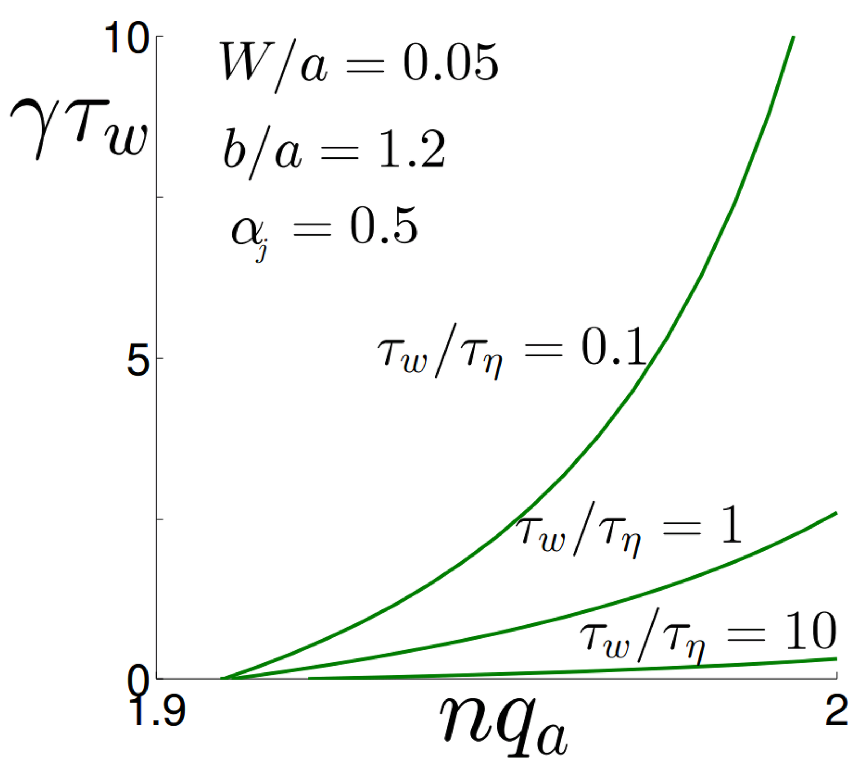


Fig. 4. Normalized growth rate of the locked mode vs. edge safety factor for different ratios of the wall and resistive layer times.

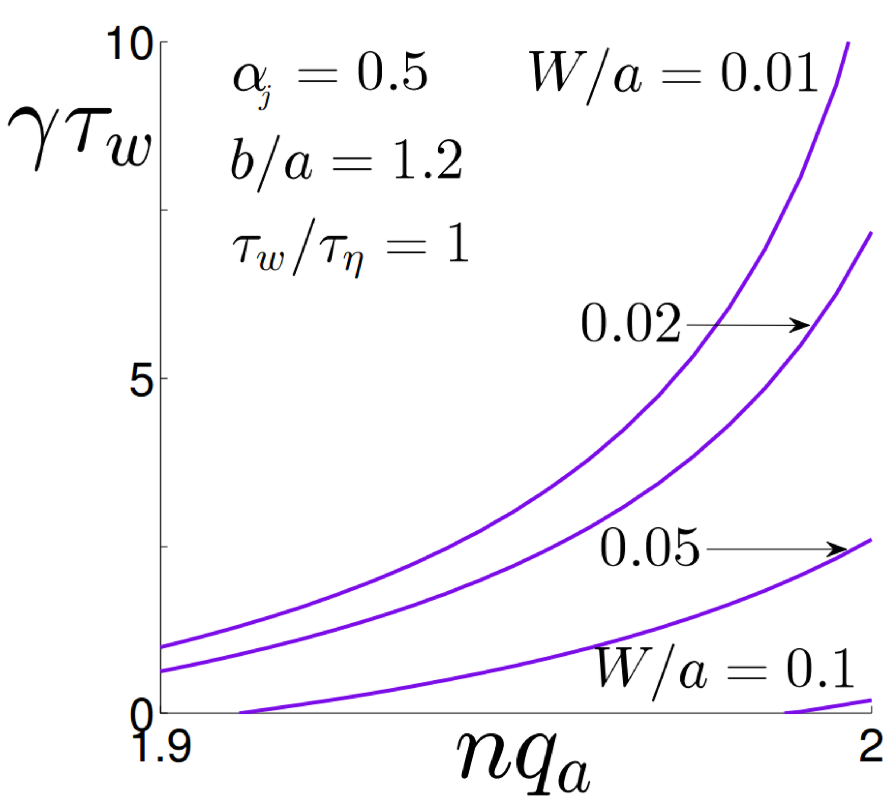


Fig. 5. Normalized growth rate of the locked mode vs. edge safety factor for the different thickness of the resistive layer.

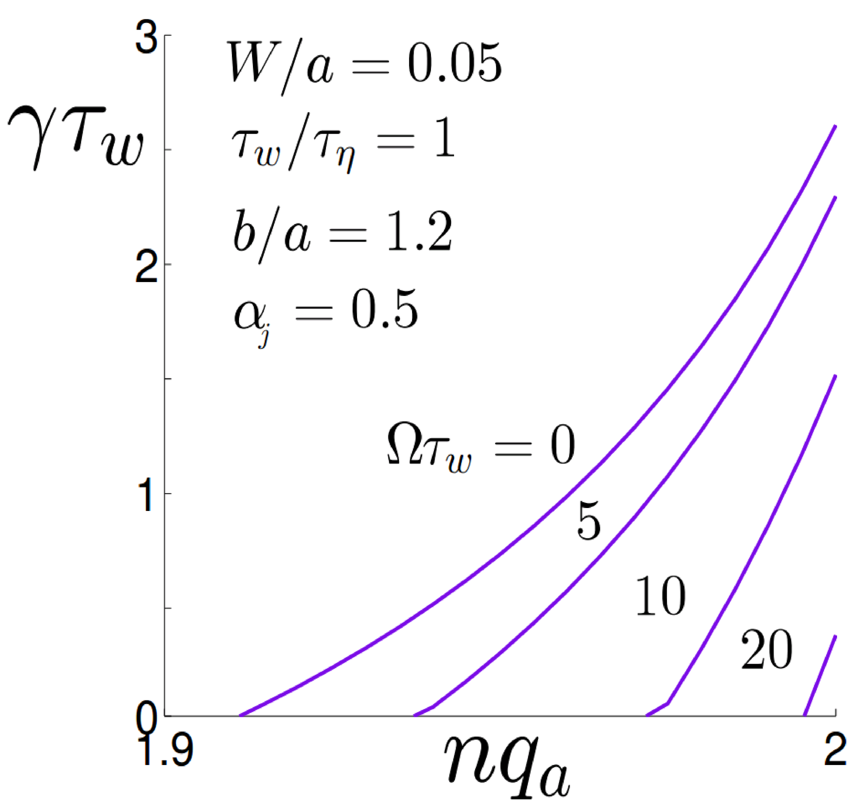


Fig. 6. Normalized growth rate of the rotating mode vs. edge safety factor for different plasma velocities.

Formulation of the problem

- Calculation of the surface/edge currents after the thermal quench and their contribution to the halo currents during the current quench
- Ideal and resistive plasmas are considered
- Cylindrical approximation
- Ideal plasma – this equation must not be used at the vicinity of the rational surface since in this case the plasma displacement $\xi \to \infty$

$$f(\mathbf{r},t) = \mathrm{Re}\left[f_{mk}(r,t)\exp(im\theta - ikz + \gamma t + i\omega t)\right]$$

$$\vec{b} = \nabla\psi \times \vec{e}_z$$

$$\left[r(\tilde{\gamma}^2 + \tilde{\mu}^2)\eta'\right]' = \frac{m^2}{r}(\tilde{\gamma}^2 + \tilde{\mu}^2)\eta + (\tilde{\mu}^2)'\eta \qquad \tilde{\gamma}^2 \equiv \frac{\mu_0\rho\gamma^2 R^2}{m^2 B_z^2}$$

$$\psi \propto \tilde{\mu}\xi \qquad \eta \equiv r\xi$$

$$\mu(r) \equiv 1/q(r) = RB_\theta / rB_z \qquad \tilde{\mu}(r) \equiv \mu - n/m$$

- Resistive layer at the vicinity of the rational surface

$$\frac{\partial\psi}{\partial t} - i\Omega\psi = \frac{\eta_{pl}}{\mu_0}\Delta\psi \qquad \Omega = \frac{nV_z(a)}{R} - \frac{mV_\theta(a)}{r}$$

$$\tau_\eta\left[\gamma + i(\omega - \Omega)\right] = \left.\frac{r\psi'}{\psi}\right|_a - \frac{a}{r_-}\left.\frac{r\psi'}{\psi}\right|_{r-}$$

$$\tau_\eta \equiv \mu_0\sigma_{pl}aW \qquad r_- = a - W$$

- The resistive wall

$$\frac{\partial\psi}{\partial t} = \frac{\eta_w}{\mu_0}\Delta\psi$$

$$\tau_w(\gamma + i\omega) = \left.\frac{r\psi'}{\psi}\right|_{b-}^{b+}$$

$$\tau_w \equiv \mu_0\sigma_w bd$$

- For parabolic distribution of the equilibrium current [9]

$$j = j_0\left(1 - \alpha_j\frac{r^2}{a^2}\right) \qquad \left.\frac{r\psi'}{\psi}\right|_{r-} = m + 2z(\ln F(A,B;A+B+1;z))'_z\Big|_{r-}$$

$$z = \frac{\alpha_j r^2}{2a^2(1 - nq_0/m)} \qquad A = (m - \sqrt{m^2+8})/2 \qquad B = (m + \sqrt{m^2+8})/2$$

- Currents:
- Ideal plasma surface currents (for flat equilibrium current profile)

$$\mu_0 i_{pl} = \left(-\psi' + B'_\theta(r)\xi_r\right)\Big|_{a-}^{a+} = \frac{2B_\theta(a)}{a}\left\{\frac{(m-nq)\left[1 + 2m/(\tau_w\gamma)\right]}{\left[1 - (a/b)^{2m} + 2m/(\tau_w\gamma)\right]} - 1\right\}\xi_r$$

- Resistive plasma "surface" currents

$$\mu_0 i_\eta = -\psi'\Big|_{r-}^{a} = -\tau_\eta\left[\gamma + i(\omega - \Omega)\right]\psi(a)$$

- Eddy currents in the wall

$$\mu_0 i_w = -\psi'\Big|_{b-}^{b+} = -\tau_w(\gamma + i\omega)\psi(b)$$

Results

In contrast with results in [5, 6] the model predicts increase of the perturbed plasma edge current for steeper profiles of the equilibrium current. For locked modes it becomes larger with a more distant wall, colder plasma and thinner resistive layer. Plasma rotation provides mode stabilization, to address its influence on the perturbed edge current dynamics further analysis is needed. Our consideration is free from the assumption that the mass density has a jump at the plasma boundary, which is the main reason leading to the existence of the surface currents within the ideal MHD.

References

[1] ITER Physics Expert Group on Disruptions, Plasma Control, and MHD and ITER Physics Basis Editors, Nucl. Fusion **39**, 2251 (1999).
[2] T. C. Hender *et al.*, Nucl. Fusion **47**, S128 (2007).
[3] R. Paccagnella *et.al.*, Nucl. Fusion **49**, 035003 (2009).
[4] H. Strauss *et.al.*, Phys. of Plasmas **17**, 082505 (2010).
[5] L. E. Zakharov, Phys. Plasmas **15**, 062507 (2008).
[6] L. E. Zakharov, Phys. Plasmas **18**, 062503 (2011).
[7] J. M. Finn, Phys. Plasmas **2**, 198 (1995).
[8] J. M. Finn, Phys. Plasmas **2**, 3782 (1995).
[9] A. B. Mikhailovskii, *Instabilities in a Confined Plasma* (Institute of Physics, Bristol, 1998).