RMP effect on slowing down of locked-mode-like instabilities in helical plasma

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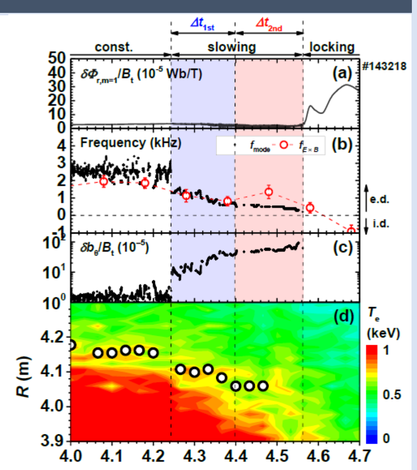
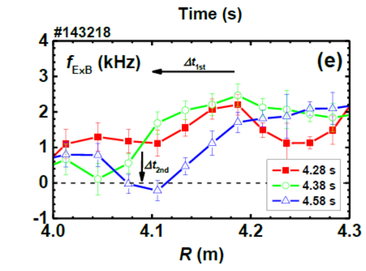
ABSTRACT

- Effects of an external RMP (Resonant Magnetic Perturbation) on the slowing-down duration time ($\Delta t_{slowing}$) of the locked-mode-like instability are investigated in the LHD.
- As the external RMP amplitude increases, $\Delta t_{slowing}$ decreases, and the observed RMP dependence is consistent with the prediction based on the deaccelerating $\boldsymbol{j}\times\boldsymbol{B}$ force due to the interaction between the precursor and the external RMP (F_{RMP}).
- And, the relationship between the amplitude and the frequency of the precursor during the slowing-down is consistent with the F_{RMP} model.
- Suggests that the slowing-down occurs due to $\boldsymbol{j}\times\boldsymbol{B}$ force driven by the external RMP when the external RMP amplitude is finite.

BACKGROUND [1]

- Typical characteristics of locked-mode-like instability:
  - After rotation of precursor slows down with increasing amplitude of precursor, non-rotating mode rapidly grows and minor collapse occurs.
  - Observe two types of locked-mode-like instabilities depending on radial mode structure of precursor in different regime of beta value and shear:
    (1) interchange-type precursor
    (2) tearing-type precursor

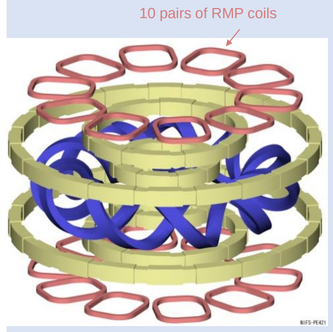


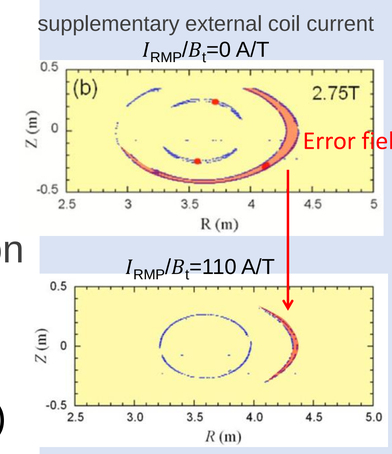


- Investigate slowing-down mechanism in previous work
  - Two slowing processes of $\boldsymbol{E}\times\boldsymbol{B}$ flow deciding rotation of both precursors.
  1. Δt_{1st}: Resonant surface moves to core small flow region, which is caused by large plasma current due to NBIs.
  2. Δt_{2nd}: Flow around resonant surface decreases regardless of almost fixed resonant surface -> mechanism is not clear.
- Effect of external RMP on Δt_{2nd} of locked-mode-like instability with interchange-type precursor is obtained and it is compared with the slowing-down models proposed for locked mode of tokamaks.

METHODS

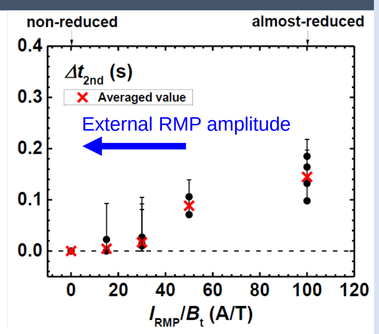
- Amplitude of error field of LHD is changed by supplementary coils with I_{RMP}/B_t.
  - As I_{RMP}/B_t increases to 100 A/T, effective external RMP amplitude decreases.
- As slowing-down model, accelerating/deaccelerating forces are considered [2].
  - Two deaccelerating $\boldsymbol{j}\times\boldsymbol{B}$ forces (F_{rw}, F_{RMP}) between perturbed current due to precursor and perturbed magnetic fields.
    - B_{rw}: due to eddy current induced on resistive wall by instability.
    - B_{RMP}: due to supplementary coils.
  - Accelerating neoclassical viscous force (F_{vc})





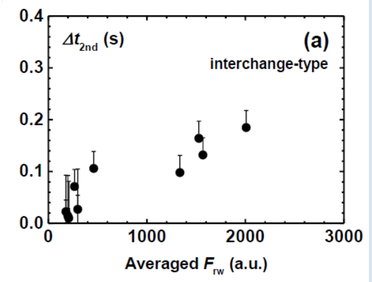
OUTCOME

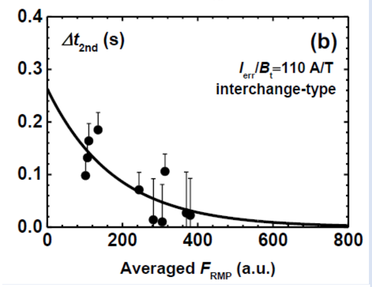
- Δt_{2nd} decreases with I_{RMP} and with increasing effective external RMP amplitude.
- Compared with slowing-down models,
  - Δt_{2nd} increases with F_{rw}.
  - Δt_{2nd} decreases with the increase of F_{RMP}.

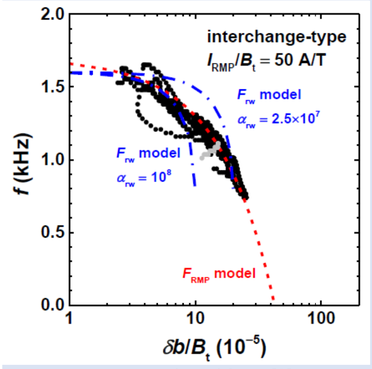


$$F_{rw} \propto \delta j_t^2 \frac{\omega\tau_w}{1+\omega^2\tau_w^2} \sim \delta b_r^2 \frac{\omega\tau_w}{1+\omega^2\tau_w^2}. \qquad F_{RMP} \propto \frac{\omega_0'\tau_{rec}}{\sqrt{1+(\omega_0')^2\tau_{rec}^2}}\delta j_t \times (I_{err}/B_t - I_{RMP}/B_t)$$

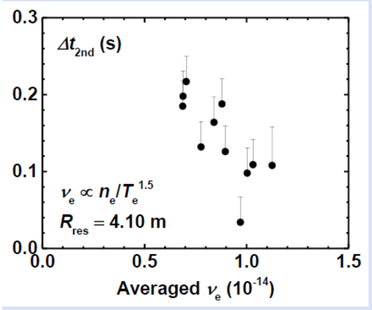
$$\sim \frac{\omega_0'\tau_{rec}}{\sqrt{1+(\omega_0')^2\tau_{rec}^2}}\delta b_r \times (I_{err}/B_t - I_{RMP}/B_t)$$







Reproduced from [3]



$$F_{vc} \propto (f_0 - f) \qquad F_{rw} = -F_{vc} \quad f = \beta_{rw}\left(1+\sqrt{1-\alpha_{rw}(\delta b/B_t)^2}\right)$$

$$F_{RMP} = -F_{vc} \quad f = -\alpha_{RMP}(\delta b/B_t) \times (I_{err}/B_t - I_{RMP}/B_t) + \beta_{RMP}$$

Even if error field is almost cancelled, slowing-down occurs with finite duration time.

- As the collisionality increases, Δt_{2nd} decreases.

✓ Acceleration force due to neoclassical poloidal viscosity decreases as collisionality increases in case of small external RMP

if there is finite deceleration force and amplitude of deceleration force is constant.

- According to neoclassical theory, poloidal viscosity depends on collisionality.

Future work

- Improve accuracy of δj_t in order to quantitatively evaluate deaccelerating forces.
  - δj_t is assumed to be proportional to δb_r observed outside a plasma.
- Investigate deaccelerating force when error field is almost cancelled.

✓ Suggest that F_{RMP} mainly contributes to Δt_{2nd}.

- If deaccelerating force works to slowing-down, correlation between them is negative.

- Relationship between amplitude and frequency of precursor is consistent with force balance of F_{vc} and F_{RMP}. (in tokamaks, relationship is consistent with force balance of F_{vc} and F_{rw})

✓ Support above result.

CONCLUSION

- The slowing-down of the 2nd stage of the locked-mode-like instability with the precursor having the interchange-type mode structure is mainly caused by the deaccelerating $\boldsymbol{j}\times\boldsymbol{B}$ force between the perturbed current due to the instability and the perturbed magnetic field due to the external RMP coils.

ACKNOWLEDGEMENTS / REFERENCES

- [1] Y. Takemura et al. NF 2019
- [2] R. Fitzpatrick NF 1993
- [3] Y. Takemura et al. NF 2021