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Status and Future Plans for Low-Aspect-Ratio RFP Research in RELAX

RELAXにおける低アスペクト比RFP研究の現状と展開

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RELAX is a low-aspect-ratio (A=2) machine aiming at experimental demonstration of advantages of low-A RFP configuration. Since its initial operation, the RELAX experiments have demonstrated MHD properties characteristic to low-A RFP: easy access to quasi-single helicity (QSH) state in shallow-reversal regimes, and attainment of extremely deep reversal regimes without discrete dynamo events. Next step of the research would be attainment of high-current (Ip>100kA) operation with good confinement to achieve high-beta RFP plasmas where we expect sizable pressure-driven bootstrap current.

1. Introduction

One of the characteristics of the reversed field pinch (RFP) is that it can confine high-temperature plasmas with weak external magnetic field; lower than in tokamaks by an order of magnitude. Two schemes have been shown to be effective to achieve improved confinement: pulsed parallel current drive (PPCD) to realize tearing-stable current density profile, and quasi-single helicity (QSH), or single helical axis (SHAx) state. In these two schemes, nested flux surfaces are recovered in otherwise stochastic field lines either by suppression of fluctuation amplitudes of all the unstable modes (PPCD) or by spontaneous growth of a single magnetic mode, resulting in helical deformation of the core (QSH or SHAx).

For further geometrical optimization of the RFP configuration, the aspect ratio A=R/a is one of the important parameters which characterize MHD features and possible sizable fraction of the pressure driven bootstrap current when high beta value can be achieved.

RELAX (R/a=005m/0.25m) is a circular cross sectional RFP machine with the lowest A. The major objectives of RELAX include characterization of MHD behavior in the low-A RFP, and experimental observation of the pressure-driven bootstrap current in the RFP at high beta (~30%). Typical parameters of RELAX plasmas are as follows: plasma current I_p from 40-125kA, electron density n_e from $0.1\text{-}2.0\times10^{19}\mathrm{m}^{-3}$, electron temperature T_e ~50eV from double-filtered SXR measurement, with discharge duration of ~2ms.

2. Operational regions and MHD in RELAX

The MHD behavior in the regime of Ip from 40-60kA has been reported[1]. The discharge regimes of RELAX plasmas in (Theta, F) space are summarized in Fig.1, showing two characteristic regimes which have a potential confinement improvement[2]. In shallow-reversal regions, where toroidal field reversal is weak or almost zero, the plasma tends to realize QSH state. Soft-X ray diagnostics have shown the hot or dense helical core[3] in these discharge regions, an indication of improved confinement in the core region. Another region is the extremely deep reversal regions, where the magnitude of the reversed edge toroidal field is larger than that of

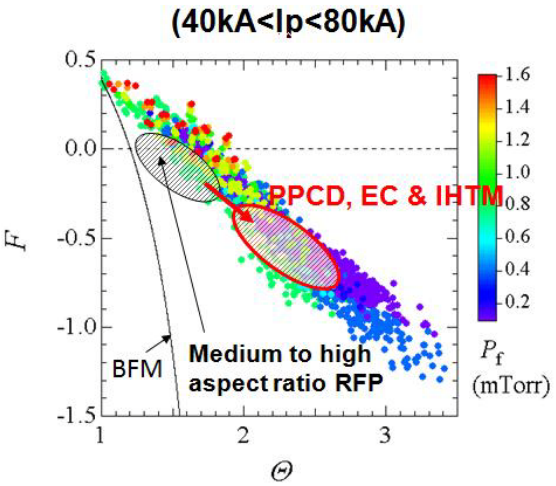

Fig.1: Discharge regions in (Theta,F) space in RELAX.

the average toroidal field, indicating strong magnetic shear configuration. The SXR emission intensity is enhanced with suppressed magnetic fluctuation amplitude, an indication of possible confinement improvement.

The neoclassical equilibrium analyses have shown that the bootstrap current in RELAX depends strongly on the beta value and pressure profile. An analysis has shown that beta value of 25-30% at plasma current of 100kA is required to realize an equilibrium with sizable fraction (~25%) of the bootstrap current. In this paper we will summarize the characteristics of high-current (90kA<Ip<125kA) RELAX plasmas, to search for possible scenarios for high-current, high-beta plasmas.

3. Characterization of high-current discharges

Figure 2 shows an example of the low-resistance 100kA discharge attained in RELAX. The loop voltage went down to 30V in the flat-topped current phase. The magnetic fluctuation behavior depends on the discharge phase; in the current rise phase quasi-periodic growth of m=1/n=4 mode is observed with realization of the spectral index lower than 2. In the flat-topped current phase, growth of a single mode is not very clear as in the current rise phase, with higher value of spectral index.

Figure 3 shows the dependence of discharge resistance on the amplitude of the core resonant m=1/n=4 mode. The lower amplitude regions correspond to the discharge of the type shown in Fig.2, while the higher resistance regions the

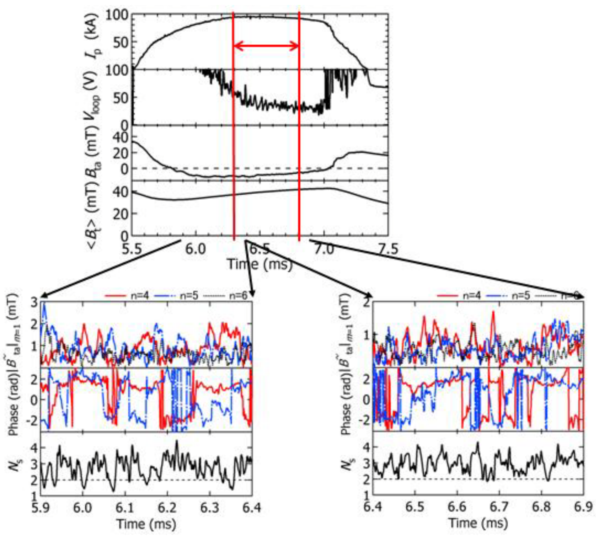

Fig.2: A 100kA discharge in RELAX with MHD behavior.

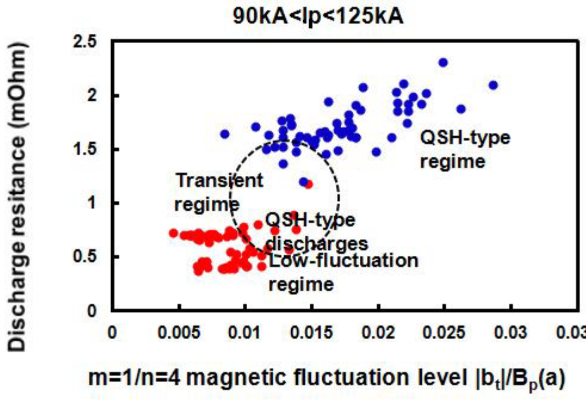

Fig.3: Discharge resistance vs. m=1/n=4 magnetic fluctuation level.

QSH type discharges in which magnetic fluctuation amplitude tend to concentrate on a single mode. The m=1/n=4 mode amplitude appears to have correlation with discharge resistance.

4. Scenarios for high current operation

Since the iron core capability of the RELAX machine is restricted to ~0.25 Volt-sec, it would be more desirable to reduce the volt-sec consumption to achieve the plasma current higher than 100kA. Therefore, we have to develop a scenario to drive high current without significant grow of m=1/n=4 mode, then to increase the density which may lead to QSH in high-current regime in RELAX.

In the current rise phase, lower fill pressure is shown to be desirable to reduce the volt-sec consumption. We have observed that the electron density in flat-topped current phase is $\sim 0.2\times 10^{19} m^{-3}$ in low fill pressure case. So, we have been developing a supersonic gas injection system which allows gas injection with very short time scale.

References

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