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Loop Voltages of Reversed Field Pinch Plasmas with Resistive Shell

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1. Introduction

Loop voltages of reversed field pinch(RFP) plasmas are studied using a resistive MHD stability code[1] in the linearly growing phase of MHD mode. The experimental RFP plasmas are operating just on the boarder of the stability boundary of MHD modes near the plasma center [2], which sustain the RFP equilibrium configuration as "dynamo action", the MHD dynamo model. The loop voltage of RFP increases with poor shell proximity as the growth-rate of dynamo modes increase quickly. Fully nonlinear calculations give the loop voltage of steady state RFP configurations sustained by the dynamo mode [3].

2. Evaluation of loop voltage

To evaluate the loop voltage dependency on the shell proximity by a linear calculation, the poloidal electric field created by the dynamo mode and that of the equilibrium resistive component is balanced. Then the increased toroidal electric field at the plasma center by the $\int E_{\theta\mathrm{mode}}\, dr = \int E_{\eta j_\theta}\, dr \quad \Rightarrow Ez(0)(\equiv E_{z,\mathrm{mode}}(0) + \eta j_z(0))$ mode is defined as the loop voltage increase. It should be noted that $E_\theta(r)$ is not necessarily match in this case. Fig.1 shows the normalized toroidal electric field, $Ez(=Ez_{mode}+Ez_{\eta j0})/Ez_{\eta j0}$, dependence on the perfect shell position without the resistive shell. An equilibrium configuration similar to the experimental result is created by the α model [4], θ/F=1.9/-0.38(θ_0/α =1.9/2.3) with β_p =0.15. The magnetic Reynolds number of 10^4 is used in the calculation. A single m=1/n=-7 mode selected is the non-resonant dynamo mode. The resistive shell has the stabilizing effect on fast mode phenomena. The resistive shell is not included here as it has no effect in the nonlinearly saturated state. As seen in Fig.2 and 3 when the perfect shell moves away from the plasma surface, the $E_{\theta mode}$ quickly decreases its amplitude and moves the peak position out, while Ez_{mode} is not changed much. The $\langle b_r x v_z \rangle$ term of the $E_{\theta mode}$ decreases the amplitude and the $\langle b_z x v_r \rangle$ term, which has opposite sign, increases. Here b_r, b_z, v_r and v_z are mode components. The main reason is that the b_r decrease and the v_r increase with moving the boundary condition out. As the result the dynamo-mode efficiency on creating the poloidal electric field drops in the poor shell proximity condition. As the mode amplitude becomes larger to keep the required poloidal electric field, higher loop voltage is necessary to sustain the plasma current.

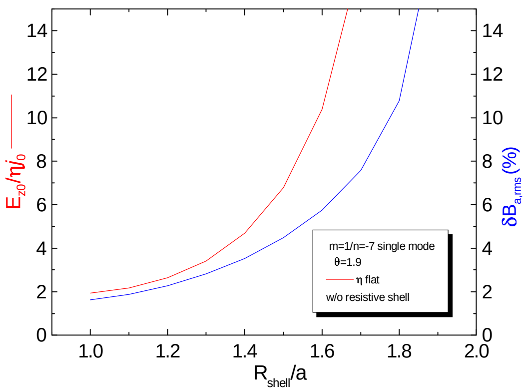

Fig.1 Loop voltage increase on perfect shell position.

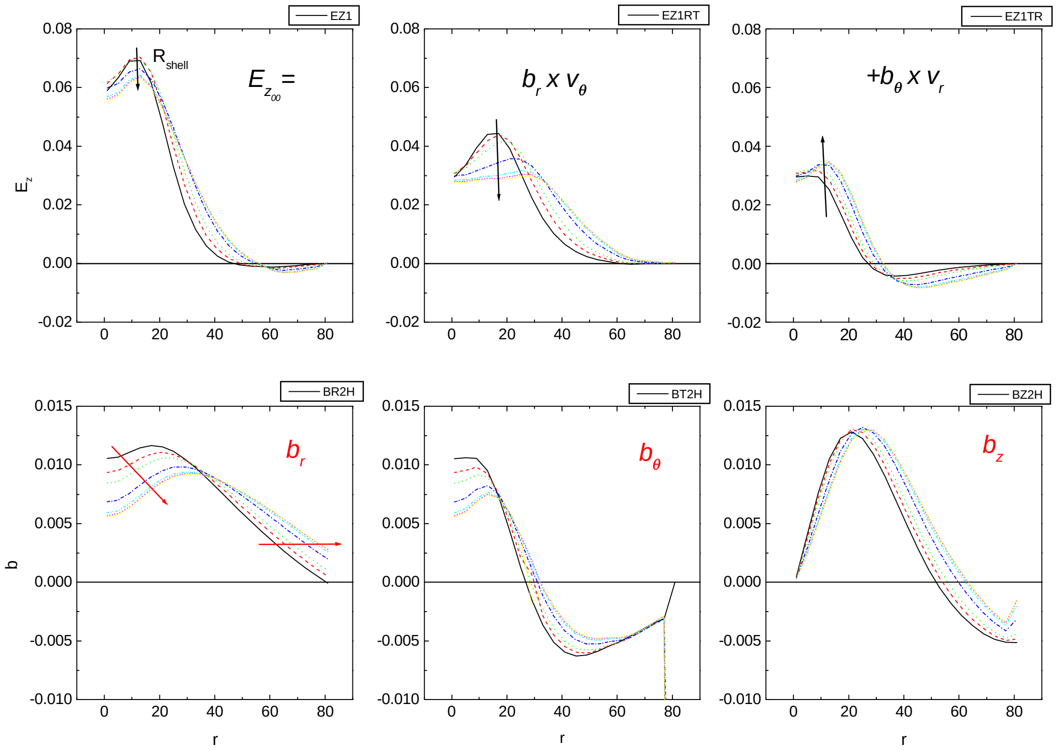

Fig.2 Toroidal electric field driven by mode and its component.

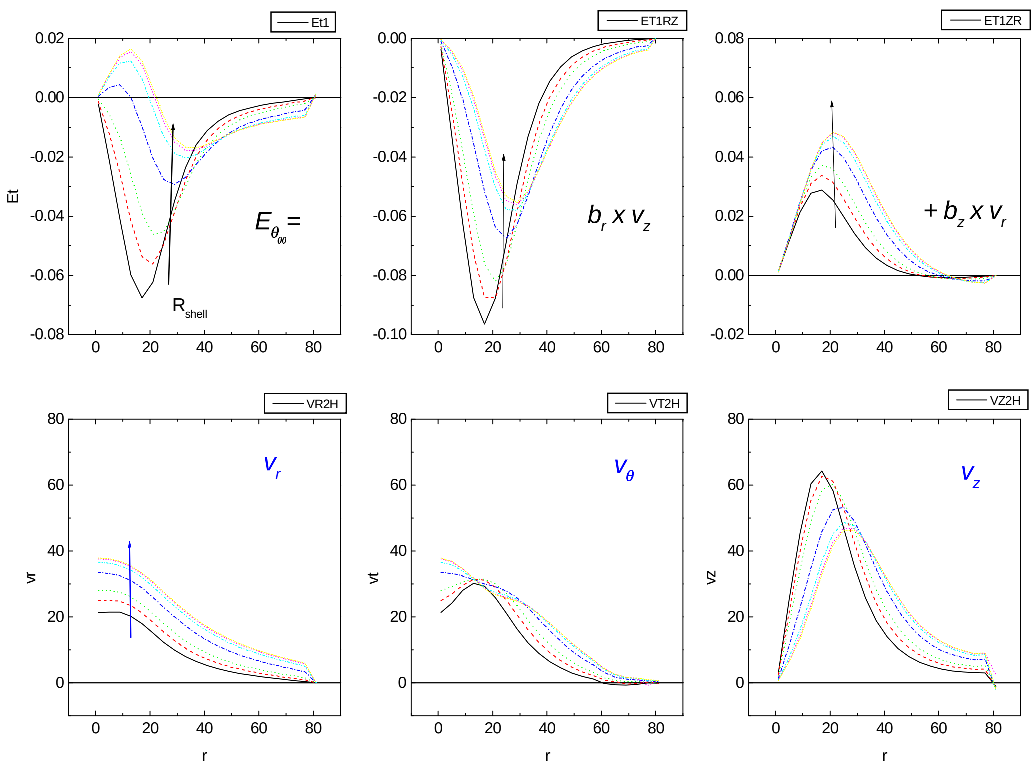

Fig.3 Poloidal electric field driven by mode and its component.

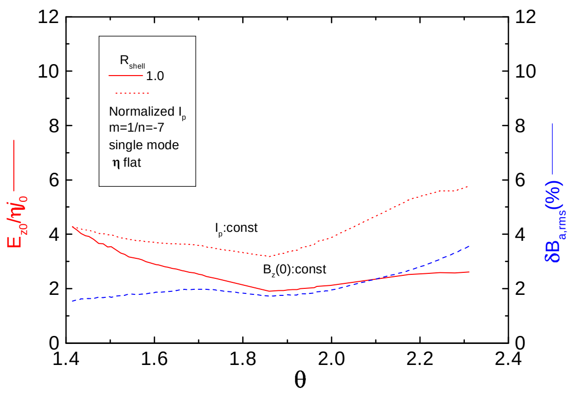

Fig.4 Pinch ratio dependence of loop voltage.

3. Pinch-ratio dependence

The pinch-ratio θ dependence of the loop voltages is studied. Equilibrium profiles are those described in ref.[2]. As shown in Fig.4 $E_{z0}/\eta j_0$ has minimum of 2 around θ=1.9 where the mode m=1/n=-7 is on- axis mode. Here $B_z(0)$ keeps constant in the profile change when varying θ. It is clearly seen that the efficiency of creating ploloidal electric field has maximum in the case of on-axis mode. The dotted line shows the case of plasma current keep constant. The loop voltage in θ between 1.4 and 1.9 are almost constant of 3.5-4 ,which qualitatively has good agreement with the experimental result in TPE-1RM20.

4. Effect of resistivity profile

E_{z0} is converted to E_θ by the dymano-mode. Large E_θ is required at the plasma edge with low edge temperature and the loss of poloidal current by the edge plasma turbulence. It results in large loop voltage in RFP. Fig.5 shows the effect of the shell proximity, same as shown in Fig.1,in this case with including the effect of edge resistivity profile used in ref.[3]. It is clearly seen that high edge resistivity results in large loop voltage increase. A comparison of E_{z0} with the effect of R_{shell}, perfect and 1.2 , is shown in Fig.6 on the pinch-ratio θ with the parameter of resistivity profile *n*. In poor shell proximity case the edge resistivity has much larger effect. Introducing the parameter of resistivity increment defined by

$$\delta\eta_{90} = \int_0^{0.9} (\eta - \eta_0)/\eta_0 \, dr$$

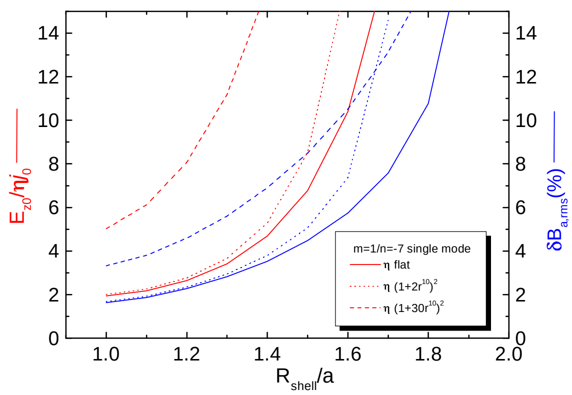

Fig.5 Loop voltage on shell position with plasma edge resistivity profile.

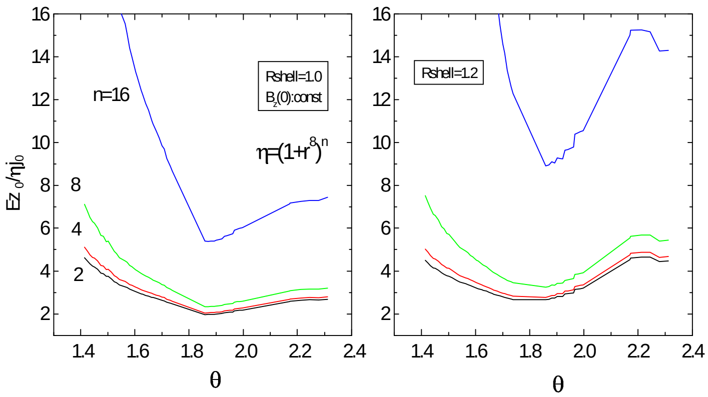

Fig.6 Loop voltage on pinch ratio with plasma edge resistivity profile.

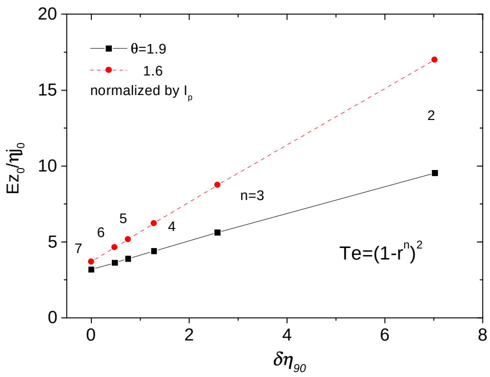

Fig 7 Loop voltage increase on edge resistivity increment.

E_{z0} increase linearly with the resistivity increment as seen in Fig.7. The importance of low edge resistivity in RFP is clear. The loss of edge poloidal current observed as the high heat asymmetry in experiment is equivalent to the high resistivity at the plasma edge.

5. Summary

Loop voltages of reversed field pinch(RFP) plasmas has been studied using the resistive MHD stability code.

(1) The result on the shell proximity is that loop voltages abruptly increase when R_{shell}>1.4-1.5. As the boundary condition of the stabilizing shell moves out, the efficiency of creating poloidal electric field decreases and the loop voltage required sustaining the poloidal current in equilibrium should increase.

(2) Result on the pinch-ratio dependence of the loop voltage shows good agreement with the experimental result in TPE-1RM20.

(3) Edge plasma resistivity has larger effect on the loop voltage than the shell proximity.

(4) The loop voltage increases proportionally with the edge resistivity increment.

(5) From the result of calculation experimental loop voltage suggests very flat edge resistivity profile that is very different from Thomson scattering result. This means that the electron velocity distribution at the plasma edge seems to be in the slide-away condition as observed in soft x-ray measurement.

(6) In TPE-1RM20 $E_{z0}/\eta j_0$ is around 15 with Z_{eff} of 1–2. In experiment much higher loop voltage than in the calculation is required. The helicity leakage by the edge turbulence, as observed by the large heat asymmetry at the plasma edge, could be responsible, which brings the edge resistivity increase equivalently.

References:

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