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Improvement of Feedback Control System in RELAX for Precise Control of Localized Effects

RELAXにおけるRWMフィードバック制御系の高度化による
プラズマ性能改善

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A feedback control system consisting of 64 saddle coils (poloidally 4×toroidally 16 sensor and actuator coil arrays) for the stabilization of RWM was applied to a low-aspect-ratio (low-A) reversed field pinch (RFP) machine RELAX. In the initial experiment, it was shown that the most unstable m/n = 1/2 RWM was stabilized by the coil configuration for the single mode control with two power supplies. In the present experiment, independent control is performed only at two toroidal sectors including the insulated poloidal gap where localized large field errors are produced by the flanges. The results show further improvement of the discharge performance.

1. Introduction and Background

The reversed field pinch (RFP) is one of the magnetic confinement systems for high-beta plasmas. Relatively weak external magnetic field is enough to confine the plasma, and therefore, the magnetic field outside the plasma is mostly due to the plasma current. Thus engineering beta is quite high, which is a great advantage of the RFP reactor concept. However, Resistive wall mode (RWM) is an MHD instability which grows magnetic field diffusion time in the wall surrounding the plasma [1]. Sometimes, the RWM degrades the plasma performance in toroidal fusion plasmas.

2. RELAX machine and MHD studies in low-A

RELAX is a low-A RFP machine (R/a = 0.51 m/0.25 m), which aims to confirm experimentally the advantages of low-A RFP [2]. In order to realize good confinement in the RFP, We have to suppress current driven MHD instabilities. In particular, it has been shown experimentally and theoretically that non-resonant kink mode with $(a/R)\times n$ = 1 grows with time scale of the field penetration time of the vacuum vessel (resistive wall), and is responsible for degradation of the RFP discharge, whehe n is the toroidal mode number. A 3-D MHD simulation [3] using RELAX plasma parameters predicted the MHD mode evolution as shown in Fig.1. The simulation has been performed using DEBS code with RELAX plasma parameters. The result shows that the most unstable RWM is m/n = 1/2 (externally non-resonant kink mode), being consistent with the experiment and our previous linear stability analysis in cylindrical geometry.

3. Feedback Control System in RELAX

We have attached saddle coil arrays covering the outer surface of the whole torus for active MHD control. The present report is focused on active feedback control of magnetic boundary conditions to suppress RWM in RELAX as shown in Fig.2. We set saddle sensor/actuator coils covering the whole torus surface outside of the vacuum vessel. The number of saddle coils are as follows: poloidally 4×toroidally 16 sensor and actuator coil arrays. As the initial experiment, we have performed feedback control of a single mode by connecting these coils to form m/n = 1/2 and the mode are suppressed successfully [4]. Figure 3 shows the effect of the feedback control on the m/n = 1/2 single mode evolution and the plasma performance. It is clear that growth of the m/n = 1/2 magnetic perturbation is suppressed below the preset level when the feedback is applied, where the perturbation otherwise growths with the time scale of the vessel time constant (~ 1.5 ms). It should be noted that the loop voltage during the current rise and flat-topped phase has not been improved by the feedback. We suspect it is because of the toroidal non-uniformity of the field penetration time of the

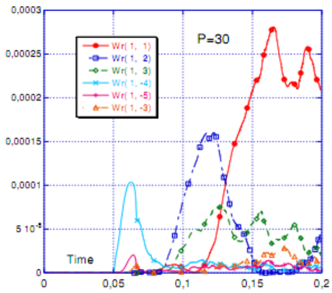

Fig.1. Time evolutions of the MHD modes from 3-D MHD simulation.

vacuum vessel because we apply rapidly changing reversed toroidal field during the current rise phase.

4. Results and discussion

In addition to the two power supplies in the initial experiment, we have prepared 6 power supplies for separate control of the magnetic boundary conditions at the two toroidal sectors which include the poloidal insulated gas and flanges. The inner side saddle and outer side saddle coils are controlled independently such that the radial flux penetrating the sensor coil remains zero, while the top and bottom saddle coils are connected in series to form the *m* = 1 structure. Therefore, three power supplies are used at each of the two sectors. The saddle coils at the remaining 14 sectors are connected in series to form the *m/n* = 1/2 structure. Since the localized magnetic perturbation is controlled separately from global helical perturbation by use of this control system shown in Fig.4, we expect further improvement of the plasma performance. As the first step experiment, we have performed feedback control of a single mode by connecting these coils to form *m/n* = 1/2 structure. Figure 5 shows the effect of the feedback control of the *m/n* = 1/2 single mode on plasma performance. The mode amplitude has been suppressed to 0.5 % (normalized to the edge poroidal field) throughout the discharge. The discharge duration extends from ~ 2.9 ms (without feedback) to ~ 3.9 ms with new-scheme feedback. The discharge lifetime with new control scheme is also determined by the saturation of the iron core, with further reduction of the loop voltage near the end of discharge.

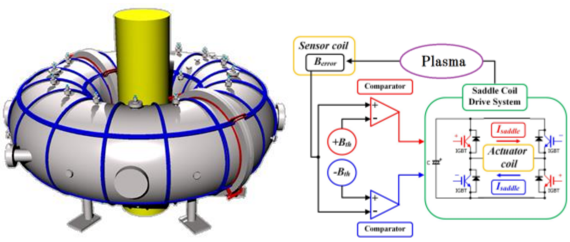

Fig.2. Saddle coil array for the actuator and sensor coils in RELAX (left) and block diagram of the control system.

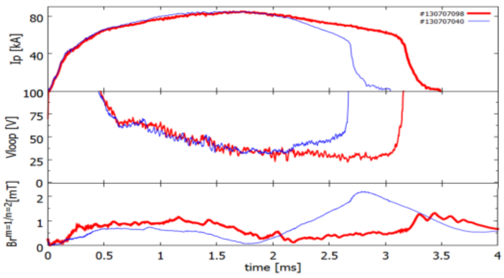

Fig.3. Time evolutions of I_p, V_{loop}, and *m/n*=1/2 mode amplitude from sine and cosine B_r array, without (blue) and with (red) active control.

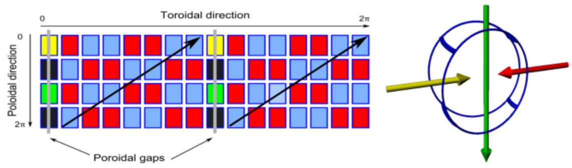

Fig.4. An envelope of the array surface showing the coil connection in new control scheme (left). At the poloidal gap sector, inner and outer side horizontal components are controlled independently, while the vertical component is controlled using top and bottom coils (right).

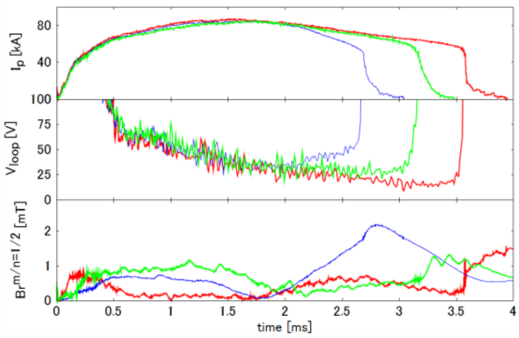

Fig.5. Time evolutions of I_p, V_{loop}, and *m/n*=1/2 amplitude from sine and cosine B_r array, without (blue) with (green) active control and with (red) improved control scheme.

References

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