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Plasma current start-up experiments without central solenoid in the iron core STOR-M tokamak

STOR-M鉄心トカマクにおけるCS無し電流スタート実験

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We have demonstrated that the plasma current up to 10~15 kA can be started up using the outer Ohmic heating (OH) coils without central solenoid (CS) and that the plasma current can be maintained further by he outer OH coil using the 3rd capacitor bank during iron core saturation phase in the STOR-M tokamak [1]. This plasma is vertically stable due to the iron core image field by the plasma current itself. This is the first experimental demonstration of the possibility of slow transition from the iron core to air core transformer. Thus, a reliable plasma current start-up by the outer OH coils and the current ramp-up to a steady state by additional heating power and vertical field coils could be an operation scenario for future ST reactor with an iron core transformer.

1. Introduction

The plasma current start-up without central solenoid (CS) is one of unresolved issues in the research of spherical tokamaks (ST). Although induction by the vertical magnetic field can start up the plasma current together with the heating power in an air core tokamak without CS [2-6], it is still difficult to control the initial plasma position without a small CS. In this work, we demonstrate a novel plasma current start-up scenario without CS using the iron core and sustainment of plasma current during the subsequent transition phase from the unsaturated to saturated phase in the STOR-M tokamak [7]

2. Experimental layout

STOR-M R=0.46m, a=0.12 m and B_t=0.6 T) is a conventional iron core tokamak with an iron core transformer. STOR-M is equipped with the inner and outer OH coils (total turn number of N=8) and the vertical field coils with return windings for a typical plasma current of 20 kA. In this work, CS is disconnected and only the outer OH coils (equivalently vertical field coil) are used to drive the plasma current as shown in Fig. 1.

Plasma current start-up experiments have been conducted without bias current to obtain an earlier iron core saturation for the turn number N=4 of the outer OH coil. As the plasma current is driven by the outer OH coil, the plasma current is almost a half of that in the normal operation for the same coil current. When the iron core approaches saturation, an additional 3rd bank is applied to drive the plasma current, and the plasma position is controlled by the feedback B_V coils placed near the vacuum chamber as shown in Fig. 1.

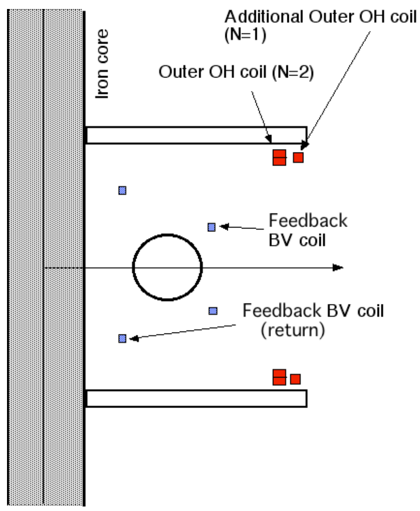

Fig. 1. Poloidal coil layout for the saturable iron core operation without CS in STOR-M.

3. Experimental results

Temporal evolution of discharge waveforms are shown in Fig. 2. The plasma current (Fig.2-(a)) is reproducibly generated because of a wide null field region due to the absence of bias current. The magnetizing current of the iron core transformer is shown in Fig. 2-(c) which is estimated by I_M= I_{OH}-I_P/N where I_{OH} is the outer OH coil current and I_p is the plasma current. When the magnetizing current reaches 1 kA at 30 ms near the iron core saturation before the end of the discharge, the 3rd bank is applied to extend the pulse length. An increase in the plasma current is clearly seen in Fig.2-(a) after 30 ms. The central iron core flux which is numerically integration of the one turn loop voltage on the plasma ring is shown in Figure 2-(d), indicating that the iron core is near saturation. This is also seen from the dynamic hysteresis curve drawn as a function of the magnetizing current I_M as shown in Fig. 2-(f), The 3rd bank is applied at I_M=1 kA and the discharge is terminated at I_M=2.8 kA. Although the hysteresis curve seems to be saturated at this magnetizing current, it was partially saturated as found by numerical calculations.

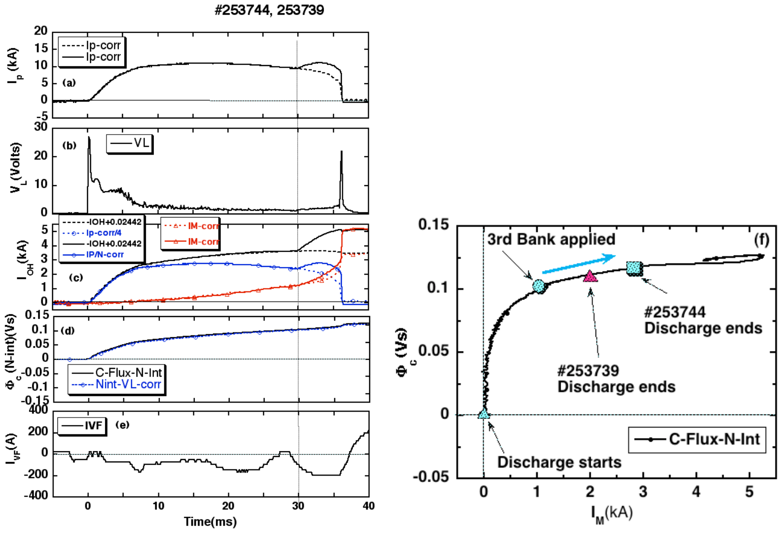

Fig. 2. Experimental results on the plasma current sustainment by iron core saturation operation without CS for N=4 (#253738). 3rd bank (I_{OH} in (e)) is applied at core saturation phase (Φ_{OH} in (f)). (a) Plasma current I_p, (b) Loop voltage V_L, (c) Outer OH coil current I_{OH}, the plasma current divided by N and the magnetizing current I_M=I_{OH}-I_p/N, (d) Iron core flux Φ_{OH}, and (e) Feedback B_V coil current for compensation. (f) Dynamic hysteresis curve as a function of the magnetizing current I_M

However, slow transition from the unsaturated to partially saturated phase is demonstrated in the iron core tokamak without CS.

4. Vertical stability during unsaturated phase

As the configuration of the feedback B_V coils (Fig. 1) seems to provide the unstable n-index. However, they subtract the vertical field for plasma equilibrium, yielding the positive n-index. Moreover, the plasma current produces the positive n-index due to the iron core image field. The distribution of the vertical magnetic field line calculated at the plasma current peak (unsaturated phase) is shown in Fig. 3. It clearly shows the good curvature of the vertical field line all over the area, which ensures stability to the vertical plasma movement in this CS-less operation.

5. Summaries

In summary, we have demonstrated that induction due to the vertical field coils can start-up the plasma current without CS using a iron core, and plasma current can be maintained in the iron core saturation phase in the STOR-M tokamak. The results suggest the feasibility of operation scenario in a future ST without CS in which a small plasma current is produced by the vertical field coils with the iron core, and a larger plasma current can be further ramped up by application of additional heating power and vertical field coils after iron core saturation.

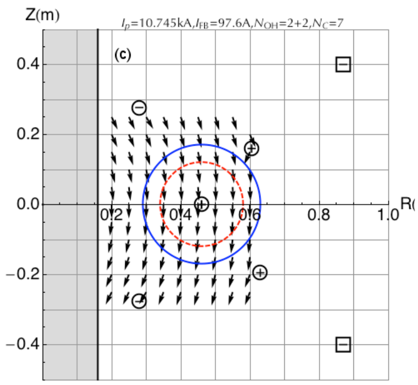

Fig. 3. Magnetic field vector ditribution at the plasma current peak 15 ms in the relative permeability μ_r=950 unsaturated phase for the coil current cases of I_{outOH}=2800 A, I_{FB}=97.6 A, and I_p=10 kA.

Acknowledgments

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