The experimental study of the tearing mode stability with changing the mode frequency by rotating RMPs in J-TEXT

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Abstract:

This paper presents the recent experimental results in J-TEXT to study tearing mode (TM) characteristics with the application of rotating resonant magnetic perturbation (RRMP). After applying the RRMP, the TM frequency was changed until the mode was locked on the RRMP. It's found that, statistically, the variation of TM amplitude has negative correlation with the variation of frequency. The amplitude tends to a larger constant saturation value with the decrease of frequency, while the amplitude variation has linear inverse correlation with the frequency deceleration. The results also provide proof and explanation on RRMP suppressing TM.

Key Words: rotating resonant magnetic perturbation, mode locking, tearing mode frequency, tearing mode amplitude

1 Introduction

In tokamaks, tearing mode is a common magnetohydrodynamic (MHD) instability and it leads to formation of magnetic island. This phenomenon indicates magnetic reconnection and changes the topology of the magnetic flux-surfaces, thereby degrading the particle and energy confinement. The TMs can also cause major disruption when the mode amplitude is sufficiently large [1].

The external rotating resonant magnetic perturbation (RRMP) system, as an effective method to control TM, has been operated successfully in J-TEXT tokamak [2]. The RRMP system can generate $1 \sim 6kHz$ magnetic perturbation (MP) and drive the tearing mode to overcome locked mode [3]. In recent experiments (from 2021 to 2022 campaigns in J-TEXT), we focused on the influence of the frequency difference (Δf_{TM}) between RRMP (f_{RMP}) and TM (f_{TM}) on the $m/n = 2/1$ tearing mode amplitude (represented by $2/1$ oscillated poloidal magnetic field: $\delta B_{\theta 21}$). The results show that the change of $\delta B_{\theta 21}$ and Δf_{TM} have a clear negative correlation.

2 Experimental set-up

The J-TEXT tokamak is a conventional iron core tokamak, with a circular cross section. The major radius R_0 of J-TEXT is $1.05\ m$ and the minor radius a is $0.255\ m$ [4]. Conventional discharge for generating $3 \sim 5\ kHz$ tearing mode is done with toroidal field B_t of $1.65\ T$, plasma current I_P of $165\ kA$ and plasma density n_e of $1.0 \sim 1.5 \times 10^{19}\ m^{-3}$. The safety factor $q_a = 3.1$ at the plasma edge. And in the discharge, $2/1$ TM has grown to a saturation level before the application of RRMP.

4 groups, 12 in-vessel saddle coils have been installed at 4 toroidal equivalent locations with $90°$ leading or lagging, as shown in ***Fig. 1(a)***. The configuration of the coils and the preset current direction in each group contribute to producing large $2/1$ component of RMP, the RMP spectrum is shown in ***Fig. 1(b)***. The output frequency of the RRMP system is $1 \sim 6\ kHz$. For experiments, we expect a wider range of Δf_{TM}, but the current limitation to RRMP coils is $3\ kA$ and therefore, mode locking with large $|\Delta f_{TM}|$ ($> 3\ kHz$) is hard to be achieved.

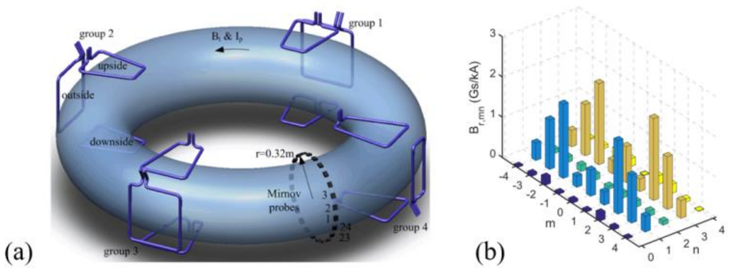

Fig. 1 *Configuration of the RRMP coils and the Mirnov probes. The coils produce strong 2/1 RRMP reaching to 1.7 Gs/kA.*

3 Experimental results

Typical effect of the high-frequency RRMP on $2/1$ TM is shown in ***Fig. 2*** (#1080291). This figure shows the details including the original characteristic of TM, the process of non-uniform rotation and the mode locking to RRMP.

The RRMP coil current is set to $5\ kHz$ and $1.5\ kA$, which is not strong enough to lock $2/1$ TM in a short time. During non-uniform rotation, the frequency of TM rises from $3.1\ kHz$ to $5\ kHz$ ($\Delta f_{TM} = 1.9\ kHz$). The amplitude of $2/1$ TM is calculated by the measurement of high and low field side Mirnov probes (shown in ***Fig. 1(a)***), and the amplitude appears to drop sharply at the last several periods of frequency oscillation. The total reduction of the $2/1$ TM amplitude is $5.33\ Gs$. Under the discharge conditions, the position of 2/1 TM locates at $a = -19\ cm$ for high field side and locates at $a = 23\ cm$ for low field side, measured by the contour of electron cyclotron emission (ECE) relative fluctuation. ***Fig. 2*** also gives the plasma rotation velocity near the radial position of the $2/1$ magnetic island.

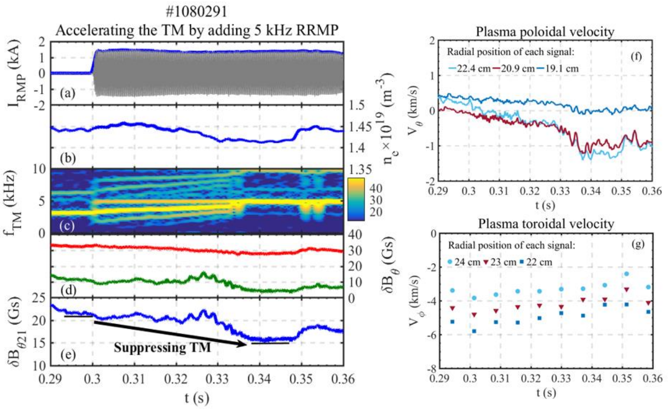

__Fig. 2__ The experimental results of accelerating TM with a high-frequency RRMP. ***(a)*** *the current of RRMP (5kHz, black curve) and the amplitude of the RRMP current (blue curve),* ***(b)*** *Line-averaged electron density at* $R = 1.05\ m$, ***(c)*** *the spectrum of Mirnov probe,* ***(d)*** *the amplitude of oscillated poloidal MP,* δB_θ, *measured by Mirnov probes at low field side (red curve) and high (green curve) field side,* ***(e)*** *the amplitude of* δB_θ *generated by 2/1 TM,* ***(f)*** *plasma poloidal rotation velocity, measured by Doppler back scattering (DBS),* ***(g)*** *plasma toroidal rotation velocity, measured by edge rotation diagnostic system (ERD).*

Typical effect of the low-frequency RRMP on $2/1$ TM is shown in ***Fig. 3*** (#1080270). This figure shows the details including the original characteristic of TM, a short non-uniform rotation period within 4 ms and the process of TM growing to saturation.

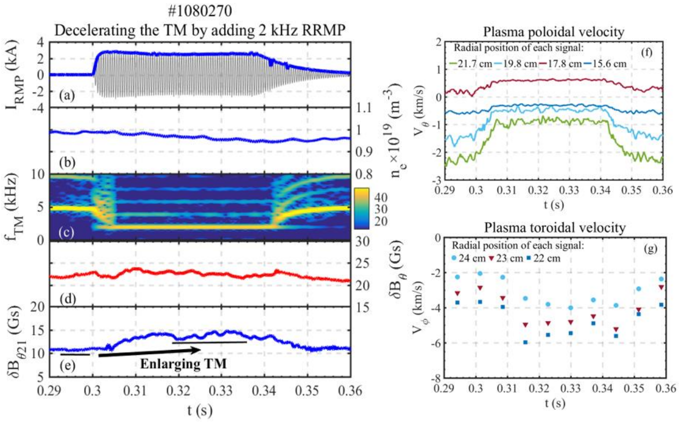

__Fig. 3__ The experimental results of decelerating TM with a 2 kHz RRMP. The graphs have same meanings as the corresponding caption of ***Fig. 2****.*

The RRMP coil current is set to 2 kHz and 2.5 kA, the frequency of TM decreases from 4.7 kHz to 2 kHz ($\Delta f_{TM} = -2.7\ kHz$). There is a small increase to the TM amplitude during non-uniform rotation and it is difficult to distinguish the increase from the subsequent evolution. The phase different between RRMP and TM is equal to 0 after mode locking, and according to the Fitzpatrick's improved evolution equations for magnetic island [5], RRMP will destabilize tearing mode until saturation. We suggest that the variation of TM amplitude is calculated by the saturation value minus the original value. So, the increment of the $2/1$ TM amplitude is $3.42\ Gs$.

The statistical result for the relationship between $\Delta(\delta B_{\theta 21})$ and Δf_{TM} is presented in the ***Fig .4.*** The yellow zone on the right displays the result of TM acceleration. $\Delta(\delta B_{\theta 21})$ and Δf_{TM} show a linear negative correlation in this region. When the TM was decelerated by the RRMP, $\Delta(\delta B_{\theta 21})$ has increase with the decrease of Δf_{TM}, but has a trend of saturation when $\Delta f_{TM} < -2\ kHz$.

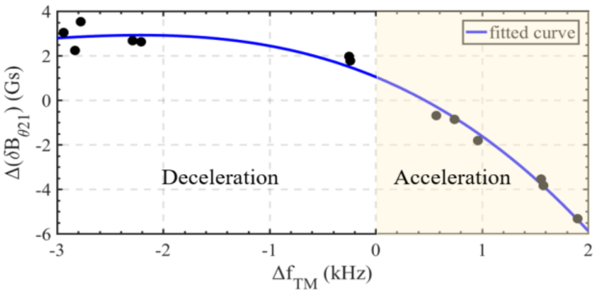

Fig. 4 *Relationship between the variation of 2/1 TM amplitude,* $\Delta(\delta B_{\theta 21})$*, and the variation of frequency,* Δf_{TM}

4 Summary

We have successfully obtained the results of accelerating or decelerating TM by adding RRMP, and found the negative correlation between $\Delta(\delta B_{\theta 21})$ and Δf_{TM}. In terms of TM acceleration, the amplitude of $2/1$TM decreases before and after mode locking, while the destabilization effect appears soon after mode locking. And with regard to TM deceleration, near the mode locking time, the amplitude of $2/1$TM increases quite small compared to the destabilization effect.

In next steps, the effect of phase difference between RRMP and TM on stabilization of TM should be deducted, and the effect of $3/1$ mode should be decoupled from $2/1$ TM too.

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References

[1] T.C. Hender et al 2007 Nucl. Fusion 47 S128

[2] B. Rao et al. /Fusion Engineering and Design 89 (2014) 378–384

[3] D. Li et al 2020 Nucl. Fusion 60 056022

[4] Y. Liang et al 2019 Nucl. Fusion 59 112016

[5] R. Fitzpatrick et al Physics of Plasmas 8, 4489 (2001)