*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-2.048 (2005)*

First Result from a New RFP Device with a Very Small Aspect ratio

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A new reversed field pinch (RFP) device with a very small aspect ratio (A=2.1), TPE-QS was constructed, and here are reported the first results of plasma experiment. The aspect ratio, A=2.1 is much smaller than those of conventional devices (A>=3). At this small A, rational surfaces appear more diversely in the core region. The minimum toroidal mode number of n=4 appears near at the mid-radius. The toroidal loop voltage Vl_{oop} will also be lowered because of smaller toroidal path. The device was designed by minimizing A after some technical scaling consideration and by q-profile calculation, and was constructed by re-use of old TPE-2M [1, 2]. The photograph of the device is shown in Fig. 1. The dimensions are summarized in Tab. 1. The RFP plasma experiment started in March 2004. The main diagnostics in the initial experiment are a magnetic pickup coil array on the inner surface of V/V, a toroidal flux loop array outside V/V, and visible and SX optics.

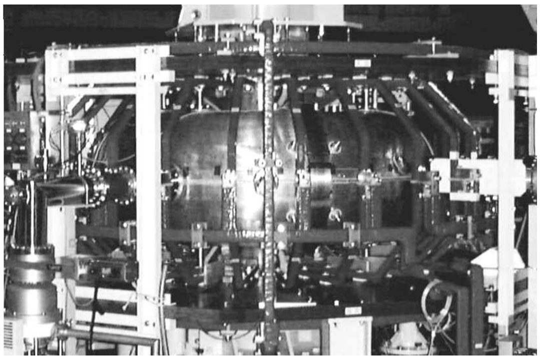
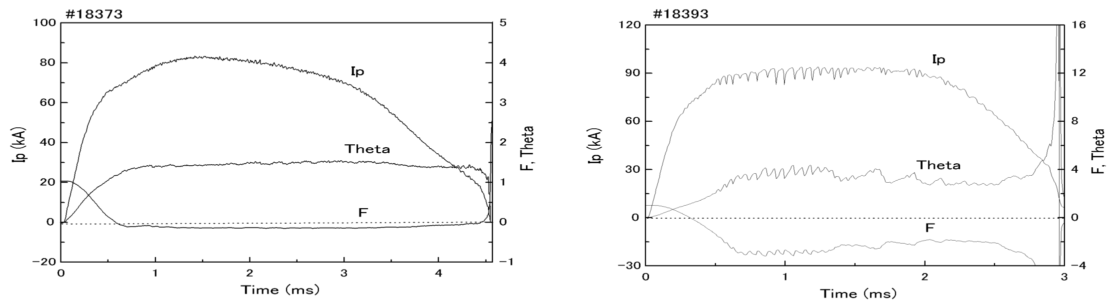


Fig. 1 The new RFP device, TPE-QS.

Tab. 1 Dimensions of TPE-QS.

R/rw	0.53 m / 0.25 m
Flux swing	0.24 Wb
Toroidal coil	24 turns
V/V	25 mmt (Al)
Base pressure	$2x10^{-7}$ torr
T-rise of Ip	0.6 ms
Max. Ip	110 kA
Max. Td	9.5 ms

In Fig. 2, typical waveforms of Ip and F/Theta are shown. The maximum Ip and Td (discharge period), so far, are 110 kA and 9.5 ms, respectively. During a year operation, V_{loop} decreased substantially from ~80 V to ~20 V at the early Ip flat-top (at 2-2.5 ms), and even to ~5 V at later flat or slowly decaying current stage as shown in Fig. 3. V_{loop} at the discharge termination was also decreased from ~20 V to ~<0 V in a year. Then the resistive term of V_{loop} (RpxIp) just before the discharge termination is very small, as the inductive term of V_{loop} is calculated to be ~-4 V. The reduced V_{loop} is due to the increased cleanliness and boronization of wall surface, and the improvement of low gas pressure discharge technique during a year. It continues still improving. More elaborate compensation of the error field at the vertical shell cut and the discharge initiation at the higher DC vertical field would further improve the discharge.



(a) Standard Theta discharge (b) Very high Theta discharge

Fig. 2 Typical waveform of RFP discharge.

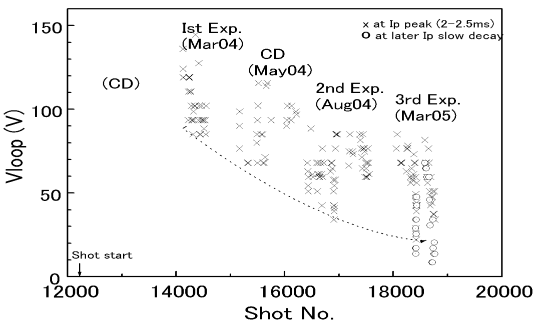


Fig. 3 V_{loop} reduction in a year.

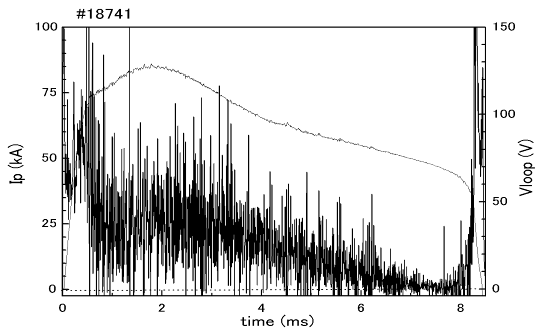


Fig. 4 Very low V_{loop} discharge in the later stage.

The F-Theta ranges of discharge are shown in Fig. 5. The F-Theta curve changed little, but the limit was extended during a year. The higher limit of Theta increased from 2.5 to 4. The value Theta=4 is quite higher than the conventional one. The high Theta discharge is usually accompanied by a large fluctuation or relaxation oscillation in its waveform, and V_{loop} is higher. The high Theta discharge is not of main interest for the moment. Then little analysis is made.

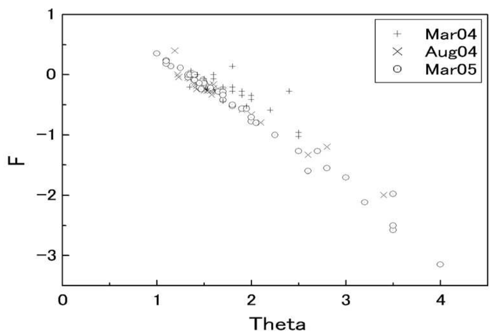


Fig. 5 F-Theta ranges of discharge.

The F value including its sign can be continuously varied in this device. RFP after the fast toroidal field reversal (F<0) can transfer to tokamak (F>0) by a further fast increase of reversal field if V_{loop} is high enough, or by a slow annihilation of reversal field to the plus sign. In the latter case, the spheromak configuration (F=0) can be reached also. The other methods are that starting at tokamak, spheromak or RFP is attained by slow decrease of toroidal field to zero or minus value. In the latter RFP setup method, the configuration builds up even without decreasing of the external toroidal coil current in a certain case. The low q (<~0.2 in the present experiment) tokamak relaxes itself to RFP. The toroidal current coil current non-artificially reverses its sign without external control during the course. An example of waveform is shown in Fig. 6. This means that RFP can be configured by the self-organization process even if the conducting shell is poloidally open (but the coil circuit is closed electrically). The F-Theta locations before and after the relaxation transition are shown in Fig. 7. F after relaxation lies in a narrow range, irrespective of the initial value, but Theta ranges rather widely; if the initial value is higher, the relaxed value tends to be also higher. When relaxed Theta is higher, F is larger in the minus sign, that is, the F-Theta combination settles to a more relaxed state (nearer to BFM). The relaxation transition from tokamak to RFP occurs more easily at a lower OH input power stage in the later period of discharge. This process was observed not clearly at an earlier high V_{loop} discharge, but very clearly in a recent low V_{loop} discharge. This fact suggests that the self-organization process is more predominant in a more closed system (lower input power from the OH circuit). The naturally relaxed RFP is more quiescent compared with controlled formation, especially in the near-saturated stage of OH flux-swing; V_{loop} and Bp fluctuations decrease substantially to ~2V and ~0.2%, respectively.

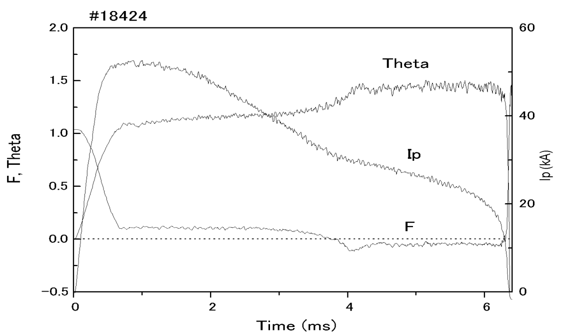


Fig. 6 F-Theta trajectory at relaxation transition.

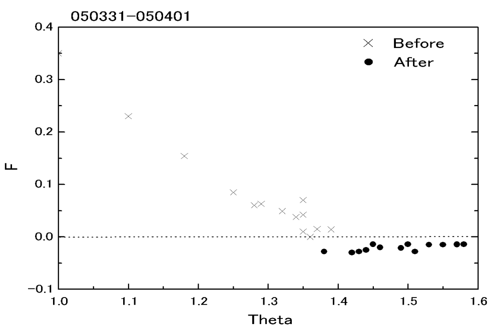


Fig. 7 F-Theta locations before and after the relaxation transition.

MHD mode behavior was investigated from Br and Bp pick-up coil array signals. The poloidal mode m =1 is dominant in most cases. The minimum n seems to be 4, as expected from the equilibrium calculation. Usually the number of mode is plural. However, the dominant one is within three in many cases. The observed mode number characteristics seem to be supported by the simulations on aspect ratio dependence [3, 4]. The single n discharge (SH), if any, is pursued. The case was found so far only in a relatively low Ip and high-density discharge (more resistive) when F is made shallower from the initial F>-0.1 during the period. It is sustained in F<=0. If F starts from 0 and is deepened, it does not appear. In SH (or quasi-SH), the poloidal magnetic field oscillates quite regularly (evidently sinusoidal and phased), as shown by the arrowed period in Fig. 8. Also, high frequency spikes/fluctuations are reduced and a clear relaxation oscillation is seen in the V_{loop} signal. The n spectra of observed SH and DH (two modes) are shown as examples in Fig. 9. The spectral profile varies during the discharge within the limit of analytical accuracy. Initially, the dominant n is 4. While F goes to zero, the dominant n tends to move to 5. The RFP relaxed from tokamak (F=-0.02~-0.05) at very quiescent stage is also analyzed. The spectrum is SH or DH, however, the dominant n is higher.

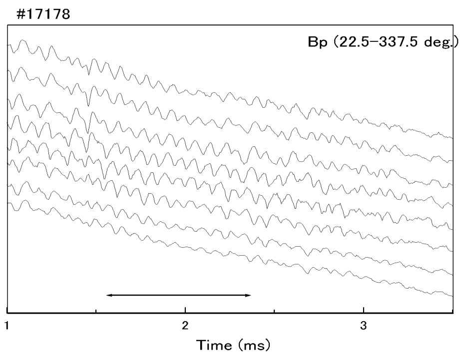


Fig. 8 Bp array fields.

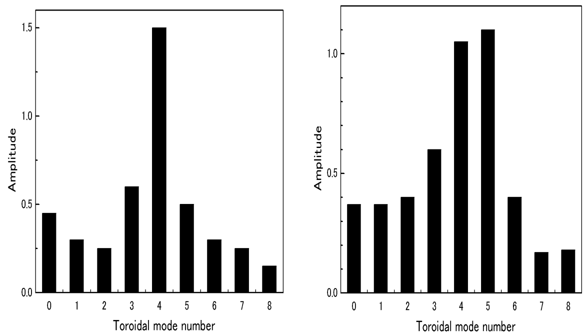


Fig. 9 SH (left) and DH spectra (right).

The toroidal structure of toroidal flux signals is shown in Fig. 10. The toroidal symmetry is quite good. The deuterium line emission pulse coincides well with the flux peak; it shows the plasma-surface interaction. In some cases, it seems very fast propagating in either direction (~50 ns). The case is considered to correspond to the partial intrusion or effusion of toroidal flux through the vertical shell cut, as observed by local flux loops on the shell cut.

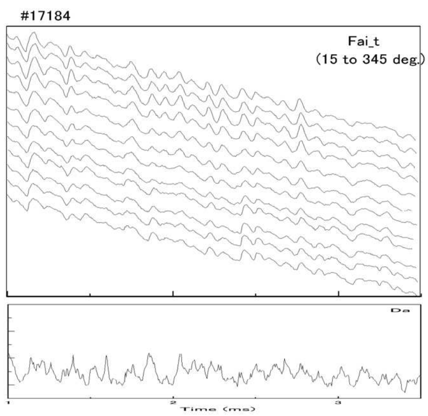


Fig. 10 Toroidal flux and deuterium line intensity.

The author thanks to the TPE-experiment and theory staffs for their kind help and useful discussion. This work was financially supported by the MEXT and AEC of Japan.

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