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Estimate of Fluctuation-Induced Electromotive Force in RELAX RFP
低アスペクト比RFP装置RELAXにおける揺動起因起電力の定量的評価

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In the reversed field pinch (RFP) configuration with aspect ratio A lower than 2, the neoclassical bootstrap current fraction can be increased to 20~30% at total β of 20~30% depending on the pressure profile, if the closed flux surfaces remain undestroyed. In RELAX, maximum central electron β_p of ~15% is achieved, and plasma parameters are close to this regime. In addition to the equilibrium reconstruction to estimate the bootstrap current, we are planning to estimate the local bootstrap current directly by estimating the electromotive force terms in the generalized Ohm's law. Methdos for experimental estimates are discussed.

1. Introduction

The RFP is one of the toroidal magnetic confinement systems for high β plasmas. The RFP configuration is characterized by the toroidal field reversal at the edge, which causes strong mageticshear. This toroidal field reversal can be sustained (against resistive diffusion) as long as the toroidal plasma current is sustained. This characteristic is often referred to as the self-organization. The resistive MHD instabilities play important roles in the self-organization process, and therefore, electromotive forces arising from turbulence are important in sustaining the current.

In the RFP configuration, plasmas can be confined with relatively weak external toroidal magnetic field, which results in efficient plasma confinement. One of the remaining issues is the method to sustain the toroidal (or parallel) current for steady state operation.

Some theories predict that the neoclassical effect becomes important as the aspect ratio is lowerd with increasing the β value[1]. Specifically, when the aspect ratio A is lower than 2, the neoclassical bootstrap current fraction can be increased to 20~30% at total β of 20~30% depending on the pressure profile, if the closed flux surfaces remain undestroyed. The fraction of 20~30% may be detectable experimentally. In the reactor-relevant regime, it is predicted that there exist an equilibrium with bootstrap fraction higher than 90% at total β of ~60% [2].

One of the motivations for low-A RFP research is related to the bootstrap current issues.

2. Generalized Ohm's law and turbulence induced electromagnetic force terms

In the RFP, the reversed toroidal magnetic field is sustained as long as the toroidal plasma current is sustained. The mechanism for current sustainment may be interpreted as follows. When we decompose the physical quantities (such as electric field, magnetic field, velocity field, current density, etc.) in averaged and fluctuating components, the generalized Ohm's law can be written down as follows,

$$\eta\bar{j} = \bar{E} + \langle\tilde{v}\times\tilde{B}\rangle - \frac{1}{en_e}\langle\tilde{j}\times\tilde{B}\rangle \tag{1}$$

where $\bar{j}$ is the mean (time-averaged) current density, $\bar{E}$ the mean electric field, and η the electric resistivity. The quantities with ~ are the fluctuating components. The bracket < > stands for the averaging over time. The second term in the right hand side is the MHD dynamo term, arising from nonlinear interaction of fluctuating velocity and magnetic fields, and the last term, the Hall dynamo term arising from nonlinear interaction of fluctuating current density and magnetic fields. Interaction between the fluctuating quantities generates current in the direction of the average current.

When we look at the eq.(1) carefully, we may notice that the bootstrap component of the current density might be estimated if we could measure each electromotive terms.

A small magnetic probe can be used to measure the magnetic field fluctuations, and A Mach probe can be used to measure the velocity fluctuations.

Either a small Rogowski coil or 4-point measurements of the magnetic fields could provide the current density fluctuations. We will be able to estimate the time-averaged quantities by statistical correlation analyses using these fluctuating quantities.

3. Experimental Apparatus

As a first step, we are preparing a dynamo probe to estimate the MHD dynamo term arising from interaction between velocity and magnetic field fluctuations in RELAX.

RELAX is an RFP machine with major radius of 0.5m and minor radius of 0.25m, the aspect ratio A being 2. The plasma parameters attained to date are as follows: toroidal plasma current I_p 40~120 kA, electron density n_e 10^{18}~2×10^{19} m^{-3}, Thomson electron temperature T_{e0} 100-200 eV. The discharge duration is ~3.5 ms.

The dynamo probe structure is shown in Fig.1. It consists of four pairs of electrostatic double probes, three triple probes, and a magnetic probe inside the ceramic shield. The four pairs of double probes provide electric field, electron temperature, and electron density. Three components of the flow is provided by the three Mach probes[3].

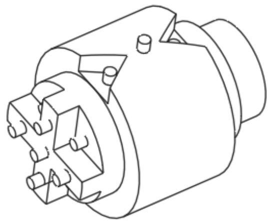

Fig.1. Structure of the complex probe to estimate the dynamo term.

Structures of some different types of complex probes will be discussed for experimental estimate of the turbulence-induced electromotive force terms.

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