MHD Issues in Low-A RFP Machine RELAX

S. Masamune, A. Sanpei, R. Ikezoe, T. Onchi, K. Oki, T. Yamashita, H. Shimazu, H. Himura, N. Nishino\textsuperscript{1)}, R. Paccagnella\textsuperscript{2)}

\textit{Kyoto Institute of technology, Kyoto, Japan}
\textsuperscript{1)}\textit{Hiroshima University, Higashi-hiroshima, Japan}
\textsuperscript{2)}\textit{Consorzio RFX, Padova, Italy}
REversed field pinch of Low-Aspect-ratio eXperiment

- $R/a = A = 2$
  (51 cm/25 cm)

- Optimization in progress

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Normal RFP discharges established

- Ip (kA)
- Voop (V)
- Bt-wall (mT)
- \(\langle B_t \rangle \) (G)

Time (ms)

\(~ 30 \, V\)
• Experimental study on advantages of low-\( A \) RFP configuration
- Improved confinement with QSH for achieving high beta
- Experimental identification of bootstrap current
  (target parameters: \( T_e \sim 300\text{eV}, \ n_e \sim 4 \times 10^{19}\text{m}^{-3} \) at \( I_p \sim 100\text{kA} \))
Tearing and RWM play important roles in the RFP configuration and sustainment through nonlinear MHD phenomena.

Nonlinear MHD Phenomena:
- Relaxation
- Dynamo
- Magnetic reconnection
- Magnetic chaos
- Ion heating
- Momentum transport

RFP Configuration (Global structure)

MHD Instabilities

- Formation and sustainment of the configuration through nonlinear MHD
- Of general interest as a control problem of highly nonlinear system
Lower $A$ means lower $n$ for dominant $m = 1$ modes.
Quasi-periodic growth of a single dominant helical mode \((m=1/n=4)\)

Spectral index \(N_s\)

Characteristic of the QSH RFP state: lower dominant mode number (mostly \(n = 4\)) and higher amplitudes than in other RFPs.
Dominant helical structure observed with high-speed camera

Filament structure indicates simple structure of plasma parameters $\rightarrow$ effect of lowering $A$
Possibility of rotating Helical Ohmic Equilibrium state
- A large-scale magnetic field profile change -

- Quasi-periodic oscillation between reversed and non-reversed states
- Similar large-scale oscillatory behavior in $B_r$ and $B_\theta$

![Graph showing time series data of magnetic fields and plasma current](image.png)
Measured field profile agrees well with Helical Ohmic Equilibrium state with closed helical flux surfaces

\[ B = B^{(0,0)} + b \]

**Theory**

**Numerical solution of Helically symmetric RFP equilibrium**

Flux surfaces recovered!

**Experiments**

\[ B^{(0,0)} : \text{Low-frequency (} f < 2 \text{kHz}) \text{ component} \]

\[ b : b = B - B^{(0,0)} \]

Excellent agreement may be an indication of rotating Helical Ohmic Equilibrium state

R. Paccagnella, IEA / RFP Workshop 2000
3D MHD simulation can reproduce major MHD characteristics of RELAX plasmas.

Fig. 1: $F$ vs. time, light blue curve refers to the ideal wall while the other curves are the resistive wall cases.
MHD simulation reproduces quasi-periodic oscillation of the dominant $m=1/n=4$ mode

Oscillating behavior of the tearing part of the spectrum ($m=1/n=4, 5, \ldots$) in RELAX can be compared with 3D MHD simulation with ideal wall boundary condition.
- due to mode rotation
- due to short discharge duration

Fig. 2: Radial mode energy vs. time for the ideal wall simulation.
MHD simulation predicts RWM will be problematic for longer pulse operation

Fig. 6: Radial mode energy vs. time for the RW simulation with $\tau_w = 0.02$ ($P=30$, $S=3 \times 10^4$).
Experimental implication of RWM in RELAX

Br (m=1/n=2) measured on the outer surface of the vacuum vessel.

Growth rate vs. na/R of external kink modes for α-Θ₀ model profiles

\[ \frac{\tilde{B}_r(a)}{B_p(a)} \approx 1 - 1.5\% \]

\[ \Rightarrow I_p \text{ starts decreasing} \]
MHD control plans in RELAX

- Discharge performance improvement:
  - $I_p \sim 100\text{kA}$, $\tau: \sim 2\text{ms} \Rightarrow 5\text{ms}$ (within present capability)
    - Static helical perturbation
  Further improvement will require improved magnetic boundary:
    - feedback control system

Another means for confinement improvement (current profile control, e.g.) may be necessary
Conclusion

• RFP plasma with MHD properties characteristic to low-$A$ configuration attained in RELAX
• Dominant mode with lower n realized
• Simple helical structure observed
• Possible Helical Ohmic Equilibrium state demonstrated
• 3D MHD simulation could reproduce most of the characteristics
Growth of dominant mode is related to mode rotation

**m=1/\(n=4\) mode behavior:**

- Longer QSH period for slower rotation
- Shorter QSH period with higher spectral index \(N_s\) for faster rotation