

Studies of Resonant Magnetic Perturbations in the STOR-M Tokamak*

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Introduction

The use of resonant magnetic perturbations (RMPs) [1] for error field correction [2] and edge localized modes (ELMs) control [3] has been successfully demonstrated in tokamaks. The early implementation of RMP, however, involved the control of magnetohydrodynamic (MHD) instabilities since they are deemed as the leading cause of loss of energy and particles and the precursor of disruptions in tokamaks [4]. In the STOR-M tokamak, a set of resonant helical windings in the ($m = 2, n = 1$) configuration [5] has been utilized to study the influence of RMP on MHD instabilities as well as other plasma parameters.

In the following sections, we present the experimental setup and the results of three experiments conducted using RMP: (a) control of MHD instabilities, (b) modification of toroidal flow in the plasma core, and (c) modification of plasma parameters (i.e. ion saturation current I_s and floating potential V_f) at the plasma edge and the scrape-off-layer (SOL) region.

Experimental setup

STOR-M is a small research tokamak housed in the Plasma Physics Laboratory at the University of Saskatchewan [6]. The major and minor radii of the STOR-M tokamak are 46cm and 12cm, respectively. The toroidal magnetic field is 0.7T and the typical discharge current is about 20kA. The STOR-M is equipped with various diagnostics including triple and rake probes for density (n) and temperature (T) measurements, a 4mm microwave interferometer for density measurement, optical spectrometer for monitoring H_α and impurity radiation lines, a soft x-ray (SXR) imaging system for measurement of SXR emissivity profiles in the plasma [7], an ion Doppler spectrometer (IDS) for plasma flow velocity measurement, and several poloidal and toroidal Mirnov coil arrays to monitor MHD fluctuations.

STOR-M is also equipped with an ($l = 2, n = 1$) helical coil. RMPs produced by this coil interact with the ($m = 2, n = 1$) tearing modes through resonant interference. Figure 1 shows the layout of the helical coil used in STOR-M. The black line shows the helicity of the (2, 1)

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mode. The blue and red lines are two sets of external windings offset by 90° in the poloidal direction and fed by DC current pulses with equal magnitudes in opposite directions. The directions of plasma current and toroidal magnetic field are also shown.

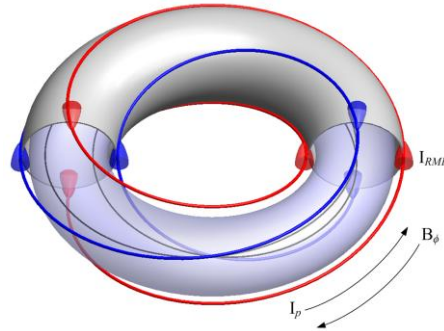


Fig. 1. A schematic of STOR-M showing the helicity of (2, 1) modes (thin black lines) and the corresponding resonant helical coil (thick red and blue lines) used to control (2, 1) modes.

Experimental Results

A series of experiments have been carried out in STOR-M to study the effects of RMP on discharge parameters. An RMP pulse of 5ms duration was applied on an MHD active phase during the discharge #246961. The discharge parameters shown in Fig. 2(a) are, from the top panel, plasma current I_p , loop voltage V_l , horizontal plasma position ΔH , edge safety factor $q(a)$, H_α radiation intensity, hard x-ray (HXR) emission, SXR emission and Mirnov fluctuations. The RMP pulse of 5ms duration was applied at 12ms during the plasma flat-top phase. The RMP current (I_{RMP}) is about 600A (2.5% of total I_p). Clear reduction in H_α and HXR emission levels is seen during the RMP pulse.

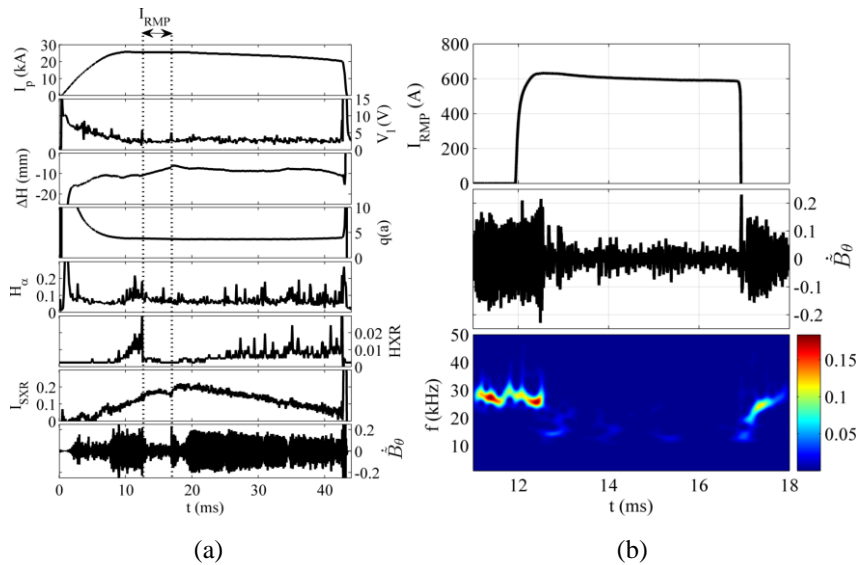


Fig. 2. Effects of the helical RMP on plasma parameters during the STOR-M discharge #246961. The resonant field was applied at 12ms for about 5ms during the plasma current plateau.

Significant suppression in MHD fluctuation signal and an enhanced SXR emission from the plasma core have been also observed. Figure 2(b) shows the expanded waveforms of I_{RMP} , the Mirnov signal, and the Morlet wavelet spectrum of Mirnov signal. The suppression of Mirnov oscillations occurs 0.5ms after the application of RMP. The sudden reduction in MHD amplitude and frequency between 12.5ms and 17ms can be also seen on the wavelet spectrum. The MHD frequency is reduced from 26kHz to 15kHz. After I_{RMP} is turned off, the MHD oscillation amplitude and frequency return to the normal level prior to RMP.

The magnitudes of $m = 1$ to $m = 4$ MHD modes are obtained using spatial Fourier analysis. The analysis was performed in the time segment of 11-18ms (1ms before and after applying I_{RMP}). The mode magnitudes are plotted in Fig. 3. The $m = 2$ (blue) and $m = 4$ (green) modes have the highest magnitude before firing the RMP pulse. A slight reduction in mode magnitudes of $m = 1$ and $m = 3$ can be seen after applying RMP. The $m = 2$ magnitude, however, responds immediately to RMP and drops suddenly by 90% at 12.5ms. The $m = 4$ fluctuation amplitude is also reduced significantly by 86%. The suppression lasts for about 4.5ms when the modes start oscillating at their original amplitudes prior to applying RMP, with $m = 2$ being the dominant mode again.

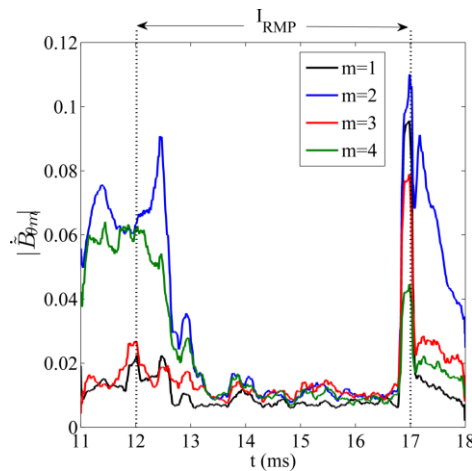


Fig. 3. Mode magnitudes for MHD modes up to $m = 4$ around the time of firing RMP.

The influence of RMP on toroidal flow velocities of O_V (650.0nm) and C_{VI} (529.0nm) impurity lines has also been investigated. The O_V and C_{VI} lines are emitted in the region near $r = 3$ cm and $r = 0$ cm (the plasma core), respectively. The toroidal flow during normal discharges is in the counter-current direction (negative) for O_V and C_{VI} impurities. As shown in Fig. 4, the magnitude of O_V and C_{VI} flow gradually decreases as the RMP current is increased between 20ms and 28ms. The direction of O_V and C_{VI} flow is completely reversed at $I_{RMP} = 850$ A and 1100A.

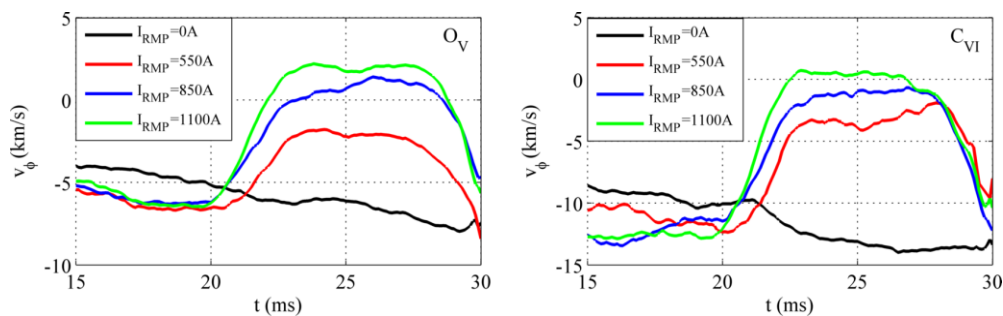


Fig. 4. The waveforms of toroidal flow velocities for O_V and C_{VI} ions at different RMP currents.

The radial profile of I_s and V_f have been measured during the RMP pulse using a movable rake probe array. Clear increase in I_s can be seen in Fig. 5, suggesting an increase in the plasma density n . The increase is more pronounced in the plasma edge than in SOL. The floating potential V_f decreases when RMP is applied. A negative E_r is generated near the limiter at $11.5\text{cm} < r < 12.5\text{cm}$.

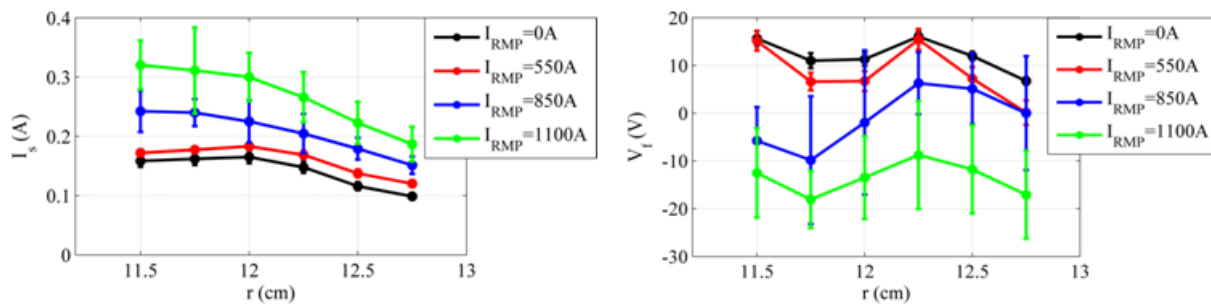


Fig. 5. The radial profiles of I_s and V_f at different RMP current values.

Conclusions

Experimental studies of RMP in STOR-M have been carried out using an ($l = 2, n = 1$) helical coil. RMP has effectively reduced the amplitude and the frequency of MHD modes. The flow of O_V and C_{VI} impurity lines changes towards the co-current direction during the application of RMP. Furthermore, the gradient of the I_s radial profile increases at the plasma edge and SOL with the increase of RMP, indicating an increase of edge density and temperature. RMP also reduces and modifies V_f profile, resulting in more negative E_r near the limiter.

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