Research on the effect of non-resonant magnetic perturbations on low-*q* limit in J-TEXT tokamak

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Introduction

The disruption can cause rapid loss of all or a large fraction of the magnetic and thermal energy of the plasma column, and irreversible damage to the tokamak device. Therefore, it is necessary to be avoided for a large device, which is one of the biggest challenges for the future fusion device. The major disruption can occur for a variety of reasons, among which the well-known operating limits, such as high plasma current and density [1,2]. For the low-q limit and density limit disruptions, the resonant magnetic perturbations (RMPs) are used to extend the operation range on J-TEXT [3]. However, stronger RMPs lead to the 2/1 RMP penetration and major disruption. Therefore, A new strategy for avoiding disruption is urgently needed. On CTH, the low-q limit disruptions are avoided by the rotation transform supplied by the stellarator coils [4].

In this paper, experiments have been carried out in J-TEXT tokamak to study the non-resonant magnetic perturbations (MPs) on the low-q discharges. The coils system is set to produce static non-resonant MPs, dominated by a m/n = -1/1 and m/n = 1/3 components and the resonant component is very small. These experimental results indicate that the operate range about limit q_a is extended from 2.5 to 2.3 by applying the non-resonant MPs. The 2/1 small magnetic oscillation (SMO) at ~ 10 kHz is not suppressed during the application of external magnetic perturbations. The appearance of the precursor TM is delayed. These results indicate that the non-resonant MPs may provide favourable effect for the low-q limit discharges.

Experimental Setup

J-TEXT [5], is a conventional medium sized tokamak with the major radius, R_0, of 1.05 m and the minor radius a, of 0.25-0.3 m. There are 8 groups of coils installed in the vacuum vessel to produce magnetic perturbations (MPs) [6] as shown in Figure 1 left. The dominated

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component of perturbed field with different m/n (m and n are poloidal mode number and toroidal mode number, respectively) can be generated by adjusting the orientation and amplitude of coil currents. In this work, the coils are operated in the m/n = -1/1 and 1/3 dominant mode, with the -1/1 non-resonant MP of ~ 3.8 Gs/kA and the 1/3 non-resonant MP of ~ 4.6 Gs/kA. The amplitude of dominant component at 2/1 rational surface and resonant component at corresponding rational surface are shown in table 1 in these experiments. It is found that the amplitude of resonant component at corresponding rational surface is very small. In additional, the 3/1 rational surface is outside the plasma when the external magnetic perturbations coil is applied. So, the 3/1 component is also a non-resonant component. The MHD activities can be systematically analysed by the poloidal and toroidal Mirnov arrays [7].

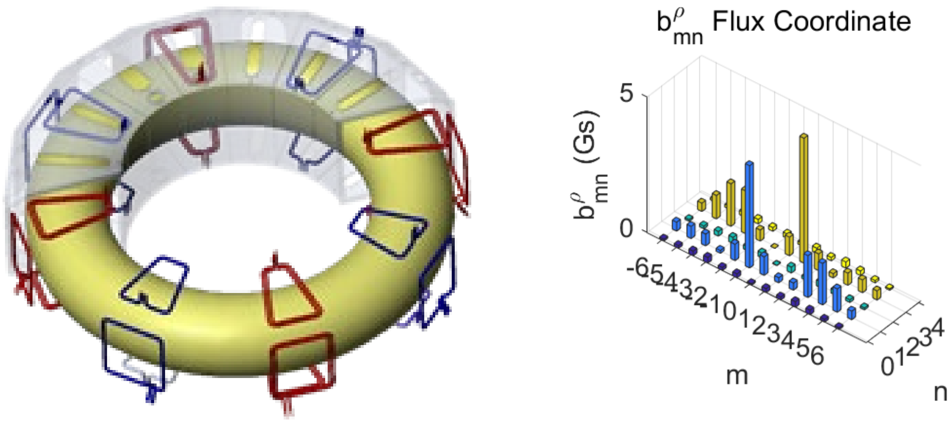

Figure 1 Left: Layout of saddle coils. Right: Spectrum of generated radial field b^{ρ} of m/n component at plasma edge at $r = a = 0.255\ m$

Table 1 The magnetic field amplitude of components at rational surface

Component	-1/1@$r_{2/1}$	1/3@$r_{2/1}$	1/1@$r_{1/1}$	2/1@$r_{2/1}$	3/1@$r_{2/1}$
Amplitude(G/kA)	3.8	4.6	0.02	0.26	1.55

The effect of non-resonant magnetic perturbations on low-*q* limit

Figure 2 displays one typical example of the low-q limit discharge for shot 1080900 without the application of non-resonant MPs. In order to approach the low-q limit, the plasma current I_p is slowly ramped up in the range from 130 kA to 200 kA with the toroidal magnetic field $B_t = 1.4\ T$, so that the edge safety factor q_a is reduced from 3.3 to 2.16 until disruption (Figure 2 (a)). The central line-averaged electron density $n_e = 3 - 4 \times 10^{19} m^{-3}$. Before the precursor tearing mode (TM) occurs, there is a small magnetic oscillation (SMO) with a frequency about 10 kHz (Figure 2 (b) and 2 (c)). The mode number of SMO is m/n = 2/1 [8]. When the plasma current increases to around 172 kA, the frequency of the precursor TM decreases from 10 kHz to 1 kHz and the amplitude of precursor TM increases rapidly. It is found that the structure of precursor TM is m/n = 2/1 [3]. Meanwhile the disruption happens when q_a approaches 2.5.

In the following experiments, the external non-resonant MPs with the -1/1 and 1/3 dominant component are applied before the onset of the precursor TM as shown in Figure 3. The case without external magnetic perturbations (shot 1080900) is also shown there for comparison. During the application of a weaker external magnetic perturbations in shot 1080901 ($I_c = 3\ kA$), the low-q limit decreases to around 2.4, and then disruption happens at $t = 0.43\ s$. With the external magnetic perturbations with the coil current $I_c = 3.5\ kA$, the low-q limit is further decreases to 2.3 and the disruption happens at $t = 0.45\ s$. These results indicate that the operate range about low-q limit is extended by the external non-resonant MPs with a dominant -1/1 and 1/3 mode.

In order to analyse the evolution of precursor TM, the power spectrum of the Mirnov signal for shot 1080901 and 1080902 with the application of external magnetic perturbations. The SMO with a frequency 10 kHz is always exist before the precursor TM occurs. However, the appearance of the precursor TM and disruption happens are delayed. These results indicate that the non-resonant MP components may provide a favourable affect for the low-q discharges. This may be due to the formation of a new three-dimensional equilibrium.

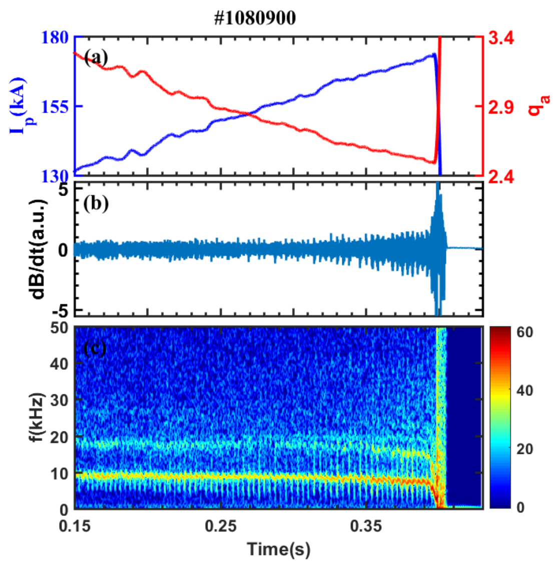

Figure 2 Typical low-q discharge in J-TEXT. Temporal evolution of (a) the plasma current I_p (blue) and edge safety factor q_a (red), (b) the Mirnov coil signal dB/dt, (c) power spectrum of the Mirnov signal to show the mode frequency and strength.

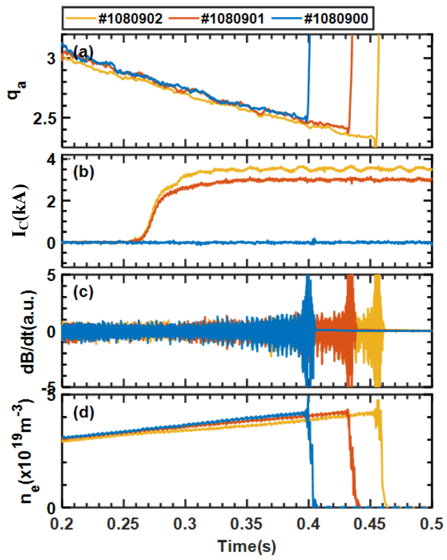

Figure 3 Influence of static non-resonant magnetic perturbations with different amplitude current on low-q discharges. Temporal evolution of (a) the edge safety factor q_a, (b) static non-resonant MP current I_c, (c) the Mirnov coil signal dB/dt and (d) line-averaged electron density n_e for shots 1080900, 1080901 and 1080902.

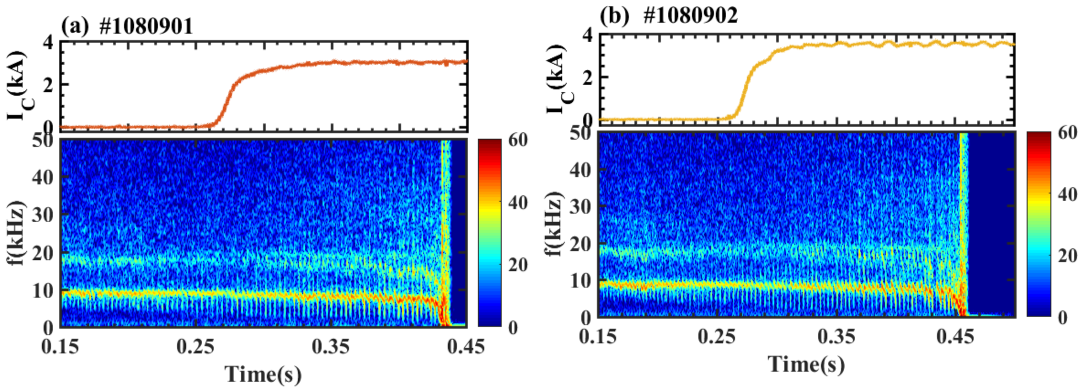

Figure 4 Corresponding to Figure 3, power spectrum of the Mirnov signal for shots (a) 1080901 and (b) 1080902 are shown together with non-resonant MP current I_c.

Summary and conclusion

In this paper, the effect of the non-resonant MPs on low-q_a limit discharges are studied in J-TEXT. The external magnetic perturbations coils are operated in the m/n = -1/1 and 1/3 dominant mode, with the -1/1 non-resonant MP of ~ 3.8 Gs/kA and the 1/3 non-resonant MP of ~ 4.6 Gs/kA at 2/1 rational surface. The amplitude of resonant component at corresponding rational surface is very small. It is observed the limit q_a decreases from 2.5 to 2.3 by applying external non-resonant MPs. The 2/1 SMO exist always during the application of external non-resonant MPs. The growth of the precursor TM and disruption happens are delayed. These experiments indicate that the non-resonant MP components may provide favourable affect for the low-q discharges. This may be due to the formation of a three-dimensional equilibrium. However, the related physical mechanisms are not clear yet and future research is still needed.

Acknowledgements

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