Design and Construction of a New Reversed Field Pinch Device with a Very Small Aspect Ratio (A~2)

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A new RFP device with a very small aspect ratio (A = 2.1) is designed and constructed. The aspect ratio of A = 2.1 is much smaller than those of existing devices (A > 3). At this small A, no rational magnetic surface appears from the axis to ψ = 0.4 in the normalized flux surface coordinate, which may reduce the chaotic properties of the plasma in the core region. The proposed examination of bootstrap current generation could also be done. For this new device, a compact and high voltage center coil and an aluminum vacuum vessel (R/r_w = 0.53 m/0.25 m) are developed. The maximum plasma current is designed to attain 100 kA. The construction of the device has been completed successfully. In the initial series of discharges, a stable region with a very high Θ value up to ~2.5 is newly found.

Keywords:
RFP, reversed field pinch, small aspect ratio, tearing mode

The reversed field pinch (RFP) is one of technically simple and economical reactor concepts, and much effort has been devoted to its improvement. The RFP is characterized by its specific confining magnetic field profile sustained by the dynamo process. Since qA~constant and q decreases with radius in the RFP, rational surfaces appear more diversely in a core region at a smaller A; that is, fewer resonant tearing modes are excited in the core region, which suggests a reduction of the stochastic region [1]. Higher bootstrap current generation is also envisaged at smaller A, which also improves the current profile and thus enhances stability [2]. The Mercier stable critical β generally decreases with $1/A$, but β~0.2 is permissible at A~2. These aspects of small A RFP; high β, a high bootstrap current fraction, and possibly easier access to a less stochastic improved confinement are attractive for the improvement of the RFP concept [3].

To examine this argument and explore a new operating regime, a new RFP experiment of very small A is planned. Pioneering experiments have been performed on an extremely small A (A < 1.3) RFP configuration based on different device conceptions, and the characteristic tearing mode excitation has been studied [4,5]. To evaluate the confinement properties in detail, however, we need a longer discharge duration as well as more refined device conditions regarding magnetic coils, stabilizing shells, and wall surfaces [6]. For this purpose, an RFP device with the technically smallest A is designed according to the conditions: a vessel minor radius (r_w) of ~0.25 m, a discharge duration time (T_d) of ~5 ms, and I_p~100 kA. An iron-core transformer and the power system of old

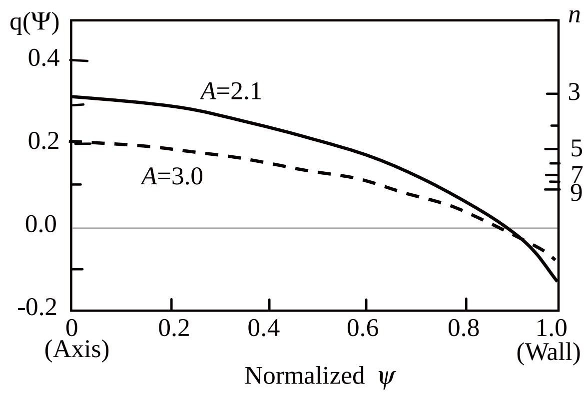

Fig. 1 $q(\psi)$ profiles at A = 2.1 and 3.0. n is shown only from 3 to 9.

TPE-2M device are also utilized. After some design considerations and calculations, we obtained the following design parameters: A = 2.1, R = 0.53 m, r_w = 0.25 m, and I_p = 0.1 MA. The setup time is ~0.7 ms and T_d~6 ms is envisaged, assuming V_{loop}~30 V, which is sufficient for the analysis of mode dynamics and current profile evolution, and for the assessment of plasma confinement.

The theoretical q profile of the standard RFP at A = 2.1 is shown in comparison with the case of A = 3.0 in Fig.1. The resonant tearing mode excites strongly at a rational surface defined by integer $1/q$ ($q = m/n$). Here m is the poloidal mode number and n the toroidal mode number. m = 1 is dominant in the RFP. It is seen that no rational surface

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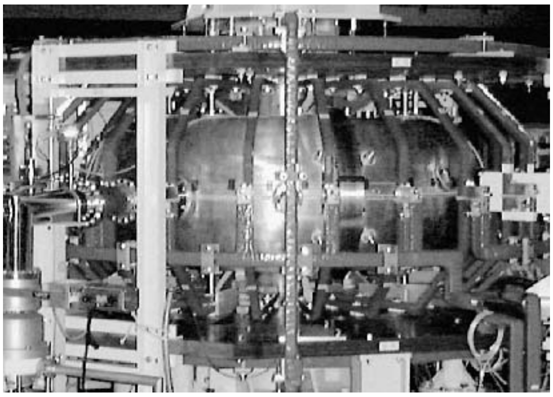

Fig. 2 Photograph of the device.

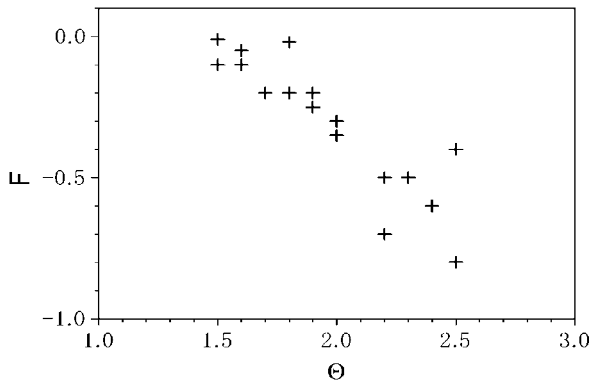

Fig. 3 *F*-Θ diagram found in the initial series of discharges.

appear from the axis to Ψ = 0.4 (q = 0.25, m/n = 1/4) and then the q = 0.2 (m/n = 1/5) surface is followed at Ψ = 0.5. A = 2.1 is critical; a q = 1/3 (m/n = 1/3) surface appears near the axis if A is designated to be slightly smaller, or if the current profile is slightly modified at the present A.

In reconstruction, the center leg of transformer's iron-core is replaced by a slender one (d = 0.316 mϕ, Φ_{max} = 0.25 Wb), as well as are all the coil systems. The key components to be developed are a compact and high voltage (18 kV) center coil of OH and a toroidal coil assembly with an iron-core, and a combined vacuum-vessel and shell assembly. The OH coil is composed of two 36-turn windings. The toroidal coil system is composed of a 24-turn coil. The DC and pulsed vertical field coil is also mounted for equilibrium positioning and for compensation for the error field at the toroidal gap, respectively. As for the vacuum vessel and stabilizing shell system, a thick (25 mmt) aluminum vacuum vessel has been manufactured. It functions effectively as a conducting shell (the skin time is over 100 ms). The vessel has only a single cut in the poloidal direction. Its vacuum sealing is attained by a skillful technique of high-vacuum epoxy-resin mold. The epoxy-mold portions are carefully and elaborately protected from plasma radiation and sputtering. The total toroidal gap width is merely 5 mm. The plasma is detached from the wall surface by molybdenum limiters and numerous thin molybdenum boxes in which magnetic sensors are installed. Thus the shell proximity ratio (defined by the shell surface radius/plasma surface radius) is as small as 1.02. This is essentially important to the plasma stability. In order to minimize an induced error field in the vessel, the maximum diameter of holes for observation and vacuum ports is limited to 30 mmϕ. The minimum base pressure is 3×10^{-7} torr, and it continues to be improved. A photograph of the vacuum vessel and coil assembly is shown in Fig. 2.

The RFP discharge operation was started successfully at I_p~50 kA after circuit adjustments and many cleaning discharges. In the initial series of discharges, a substantial extension of a stable operating regime in a F-Θ diagram is newly found as shown in Fig. 3. Stable confinement at Θ~2.5 is observed, which was difficult to obtain in conventional devices. A full plasma experiment is continuing and the results will soon be reported.

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