Topological Transition and Inductive Current Drive of a Translated Field-Reversed Configuration

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As one of the tools to study “CT related” plasma physics, we have demonstrated application of a center structure onto a conventional theta-pinch FRC.

The series of experiments have been conducted on the FAT facility which has a theta-pinch type formation and large bore confinement region with transparent quartz chamber.
This development has been conducted for following CT related subjects.

1. Extend FRC’s lifetime by the current drive.
2. Amplify the poloidal flux to confine tangentially injected fast beam ions.
3. Study the effect of topological difference between simply-connected and torus geometry on stability.
4. Stability and relaxation study from high-beta theta-pinch FRC side.

This technique can be a tool to form High-beta ST from FRC side.

**Motivations**

Fig. 2 $q \Psi - p \Psi$ diagrams of (a) conventional tokamak (aspect ratio $A \approx 5$),
(b) low aspect ratio tokamak (ST) ($A < 1.5$).
Translation Facilities at Nihon Univ

<table>
<thead>
<tr>
<th></th>
<th>NUCTE-T</th>
<th>FAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror Ratio</td>
<td>3 - 4</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>4.5</td>
<td>2.3</td>
</tr>
<tr>
<td>$B_0 [T]$</td>
<td>0.08</td>
<td>0.09</td>
</tr>
<tr>
<td>$r_c [cm]$</td>
<td>61</td>
<td>103</td>
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</table>

• “FAT” has a quasi-spherical boundary on the confinement region.

• With relatively higher mirror ratio, FRC expand radially while it keeps the length.
Demonstration of a FRC translation through a guide magnetic field.

On FAT, translation speed ranges from 80 - 220km/s in the current condition.

HS-106E, nac image technology inc., Max 1,250,000fps (0.8µs of repetition time)
A "cantilever" center solenoid is installed on the geometrical axis of a quasi-spherical confinement region.

<table>
<thead>
<tr>
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<th>$\varphi$ (mm)</th>
<th>Length (mm)</th>
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<tbody>
<tr>
<td>Liner</td>
<td>60.5</td>
<td>2100</td>
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<td>Outer layer</td>
<td>55</td>
<td>990</td>
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<tr>
<td>Inner layer</td>
<td>45</td>
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Sequence of Formation and Current Drive

- Confinement Region
- Formation Region
- Metallic chamber
- Quartz tube
- Mirror coil
- Gas puff
- Quasi-steady-state confinement coil
- Theta pinch coils

Graph showing current vs. time for Center Solenoid and Formation Section.
Injection of FRC into the torus boundary

- An FRTP-generated FRC is translated w/o any disruptive perturbation.
- The FRC with 10^{21} m^{-3} of electron density and ~ 40 eV in ion temperature is translated into the confinement region with a CS installed.

- The range of translation velocity is between 150 – 200 km/s.

⇒ CS amplifies poloidal flux (toroidal current), then a FRC dies quickly....

Time evolutions of (a) plasma radius \( z = 0.30 \) m and input current on a center solenoid.

![Graph](image-url)
Internal Magnetic Field Measurement

Specifications of magnetic probe

<table>
<thead>
<tr>
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<th>Bt</th>
<th>Pitch</th>
<th>Turn Number</th>
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<td>2ch</td>
<td>14ch</td>
<td>0.5</td>
<td>20</td>
<td>Al₂O₃</td>
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<tr>
<td>(top)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Magnetic probe array</td>
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<td>16ch</td>
<td>1.0</td>
<td>20</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td>(bottom)</td>
<td></td>
<td></td>
<td></td>
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</table>

Radial profile of toroidal and poloidal magnetic field is measured at two toroidal positions.
Internal magnetic field measurement shows increased reversed component of poloidal flux.
• Toroidal magnetic field is induced by OH current on the CS.
  ➡ Is this transient phenomena during a relaxation?
  ➡ It is maintained for several tens of alfven times.
Inductive Current Drive in a FRC

- How does the toroidal electric field work onto the electrons (and ions)?
- Conventional FRC only has poloidal flux and perpendicular diamag current.

⇒ $E_\theta$ cannot drive electrons directly into the toroidal direction.
Doppler spectroscopy doesn’t indicate any significant change in ion temperature and toroidal flow.

Toroidal flow is in the range of 2 - 4 km/s (about 1/10 of confinement region). Accelerated in the ion diamagnetic direction.

- Ion flow and temperature measures at $r = 15\text{cm}$ (magnetic axis).

- Larmor radius of deuterium ion is around 2 - 8cm in the FRC.
Inductive current drive in a FRC

- How does the toroidal electric field work onto the electrons (and ions)?
- Conventional FRC only has poloidal flux and perpendicular diamag (dominantly electron?) current.

- $E_\theta$ cannot drive electrons directly into the toroidal direction.
- Ion current is insufficient to build-up the observed poloidal flux.
Kink ($n = 1$) mode can be seen during and after translation process.

This can be a source of observed toroidal magnetic field.
Toroidal magnetic flux could form helical magnetic field structure.

Electrons can be accelerated along the helical magnetic field line by induced $E_\theta$.

This may be a reason of increased toroidal field by driven CS current.
A FRC which has simply-connected boundary can be translated into a confinement region with a center structure without disruptive perturbation.

Poloidal flux (toroidal current) is successfully induced by driven CS. However, it may change the magnetic configuration of FRC.

Toroidal magnetic field is also increased while the CS is being exited. The TF is maintained for several tens of alfvenic time.

The spontaneously generated toroidal flux potentially realize inductive current drive by induced toroidal electric field.

For further study, we have to maintain the FRC longer to observe relaxation process after the current drive.
- Collisional merging and low-frequency wave injection have been initiated at Nihon University as a heating and current drive technique.

- Because of its high beta (i.e. low magnetic field) nature, we choose low-frequency (~100kHz) range of wave.

- We will start with a pair of tandem type one-turn (n = 0) antenna.