Oscillating Field Current Drive in the MST Reversed Field Pinch

J.S. Sarff¹, A.F. Almagri¹, J.K. Anderson¹, A.P. Blair¹, D.L. Brower², B.E. Chapman¹, D. Craig¹, H.D. Cummings¹, B.H. Deng², D.J. Den Hartog¹, W.X. Ding², F. Ebrahimi¹, D.A. Ennis¹, G. Fiksel¹, S. Gangadhara¹, K.J. McColam¹, P.D. Nonn¹, R. O’Connell¹, J.A. Reusch¹, S.C. Prager¹, and the MST Team

¹University of Wisconsin, Madison, WI USA   2) University of California, Los Angeles, CA USA

Abstract—Oscillating Field Current Drive (OFCD) is an inductive current drive method which could sustain a DC plasma current without magnetizing flux accumulation. Its application in the reversed field pinch (or possibly other magnetic configurations) could provide the means to sustain a steady-state reactor plasma with Ohmic current drive efficiency. We report MST experiments in which 10% of the plasma current is driven by OFCD. The magnitude of the driven current agrees with theoretical expectations, but interestingly the maximum current does not occur for a relative phase of the oscillators which produces maximum helicity injection. The OFCD current drive efficiency is 0.1 A/W, which is about the same as that for conventional Ohmic induction. Magnetic fluctuation amplitudes from MHD tearing modes are found to depend on the relative phase, with the minimum amplitudes occurring with maximum current drive.

Current sustenance is especially challenging for the RFP

• Large plasma current required (poloidal field dominant)
• Pressure-driven current is relatively small
• If dynamo is required, it must be capable of confinement requirements

Options:
• Inductive Oscillating Field Current Drive (AC helicity injection) ➔ this poster
• Low-BT pulsed reactor likely better than PULSAR (pulsed tokamak study)

Summary

• Oscillating Field Current Drive (OFCD) increases current by 10% in MST
  – Ohmic current drive efficiency ~ 0.1 A/W
  – Maximum current does not occur at maximum helicity injection
  – MHD tearing amplitudes depend on the relative oscillator phase
• Nonlinear resistive MHD computation demonstrates OFCD
  – Dynamo-relaxation via MHD tearing, similar to conventional induction in the RFP
  – Tearing amplitudes not substantially larger
  – AC modulation amplitudes expected small at very high Lundquist number (but not small for present-day RFP plasmas, making OFCD experiments challenging)
• Oscillators being upgraded for higher power to test larger current drive by OFCD

AC magnetic helicity injection = Oscillating Field Current Drive

- Magnetic helicity balance:
  \[
  \frac{dK}{dt} = 2K\Phi - 2E \cdot B_0 / \nu = \text{magnetic helicity}
  \]
  \[
  \Rightarrow \text{apply oscillating } V_P \& \Phi:
  \]
  \[
  V_P = V_P \sin(\omega t + \Phi) \quad \text{&} \quad \Phi = V_P / \omega \sin(\omega t + \Phi)
  \]
  \[
  \delta = \text{Phase}(V_P, V_P)
  \]

(NOTE: Conventional induction maintains helicity via steady Ohmic loop voltage \( V_L = \frac{I}{R} R_1 \))

Oscillating pinch velocity produces parallel induction

- Separate AC and DC parts
  \[
  B = B + \Phi
  \]
  \[
  \text{AC cycle amp. avg.}
  \]
  \[
  V_P \cdot B = \frac{1}{2} B^2 \Rightarrow \Phi = \frac{1}{\omega} \frac{dV}{dt}
  \]
  \[
  \text{mean-field pinch}
  \]
  \[
  \text{parallel induction}
  \]

Nonlinear 3D resistive MHD computation demonstrates OFCD

- Lundquist number \( S = 5 \times 10^6 \), cylindrical geometry (DEBS code)
- Flux modulation: \( V_P = J_0 \sin(\omega t + \Phi) \)
- Energy balance with “rigid” current profile models inductive evolution at very high \( S \):
  \[
  \frac{d}{dt} \left( \frac{1}{2} B^2 dV \right) = -V_P \cdot B + J_0 \sin(\omega t + \Phi) \frac{dV}{dt}
  \]
  \[
  \Rightarrow \text{input power}
  \]
  \[
  V_P \cdot B = J_0 \sin(\omega t + \Phi) \frac{dV}{dt}
  \]
  \[
  \text{describe loop voltages for OFCD}
  \]
  \[
  \text{Evolve 1D equilibrium:}
  \]
  \[
  \frac{dV}{dt} = \lambda_0 J_0 + \lambda_1 (J_0^{\alpha})
  \]

Energy balance with “rigid” current profile models inductive evolution at very high \( S \):

- \( J_0 = \text{standard PPCD range} \)
- \( \lambda_0 = \text{standard PPCD range} \)
- \( \lambda_1 = \text{positive constant} \)
- \( \rho = \text{negative constant} \)
- \( S = \frac{V_P}{B_0} \rho \)

Maximum current drive not at maximum helicity injection

- Fully relaxed plasma with constant resistivity would have \( \Delta J = \text{max} \Rightarrow \Delta \Phi = \pi \)
- Instead, peak current with \( \Delta \Phi = \pi / 8 \)

Partial Current Drive by OFCD in MST

- Two resonant L-C tank oscillators provide 280 Hz loop voltages
  - Each ~1 MVA (insufficient for 100% OFCD)
  - Background steady induction maintained
  - Relative phase controlled by turn-on time
  - Novel pre-charge of tank capacitor ➔ “instant” high power turn-on
  - Tank switching using ignitrons

Current increased 10% with OFCD

- Added current = 20 kA
- Absorbed power = 200 kW at max. drive
- L/R saturated \( I_J \) increase projected 15%

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