MHD mode control studies in medium- and low-aspect ratio RFPs

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1. Introduction

The reversed-field pinch (RFP) is a compact, high-beta magnetic confinement concept, characterized by self-organization of the magnetic configuration and its self sustainment by the dynamo activities. Although the RFP has a great advantage that it requires relatively weak external toroidal magnetic field, one of the disadvantages is that it requires some means to control self-organization process for confinement improvement by controlling the MHD mode dynamics. As a result of great efforts for the last decades to suppress kink/tearing modes in the RFP, some interesting techniques have been established, resulting in the attainment of improved confinement modes.

We have proposed and performed the rotating helical field (RHF) experiments in the STE-2 RFP (R/a=0.4m/0.1m)[1-3]. In the experiment, it has been demonstrated that toroidal rotation of the core resonant mode, otherwise almost locked to the wall, could be driven by the RHF and subsequent suppression of its amplitude was realized. In addition, the phase and mode locking phenomena could be controlled by the RHF. When the external RHF contribution was taken into account, the shape of the toroidal mode spectrum of the m=1 modes resembled that of quasi-single helicity (QSH) RFP state, however, no significant improvement of the RFP characteristics has been observed, where m (n) is the poloidal (toroidal) mode number of the intrinsic modes. It may be attributable to the fact that the amplitudes of neighboring modes (m=1/n>8) were not suppresses by the RHF in the STE-2 experiment.

2. Experiments

The STE-2 is a small RFP which uses a 2-mm thick SS vacuum vessel with major radius *R* of 0.4m and minor radius *a* of 0.1m, operated without a conducting shell. The plasma current *I*p is 50-60 kA with discharge duration of 0.7ms. We have focused our research activities on MHD mode control with external rotating helical fields. The poloidal and toroidal mode numbers of the external helical field, M and N, are 1 and 8, respectively, whose resonant surface is located at r/a=0.4 in typical discharges. In the present experiments, relative amplitude of the external field B_{ra}/B_{pa} was in the range of 1-1.2%, which is higher than in the previous experiments[4], and most of the experiments were performed with RHF frequency of 10 kHz.

3. Results and Discussion

Figure 1 compares the toroidal mode spectrum of the m=1 modes with and without the RHF measured at the maximum plasma current with time average over 0.1ms. In standard RFP plasmas in STE-2, the spectrum has a peak at n=8, decaying gradually to the higher mode, while internal component is less significant. This type of toroidal mode spectrum is typical characteristics of the multi-helicity (MH) mode. When the RHF was applied, the resonant mode was driven to rotate in the same direction as RFH and its amplitude decreased, as shown in the figure, while the behaviour of other modes does not change significanly. It has been demonstrated that the core resonant mode which is otherwise locked to the wall can be driven to rotate with resonant RHF.

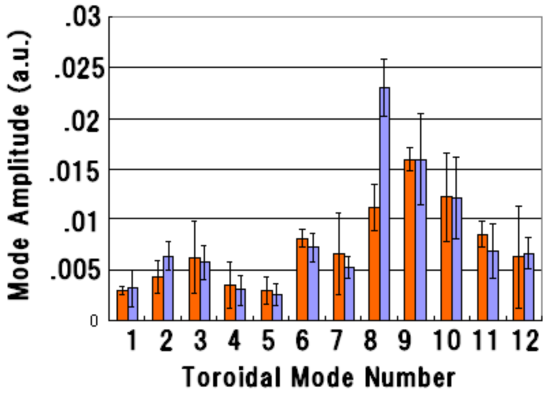

Fig.1 Typical toroidal mode spectrum of m=1 modes in cases with and without RHF (M/N=1/8, f=10kHz).

Figure 2 shows the time evolution of phase dispersion of the internally resonant m=1 modes,

$$\sigma(\theta,\phi)=\frac{1}{1+2+...+(n_{\max}-n_{\min})}\sum_{j=n_{\min}}^{n_{\max}-1}\sum_{k=j+1}^{n_{\max}}\left|\sin\left(\frac{\Phi_{m,j}(\theta,\phi)-\Phi_{m,k}(\theta,\phi)}{2}\right)\right|$$

where $\Phi_{m,j}(\theta,\phi)$ and $\Phi_{m,k}(\theta,\phi)$ are the phases of the modes j and k at the position (θ,ϕ), given by $\Phi_{m,j}(\theta,\phi)=m\theta+j\phi+\alpha_j$, with α_j the helical angle. The low value of σ indicates the phase alignment. In most of the standard RFP discharges in STE-2, the internally resonant modes are phase locked to the wall. When the RHF is applied, as shown in Fig.3, the phase alignment is not released in most of the cases, however, the phase locking

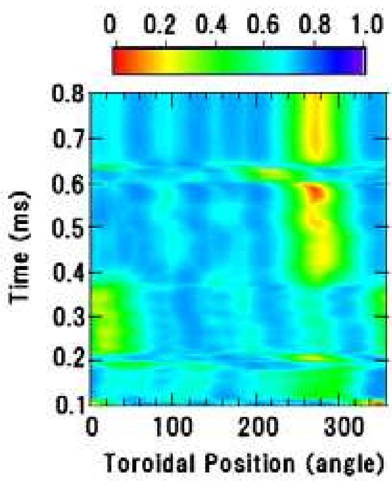

Fig.2: Time evolution of phase dispersion for internally resonant modes in standard RFP plasmas, showing phase locking to the wall.

position rotates in the same direction as RHF, i.e., in the direction of plasma current (co-rotation) in this case. It is interesting to note that when we apply the helical field rotating in the opposite direction to plasma current (counter-rotating RHF), it sometimes happens that the phase alignment is destroyed, yet each mode still remain phase locked, with different phase before application of RHF.

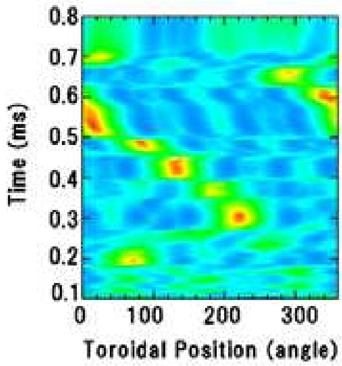

Fig.3: Time evolution of phase dispersion with RHF applied at 0.2ms. The phase locked position rotates in the same direction as RHF but lower speed.

High-frequency magnetic fluctuations were measured using two-point magnetic probes. Two pairs of magnetic probes, each separated by 25mm in the poloidal and toroidal directions, were used to analyze local characteristics of edge magnetic fluctuations in the frequency region up to 200 kHz. In standard RFP plasmas, coherence in poloidal direction (along the magnetic field line) is higher than that in toroidal direction, as shown in Fig.4(a). When we apply RHF and resultant toroidal rotation of the slinky structure is driven, as is the case in Fig.3, the coherence of poloidal and toroidal magnetic fluctuations does not change very much when compared with the case without RHF. On the other hand, when the phase alignment was destroyed as a result of RHF, the coherence decreased appreciably both in the poloidal and toroidal directions over the entire frequency region, as shown in Fig.4(b). The local structure of magnetic fluctuations reflects the global mode coupling process such as

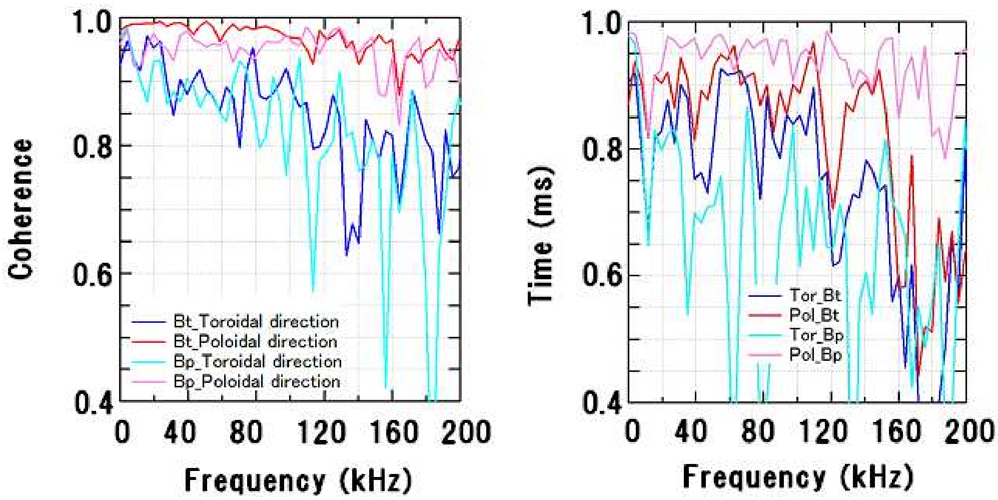

Fig.4: Coherence of high-frequency edge magnetic fluctuations measured with two magnetic probes separated by 25mm in poloidal and toroidal directions. Fig.4(a) (left) without RHF, and Fig.4(b) (right) with RHF and resultant disappearance of phase alignment.

phase alignment and wall locking.

It has been demonstrated that RHF is a useful means to control MHD mode dynamics. In particular, rotation and amplitude of internally resonant modes can be controlled with RHF. Further efforts are required to optimize the frequency and amplitude of the RHF with the help of theoretical studies on interaction external field and tearing modes.

5. Low-aspect ratio RFP

The RFP configuration is achieved and sustained by nonlinear MHD process, and the number of corresponding modes depends on the aspect ratio (A) of the machine because the q (safety factor) profile depends on the aspect ratio. The general trend is that the q profile becomes flatter with higher central value as A decreases. The low-A RFP is thus an attractive configuration because the mode rational surfaces are spaced less densely than in medium-A configuration, which may result in simpler MHD dynamics to sustain the RFP configuration[5]. Another regime of improved confinement of RFP plasmas include the transition to quasi-single helicity (QSH) RFP configuration[6], where the low-A configuration is more attractive because of larger magnetic island of the core resonant tearing mode. We have been contracting the low-A RFP machine with major radius of 0.51m and the minor radius of 0.25m. It uses 4-mm thick SS chamber, and will be operated without conduction shell in its initial phase. Research objectives include MHD mode dynamics and its control in low-A RFP configuration, possible induced transition to QSH RFP with external field, and tests of means to drive plasma flow, such as electrode biasing, electron injection, or CT injection. The research plan in the low-A RFP machine will also be discussed.

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