# MHD EQUILIBRIUM AND STABILITY OF REVERSED FIELD PINCH PLASMA

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MHD equilibrium and stability of reversed field pinch(RFP) configurations are studied using a resistive MHD stability code[1] to get the maximum $\beta_p$ and the farthest shell position.

## 1. Experimental RFP equilibrium configuration

Equilibrium configurations of RFP plasmas are characterized by pinch parameter $\theta(=Bp(a)/Bt\_av)$ and reversal parameter $F(=Bt(a)/Bt\_av)$, where Bp,Bt and Bt_av are poloidal,
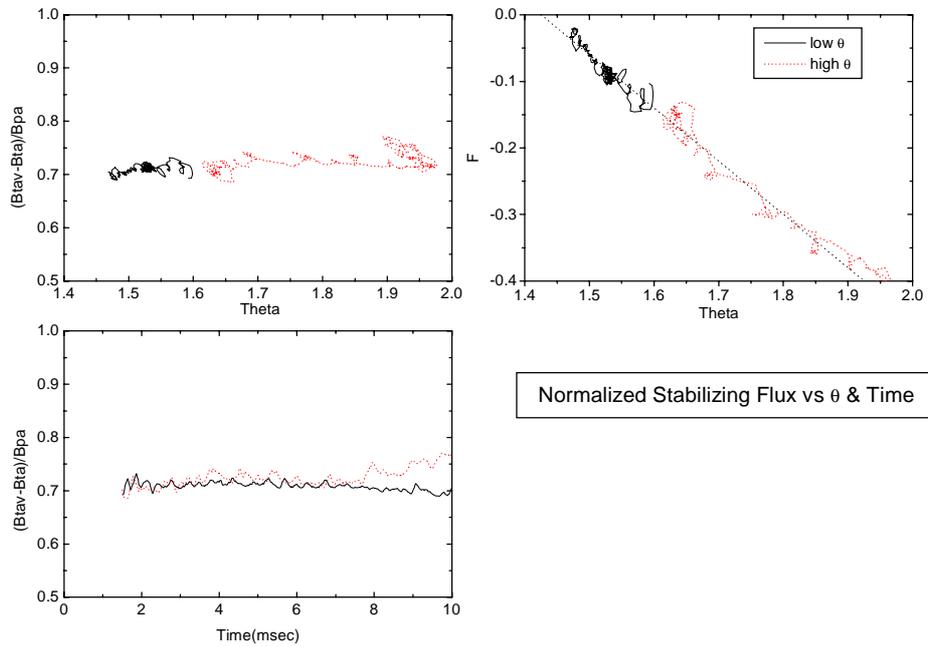


**Fig. 1.** Normalized stabilizing flux, $(1-F)/\theta$ vs. theta and time for low and high theta discharges.

toroidal and average toroidal magnetic field respectively and a is plasma minor radius. As shown in Fig.1, experimental F/θ points have a unique feature such that they follow a straight line of *F=1-C\*θ,* where *C=0.7~0.75* in TPE-1RM20 [2] as observed in many other RFP devices. TPE-Z toroidal z-pinch plasma, where no toroidal filed coil exists, shows a similar result such as the operational θ is limited of around 1.5 where F=0. The constant slope, *C=(1-F)/ θ =(Bt_av-Bt(a))/Bp(a)*, means that the stabilizing toroidal flux (i.e. paramagnetic component) inside the plasma is proportional to the plasma current in experimental RFP plasmas. The normalized stabilizing toroidal flux *C* is independent of the plasma current and the pinch ratio θ in TPE-1RM20. The study of the equilibrium configurations by the resistive MHD stability code suggests that the experimental F/θ points follow the dynamo-mode marginal stability points as shown in Fig. 2. Rothenbluth reported the similar result on the stabilizing toroidal flux required for a stable pinch plasma with sharp boundary[3]. RFP plasmas in experiments are operating just on the stability boundary of tearing modes near the plasma center, which sustain the RFP configuration as "dynamo action".

## 2. Current-driven mode free RFP configuration

RFP configurations having a resistive shell without both the m=1 internal and the external ideal MHD and tearing mode are investigated. Equilibrium configurations are constructed by using $\alpha$-$\theta_0$ model [4] for $\mu$ (=**J/B**) profile, where $\mu=2*\theta_0(1-(r/a)^\alpha)$. Plasma pressure is inflated by Suydam parameter

$C_{suydam}(r) = -4\pi p^{I}/(rB_z^2)(q/q^{I})^2$, keeping the q-profile same to identify modes between ideal MHD, tearing and resistive g-mode, with a window function to decrease pressure gradient near the plasma



**Fig. 2.** Experimental F/θ plots with marginal stability points of dynamo-mode, m=1/n=-7&8

edge. The stability of RFP plasma configurations are subject to the m=1 internal and external ideal MHD and tearing modes as global modes (In RFP the internal and the external is defined relative to the $B_t$ reversal surface). The m=0 tearing mode also exists in poor shell proximity condition, but has generally low growth-rate and is not global like m=1 mode. Stability is compared by the linear growth-rate with conditions of S(Magnetic Reynolds number)=$10^4$, $r_{mesh}$=91 and aspect ratio of 3.9. The operational regions of current-driven mode free RFP configuration are given between the internal and the external mode stability boundaries as shown in Fig. 3. Typical results are [5]:
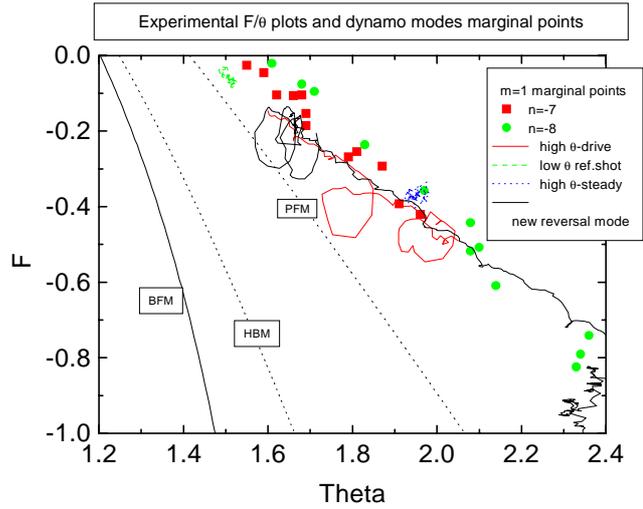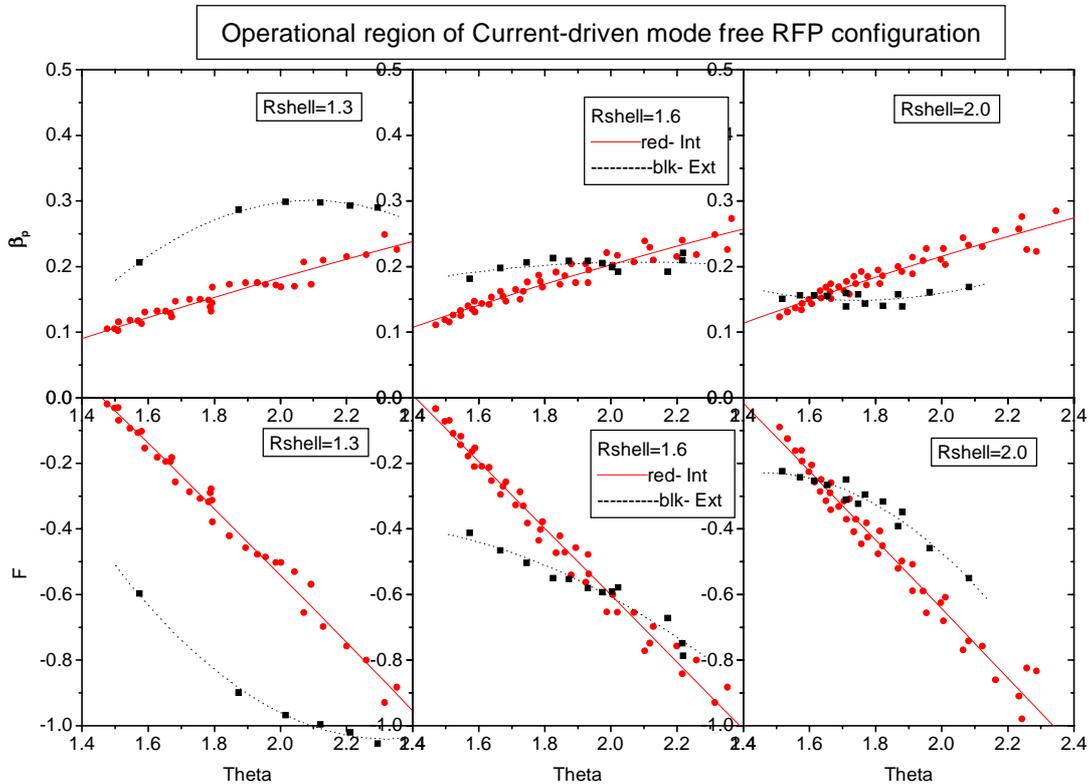


**Fig. 3.** Operational regions of current-driven mode free RFP configuration with $\beta_p$ on perfect shell position. Regions are stable against both m=1 internal mode (red) and external mode (black).

(1) Current-driven mode free RFP configurations are possible with a lose-fitting perfect conducting shell. Maximum perfect shell positions is $r_{shell}/a$ of 2 with $\beta_p$ of 0.14 against both m=1 internal and external modes, while maximum $\beta_p$ of 0.3 is possible if $r_{shell}/a$ is located closer at 1.2 as shown in Fig. 4. (2) In case of OH sustained experimental RFP configuration described before, $r_{shell}/a$ of 1.15 is the limit against the resistive shell mode as shown in Fig.5 and the $\beta_p$ is lowered around 0.12. (3) Resistive wall with resistive shell time constant of $< 10^{-3}$ has almost no effect as the stabilizing shell to MHD modes, which is also shown in Fig. 5.
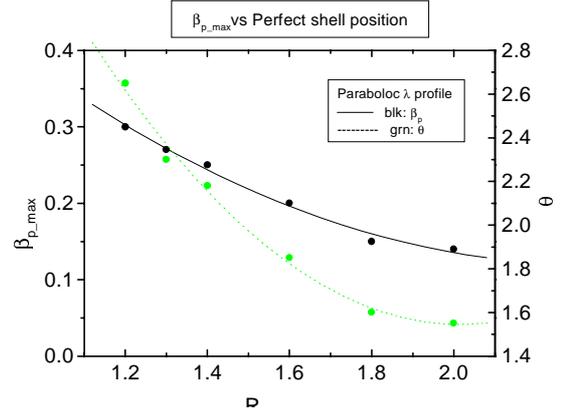


**Fig. 4.** Maximum $\beta_p$ vs perfect shell position for current-driven mode free configuration.
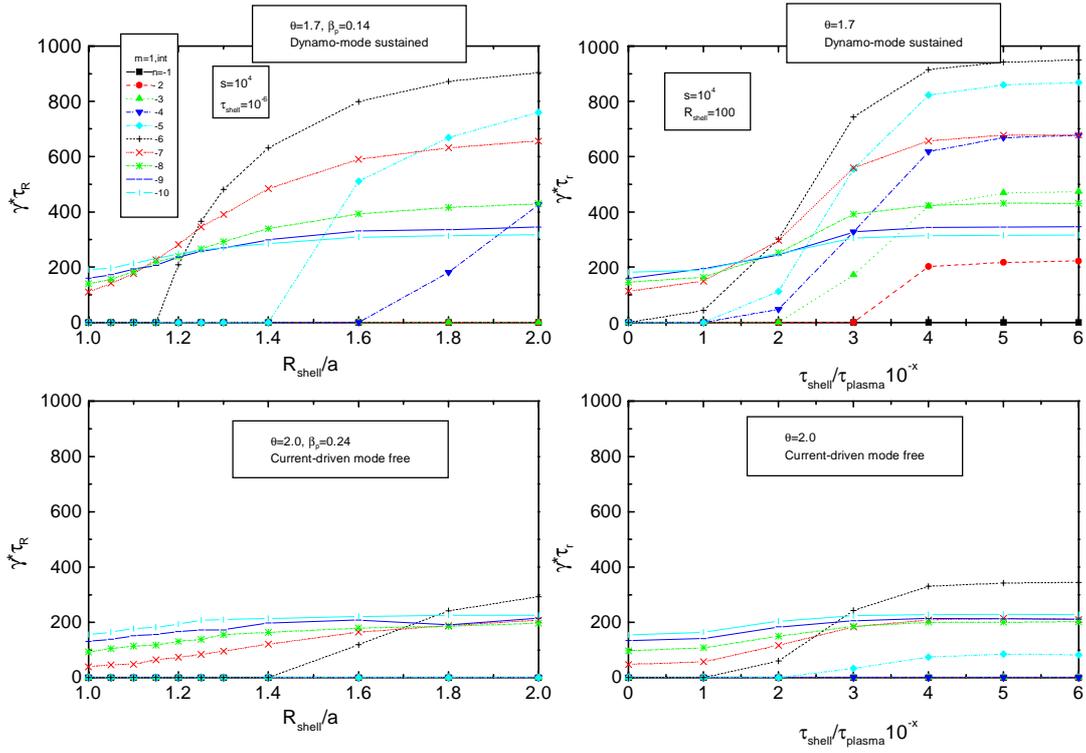


**Fig. 5.** Linear growth-rates vs perfect shell position and resistive shell time constant

## 3. S scaling of linear growth-rate

Dependency of modes on Magnetic Reynolds number in the code is briefly checked.

**On dynamo-mode:** The tearing mode without plasma pressure scales as $S^{2/5}$ when $S<10^6$. While the pressure is inflated, the mode scales as $S^{2/3}$ like the resistive g-mode. When the mode becomes non-singular, the mode scales $S^{1.0}$ as ideal MHD mode. The linear growth-rate has maximum at the mode's singular moves just the plasma center off.

**On resistive g-mode:** The resistive g-mode scale as $S^{2/3}$ when $S<10^6$. If the pressure is inflated much higher than Suydam condition, i.e. Suydam unstable, the mode scales as $S^{1.0}$ like ideal MHD mode. The m=0 mode has lower growth-rate than the m=1 mode. When S is larger than $10^6$, any mode scales as $S^{1.0}$ in this code.

## 4. $\beta_p$ scaling by resistive g-mode

Current-driven mode free RFP is possible, but there still remain the resistive g-modes in RFP plasma. The linear growth-rate of resistive g-modes is studied to get a $\beta_p$ scaling on S. Result shows that the linear growth-rate of g-mode is proportional to $\beta_p$ as $\gamma(\tau_R^{-1})=4.3*\beta_p*S^{2/3}$, while the growth-rate increases more rapidly in case of the higher $\beta_p$ than the Suydam limit.

In Fig. 6, the linear growth-rate of m=1/n=-32 g-mode vs. $\beta_p$ is shown. A simple model that the loss rate by the



**Fig. 6.** Linear growth-rates of m=1/n=-32 resistive g-mode vs. $\beta_p$.

several times of the linear growth-rate above is balanced with joule input power derives a scaling of $\beta_p\sim a^{-2/5}*ip^{-4/5}$ for g-mode. If heating power is higher enough than the loss rate, $\beta_p$ is limited by the Suydam condition.

## 5. Summary

The stabilities of RFP plasma configurations are studied by comparing the linear growth-rate of MHD modes. In the experimental configuration sustained by the dynamo-mode, the shell proximity of 1.15 is a very sever condition and the $\beta_p$ is limited to low value. In the case of the current-driven mode free configuration, higher $\beta_p$ is possible with lose fitting shell of 1.6. The $\beta_p$ scaling deriving from turbulence driven by the resistive g-mode balanced with ohmic heating power implies decreasing $\beta_p$ in larger RFP devices. Suppression of turbulence will be necessary.

## References

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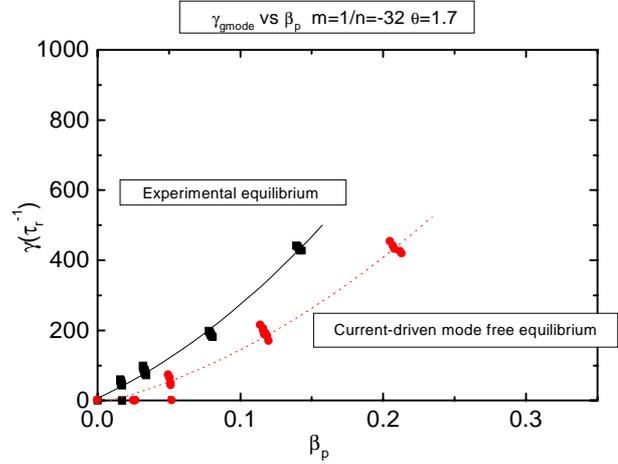[5] Y. Maejima, H. Ashida: pThpP3.29, *APS_DPP97* (1997).