Mitigation of Rotational Instability of the Field-Reversed Configuration via Edge-Biasing

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1. Abstract

- The rotational instability of the field-reversed configuration (FRC) has been shown to severely reduce the lifetime of the confined plasma.
- FRC plasmas have strong rotational modes from electric drift and ion-diamagnetic drift. Their nonlinear growth can cause plasma to scrape against the wall, resulting in loss of particles and energy.
- Edge-biasing refers to applied external fields that modify the rotation in the edge-layer of the plasma. By driven toroidal flow shear, the internal plasma is affected by the applied rotation in the edge-layer, which leads to improved stability, longer plasma lifetime, and better confinement.

2. Origin of the rotation

- FRC plasmas have strong rotational flow from the electric drift and ion-diamagnetic drift. The electric drift arising due to crossed electric and magnetic fields. The diamagnetic drift is a fluid drift due to pressure gradients.

3. End shorting

- Open magnetic field lines contact external boundaries.
- This causes a shorting effect and the transverse electric field is modified along the entire length of the field line [2].
- The transverse electric field causes an electric drift which modifies rotation in the edge layer.
- End-shorting does not effectively explain the particle-loss spin-up mechanism.

4. Toroidal spin-up

- The origin of toroidal spin-up has been postulated to be due to particle loss and end-shorting.
- Takahashi has shown by PIC simulations that poloidal flux decay can explain rotation at the separatrix [3].
- The rate of flux decay increases with greater values of anomalous resistivity.

5. Double-sided plasmoid injection

- Evidence for the mitigation suppression of the rotational instability has by double-sided plasmoid injection has been hypothesized [4].
- The plasmoids are formed in field-reversed theta-pinch (FRTP) formation chambers and merge in the center of the confinement chamber.
- Two types of plasmoid configurations were used, one with both toroidal and poloidal fields, and another with just poloidal fields.
- It was shown that while both configurations delay the onset of the instability, the poloidal only one injected plasmoid was better. Thus, it was postulated that the injected toroidal flux does not contribute to the effect of reduced spin-up.

6. Confinement enhancement at TAE

- From their edge-biasing experiments at TAE Technologies [5], they demonstrated improved FRC confinement times by factors of 2 to 4, and plasma lifetimes by factors of 1 to 4.
- To achieve this, they used plasma guns (Fig. 1) to apply radial electric fields in the plasma that were shown to have the capability to control FRC rotational instability.
- The electric field generated from the plasma gun created a azimuthal velocity shear in the edge layer possibly leading to improved confinement.

7. Collisional merging at the FAT-FRC facility

- The FAT Amplification via Translation (FAT-FRC) research facility is located at Nihon University in Tokyo, Japan.
- An aim of the experiment is to demonstrate active stabilization of rotational instability through plasmoid injection and edge-biasing.
- FRC plasmoids are formed at both ends of the confinement chamber using FRTP. They are translated to the center of the confinement chamber at speeds around 25km/s and combine to form a larger more stable FRC configuration (Fig. 2).

8. Experimental objectives

- Experimentally and theoretically verify the possibility of global and microscopic stability by edge biasing onto a collisional-merging FRC in the FAT-FRC facility.
- Radial electric field in positive and negative directions can be applied by the biasing from the end regions of formation chamber through the external guide magnetic field.
- We aim to study the stabilization mechanisms of both global and microscopic stabilization by driven toroidal flow shear and reduced spin-up.

9. Preparation of modified experimental setup

1) Upgrade the vacuum chamber
- To install biasing electrodes, we will add an extension chamber at both end regions of theta-pinch formation regions.

2) Design of the biasing electrodes
- The electrode has to apply different electric potentials onto magnetic surfaces to generate radial electric field. Therefore, coaxial layered electrodes will be designed and installed in the expansion chamber. Detailed design work including calculation of magnetic field structure will be conducted.

3) Diagnostics
- Following diagnostics are (going to be) installed for the proposed experimental campaign.
  - Ion Doppler spectroscopy: Radial profile of toroidal flow
  - Laser interferometers: Profile of electron density
  - Visible and UV tomography camera: Global structure and motion of FRCs
  - Fast camera: Overall structure of plasma
  - Bolometer: Radiated power density

10. Summary and Conclusion

- The rotational instability observed in FRC experiments severely reduces the lifetime of the confined plasma.
- FRC plasmas have strong rotational flow due to the electric drift and ion-diamagnetic drift.
- The origin of the rotational instability can be explained by the effect of end-shorting of the open magnetic field lines, and the particle loss spin-up mechanism.
- Active stabilization methods such as double-sided plasmoid injection can mitigate the growth of the rotational instability.
- Significant confinement enhancement was demonstrated by TAE Technologies through edge-biasing.
- Current research at the FAT-FRC facility aims to investigate the affect of edge-biasing using coaxial layered electrodes on global and microscopic stability of the confined plasma.

References