Diamagnetic Loop Diagnostics in CMFX

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Abstract

The Centrifugal Mirror Fusion Experiment (CMFX) harnesses azimuthal rotation of plasma through an ExB drift caused by an imposed radial electric field to enhance plasma confinement within a magnetic mirror. The centrifugal forces caused by the rotation of the plasma, also change the total magnetic flux of the mirror. Four Diamagnetic Loops (DML) are wound around the outer wall of the vacuum vessel to measure these flux changes caused by the changing magnetic field. The voltage induced in the DMLs from the changing flux is then numerically integrated to obtain the magnetic flux. The magnetic field derived from the measured flux changes is used to estimate plasma density and assess plasma stability. Integration, filtering, and detrending of this data is necessary to obtain useful signals when high amplitude noise is present. Because of this noise, new DMLs were constructed with an increased number of turns. Each DML contains 4 turns and is constructed from 18 AWG copper wire. Cables are then attached to measure the induced voltage in the loops which is then sent to a digitizer for analysis. RF-shielding foil covers the DML windings to reduce the pick-up of electromagnetic noise. Details of the DMLs, processing algorithms, and sample data are presented.

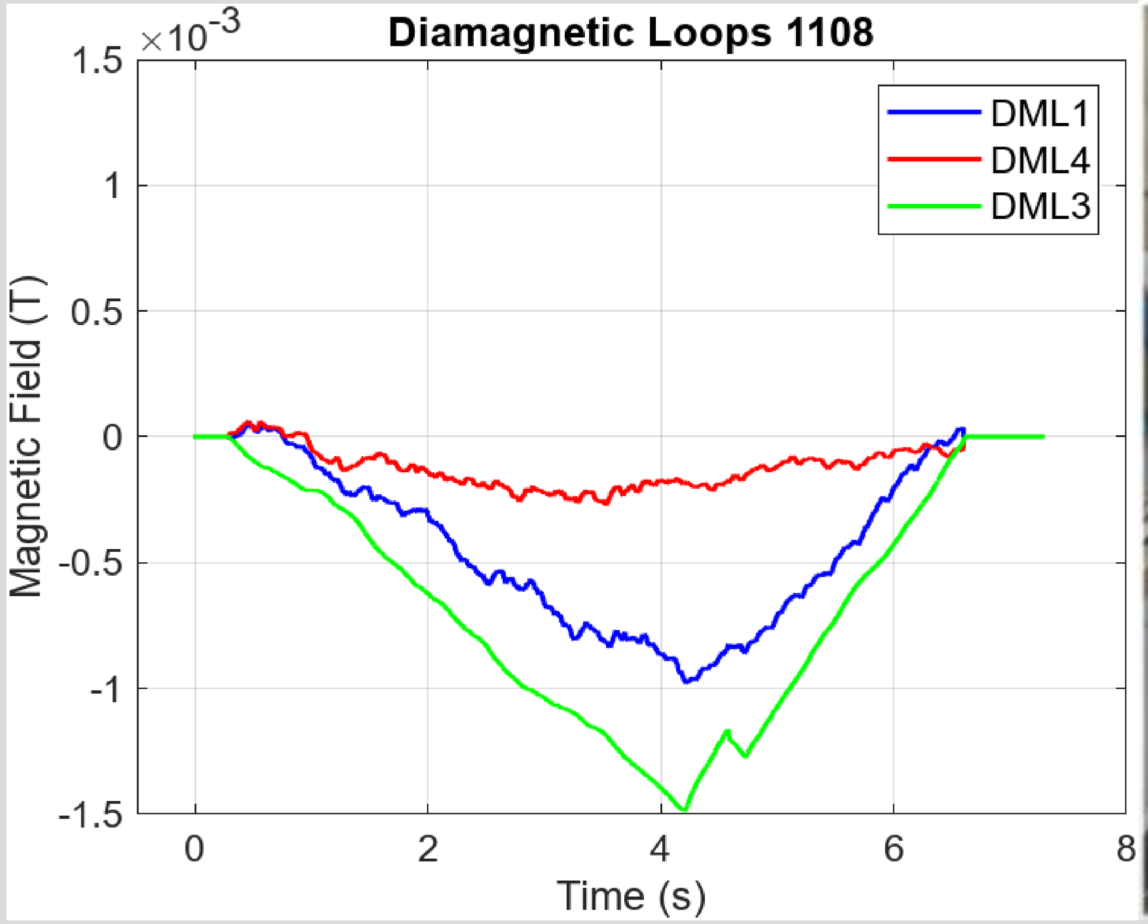
Introduction

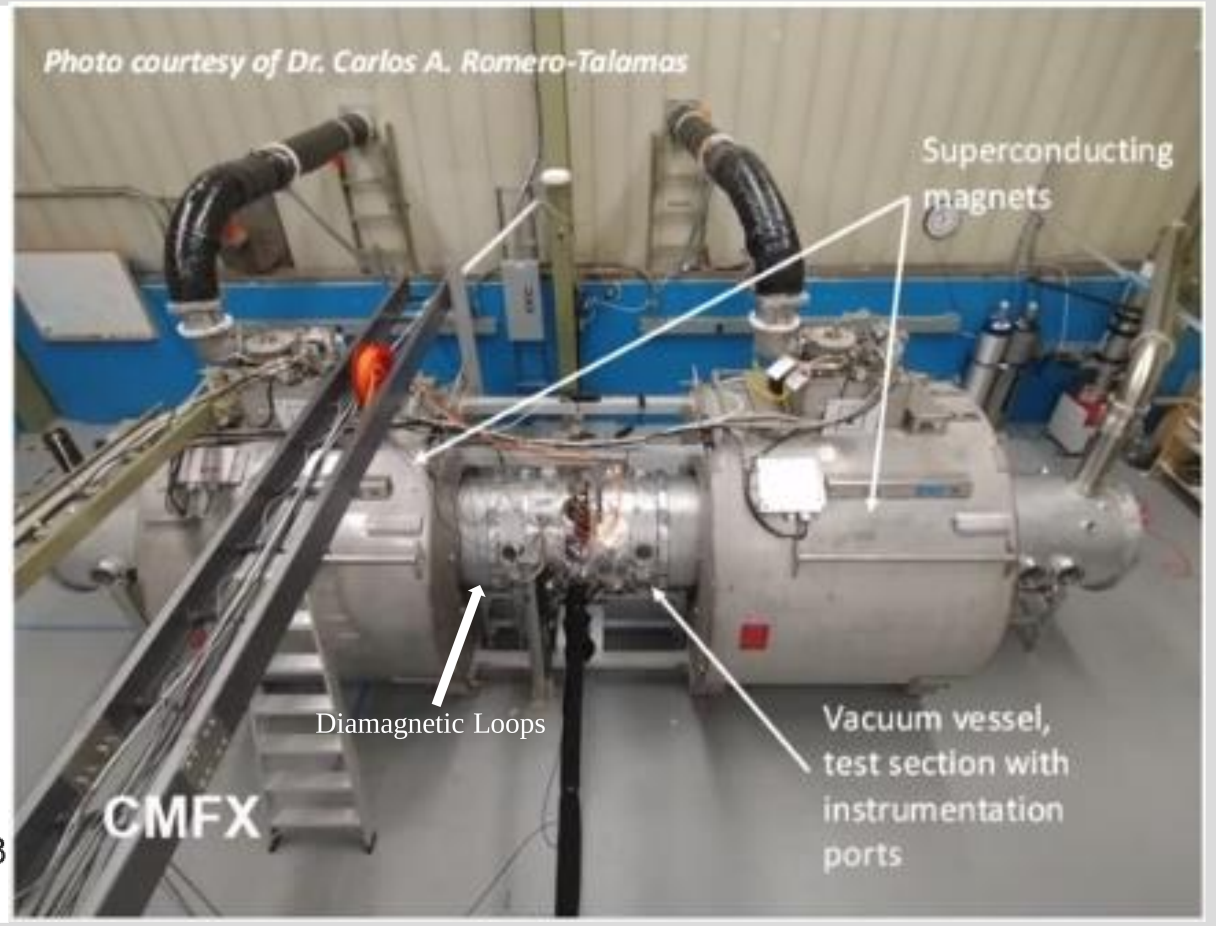
The Centrifugal Mirror Fusion Experiment (CMFX) aims to enhance plasma confinement through azimuthal rotation caused by an E×B drift. This process increases plasma density and stability within a magnetic mirror. Diamagnetic Loops (DMLs) measure changes in the magnetic flux of the plasma, providing essential insights into the plasma. Diamagnetic Loops are an easy non-invasive tool allowing measure and study of the plasma within CMFX. Magnetic Field Strength from the DMLs is being used to approximate density.

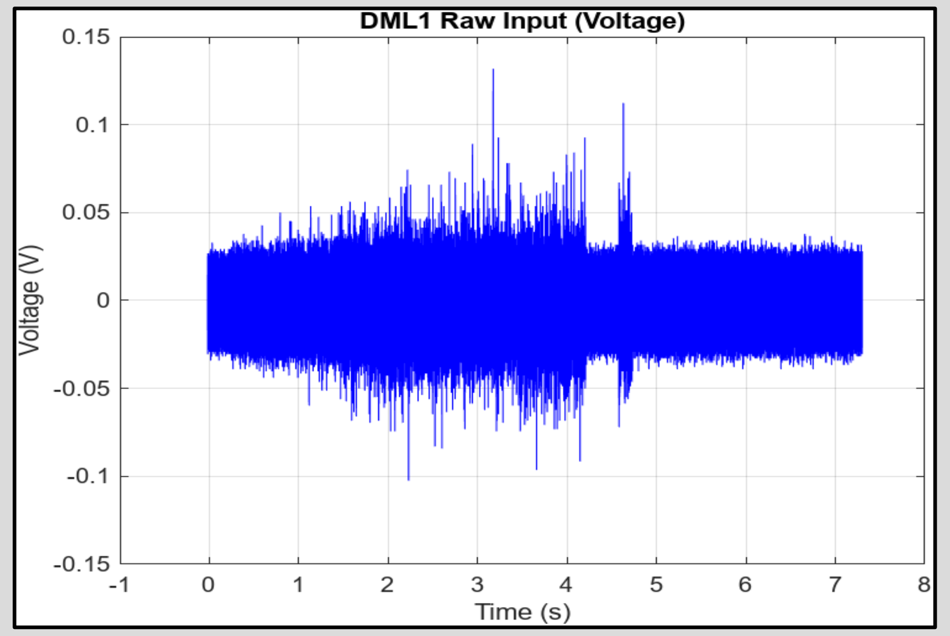
Methods

PNC cables transmit the raw voltage signal from the diamagnetic loops to a digitizer. This data is then analyzed with a MATLAB script which integrates, detrends, and manipulates with known constants to obtain the Axial Magnetic Field as it changes with time.

Results







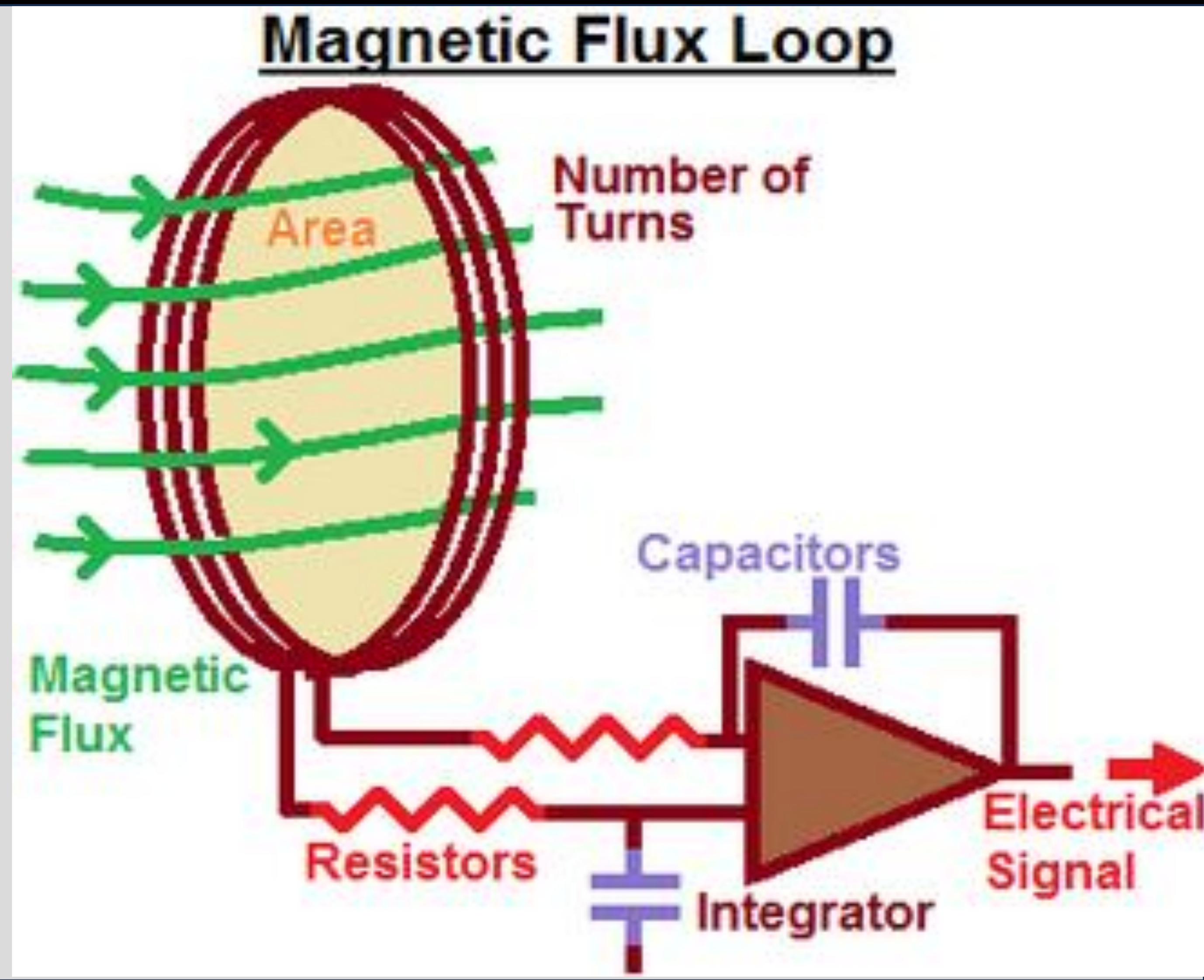
Density Approximation using DMLs

$$3.04 \times 10^{18} m^{-3}$$

Data Explanation

These plots show the resulting magnetic field and the raw voltage signal from three of the diamagnetic loops on the vacuum chamber. DML 1 and 4 are the furthest from the axis of the symmetry, while DML 3 is the closest.

1. Import Raw Data for All DMLS into MATLAB Script
2. Integrate data to get Magnetic Flux and to clear noise.
3. Detrend Data and apply scaling factors and offsets.
4. Additional Analysis, including Fourier transform, and addition of coefficients to obtain Magnetic Field in Tesla.
5. Use acquired data to approximate density and compare with theory and other diagnostic tools



Acknowledgments

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Theory

Start with 3 equations

$$\nabla \times E = -\frac{\partial B}{\partial t}$$ Faraday's Equation

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$ Amperes Law (E term goes to 0)

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = \rho \mathbf{J},$$ Ohm's Law

Take the curl of Ohm's law and Combine these three equations. Ending with this partial differential equation

$$\frac{\partial B}{\partial t} = \nabla^2 \frac{\eta}{\mu_0}$$

Approximate solution using a scaling argument

$$\frac{\Delta B}{\Delta t} = \frac{B}{L^2} \frac{\eta}{\mu_0}$$

Timescale for the Field to permeate fully (100%) through the metal surface of thickness L.

$$\frac{\Delta B}{B} = 1 \qquad L = 0.953cm$$ Chamber thickness

$$\Delta t = \frac{L^2 \mu_0}{\eta} \qquad \eta = 2.65 \times 10^{-8} \Omega m$$ Resistivity of Aluminum

Timescale

$$\Delta t = 4.3ms$$

Frequency corresponding to this timescale

$$f = \frac{1}{\Delta t} = 233Hz$$

Construction

Due to the low signal-to-noise ratio with the preexisting DMLs with CMFX. New DMLs are planned to be constructed with a higher number of turns and with wires of a higher diameter.