Magnet Flux Surface Measurements Using Electron Beam Mapping in MUSE Permanent Magnet Stellarator

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July 2023

Abstract

The first result of flux surface measurements using electron beam mapping for the newly built permanent magnet stellarator at PPPL is presented in this work. The existence of good nested flux surfaces is confirmed. Qualitative agreement of the flux surface shapes with the design is demonstrated. ι profiles are measured by investigating rational flux surface locations with different toroidal field(TF) coil currents. Indications of existence of 1/5 islands on the 1/5 rational flux surface are reported. These measurements and analysis prepare us for the next steps in error field measurement and correction.

Keywords— Electron Beam Mapping, Stellarator, Permanent Magnets, Error Fields

1. Introduction

MUSE is a table-top stellarator recently constructed at PPPL[1] with planar circular coils and permanent magnets. It is testing the approach of using permanent magnets and simple coils to generate optimized stellarator magnetic field configurations to reduce cost and engineering complexity[2]. It is also designed to be the world's first quasi-axisymmetric stellarator[3].

Figure 1: MUSE *table-top stellarator*

This paper presents recent results on flux surface topology measurements on MUSE. The purpose is to demonstrate the existence of good flux surfaces, compare with numerical models, and prepare for quantitative error field measurements and correction as the next step.

Flux surfaces are measured using electron beam mapping[4]. This is a common method used on stellarators to measure the vacuum magnetic field topology. It uses a tangentially injected electron beam, which follows the magnetic field lines (Fig.2) to a high accuracy due to the small gyro-radius of electrons ($\rho_e \approx 0.2$mm at 180 eV and 1.5 kG). The flux surface shape is visualized using the same method as on W7-X[5] by taking long exposure images of electron beams striking either a swept fluorescent rod or background gas.

In section II, a short introduction to MUSE is given, then the experimental setup for electron beam mapping experiments is detailed. In section III, the results of flux surface mapping, iota profile measurements, and preliminary island measurements are presented. Finally, a conclusion and direction for future research is given in section IV.

2. Experimental Setup

MUSE is a table top stellarator of major radius 0.3m and minor radius 4cm (the circular cross section axisymmetric vacuum vessel is 7.5 cm in radius) with on-axis field about 0.15T, ι around 0.19, and two magnetic field periods. The device is divided into 4 quadrants toroidally (90 degrees each), as shown in Fig. 3. Opposite quadrants are identical, due to the periodicity, and are denoted as X (X1 and X2 resp.) and Y (Y1 and Y2 resp.). MUSE is stellarator symmetric. The symmetry axis goes along the X(or Y) symmetry planes(yellow dashed lines) marked in Fig.3. Each quadrant is rotationally symmetric around its toroidal mid-angle.

Figure 2: Electron Beam (False Color) in MUSE with background gas

Figure 3: Top down view of MUSE in electron beam mapping configuration

Fig.3 shows the top down view of MUSE with the apparatus for electron beam mapping. The electron emitter is placed in X2 port at the symmetry plane and the electrons are injected tangentially. Two sweeping fluorescent rods (Fig.4a) are placed in the X1 and Y2