Non-Solenoidal Tokamak Startup Using High-Field-Side Local Helicity Injection on the Pegasus ST

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A New Campaign Studies Local Helicity Injection (LHI) Using High-Field-Side Injectors

- Current drive quantified by:
  \[ V_{LHI} \frac{A_{\text{inj}} B_{\text{inj}}}{V_{\text{inj}}} \]

- Edge current extracted from injectors
- Relaxation to tokamak-like state via helicity-conserving instabilities

I_p ≤ 0.2 MA (I_{\text{inj}} ≤ 8 kA)
Injector Geometries Emphasize Different Current Drives

**Low-Field-Side Injection:**
- Injectors on outboard mid-plane
- High $R_{\text{inj}} \rightarrow$ low $V_{\text{LHI}}$
- Dynamic shape $\rightarrow$ strong $V_{\text{IND}}$

**High-Field-Side Injection:**
- Injectors in lower divertor
- Low $R_{\text{inj}} \rightarrow$ strong $V_{\text{LHI}}$
- Static shape $\rightarrow$ minimal $V_{\text{IND}}$
1. Instability of current filaments
   - Long wavelength, low frequency:
     • Line-tied kink
     • Filament merger and reconnection
     • Dominates external magnetics
   - Short wavelength, high frequency:
     • Correlated with anomalous ion heating
     • Reconnection-driven turbulence?

2. Instabilities of the tokamak plasma
   • Tearing, kink modes
   • Relevant to hand-off
Abrupt Transition in MHD Behavior During HFS Injection

• Large-amplitude, low freq. in early phase
  – Large scale n=1 at 20-80 kHz
  – Line-tied kink of current streams

• Abrupt reduction in low frequency activity under some conditions:
  – $I_p$ growth continues
  – Interpreted as kink stabilization

• Several hypotheses for stabilization mechanism under consideration
Shift to High Frequency Inside Plasma Edge Suggests Short Wavelength Current Drive Mechanism

- **External Measurement** ($R > R_{\text{edge}}$)
  - Reduction at all frequencies
  - Suppression of large $n=1$ mode
  - Remaining $\tilde{b}/B$ similar to L-mode

- **Internal Measurement** ($R < R_{\text{edge}}$)
  - High-$f$ activity increases after transition
  - Turbulence, reconnection on smaller scale?
  - Continued $I_p$ growth suggests short wavelength activity drives current
$I_p$ Increases Linearly with $V_{LHI}$ when $V_{IND} \sim 0$

- Static plasma geometry $\rightarrow V_{IND} \sim 0$
  - Linear $I_p$ scaling suggests fixed $\langle \eta \rangle$
  - $Z_{eff}$, $n_e$, plasma geometry effects not yet accounted for

- Greater current drive efficacy following MHD transition
  - Low MHD: up to 50% more $I_p$
  - Relationship to confinement?
Confinement Properties Set Current Drive Scaling for LHI

- HI balanced by resistive dissipation
  - $\langle \eta \rangle$ influenced by confinement
- Crude estimates of confinement inform operation space
  - Strongly dependent on $Z_{\text{eff}}$
- Resistive dissipation complicated by:
  - Dual confinement zones?
  - Neoclassical trapping, non-thermal electrons
  - Hyper-resistivity?
High-Field-Side LHI at A~1 Provides Access to $\beta_T \sim 1$

- **A~1:**
  - Naturally high $\kappa$
  - High $I_N$ stability limit

- **HFS LHI: unique operation space**
  - High $I_p$ possible at low $I_{TF}$
  - $I_N = 5A\frac{I_p}{I_{TF}} > 10$ accessible
  - Naturally low $\ell_i$
  - Strong auxiliary ion heating

- **See invited talk Thursday AM**
  - T13.00004, J.A. Reusch

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High-Field-Side LHI Builds the Physics Basis for High-I\textsubscript{p} Non-inductive Startup and Sustainment

- High-field-side LHI: increased $V\textsubscript{LHI}$, reduced $V\textsubscript{IND}$
- Novel MHD behavior suggests short wavelength current drive mechanism
- Attainable $I\textsubscript{p}$ scales with $V\textsubscript{LHI}$; confinement under investigation
- $\beta_T \approx 100\%$ using unique properties of HFS LHI at $A \sim 1$

See Pegasus posters: Thursday PM