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Abstract Dummy Page.

Contents

1. Introduction

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At CERN, a new electron cooler is being commissioned for the AD experiment. This cooler shoots electrons into ion-beam path. These electrons then collide with the beam particles, and momentum is transferred from the beam particles to the electrons. The electrons are then steered away from the beam path, into an electron collector.

In the beam path drift of the cooler, a solenoid magnet is used to orient the electron path. This magnet comes with strict requirements on field quality, in the order of $\vec{B}_{\perp}/\vec{B}_{\parallel} < 10\mathrm{E}{-10}$. A new measurement system for solenoids has been proposed, using coils wound on a pcb. This pcb is then translated through the solenoid aperture, to obtain maps of the magnetic field. In this thesis, the metrological characterization of this system is presented, along with some post processing methods.

1.1 Project Purpose and Goal

1.2 Previous Work

2. Background

2.1 Electromagnetic Fields

The electromagnetic fields are a collection of closely linked fields. These fields govern the electric and magnetic interactions of charged particles and domains. These fields can be seen in table 2.1

Field	SI unit	Description
$\mathbf{H}$	$1\,Am^{-1}$	Magnetic Field
$\mathbf{E}$	$1\,Vm^{-1}$	Electric Field
$\mathbf{B}$	$1\,Vsm^{-2}$	Magnetic Flux Density
$\mathbf{D}$	$1\,Asm^{-2}$	Electric Flux Density
$\mathbf{J}$	$1\,Am^{-2}$	Electric Current Density
ρ	$1\,Asm^{-3}$	Electric Charge Density

These fields are described by Maxwells Equations. In differential form for the stationary case, these are as follows:

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial}{\partial t}\mathbf{D} \tag{2.1}$$

$$\nabla \times \mathbf{E} = -\frac{\partial}{\partial t}\mathbf{B} \tag{2.2}$$

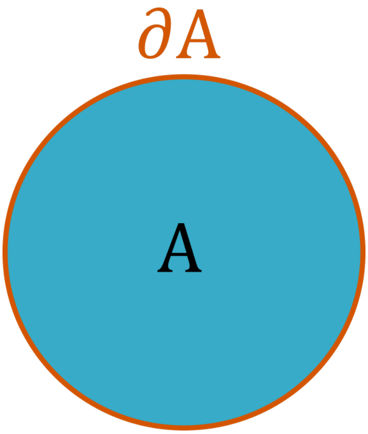
$$\nabla \cdot \mathbf{B} = \mathbf{0} \tag{2.3}$$

$$\nabla \cdot \mathbf{D} = \rho \tag{2.4}$$

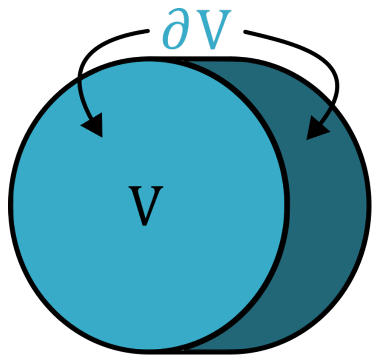
Since we're dealing with measurement of magnetic fields in this thesis, equations 2.1 and 2.3 will naturally be of the most interest. In simple cases, the **H** and **B** field obey the easy relation

$$\mathbf{B} = \mu \mathbf{H} \tag{2.5}$$

where μ is the *magnetic permeability* in the domain of interest. Formally, simple cases are where the fields are located in a medium that is linear, homogenous across its domain, invariant depending on direction, and stationary. Since the magnetic measurements are made inside the empty aperture of the magnet, the domain is only made up of air. Thus, equation 2.5 holds, and the magnetic permeability is the one of free space, that is $\mu = \mu_0 = 4\pi \times 10^{-7} Hm^{-1}$. [1, Ch.4.1-4.4]



(a) An area A and its boundary ∂A.



(b) A volume V and its surface boundary ∂V.

2.1.1 Magnetic Flux and Induction

Magnetic flux Φ is the total amount of **B** through a certain surface. Mathematically, it is defined as:

$$\Phi(\mathrm{A}) = \iint_{\mathrm{A}} \mathbf{B} \cdot \hat{\mathbf{n}} \, d\mathrm{A} \tag{2.6}$$

where A is the surface, and $\hat{\mathbf{n}}$ is the normal vector to the surface. We then have the following governing laws of electromagnetism for objects at rest:

$$\varepsilon(\partial\mathrm{A}) = -\frac{d}{dt}\Phi(\mathrm{A}) \tag{2.7}$$

$$\Phi(\partial\mathrm{V}) = 0 \tag{2.8}$$

Equation 2.7, also called faradays law, describes the voltage ε induced in a length of wire ∂A, enclosing an area A, when the magnetic flux Φ is changing with respect to time. Equation 2.8 states that the total amount of flux flowing through the boundary ∂V of the volume V must equal 0. [1, Ch.4.1.1]

2.1.2 Series decompositions of the magnetic field

Cylindrical Coordinates

Bessel Functions

Bessel-Fourier-Fourier Series

2.2 Signal Processing

2.2.1 Filters

2.2.2 Least Squares Fitting

3. The Translating Coil Magnetometer

4. Measurements

4.1 Solenoidal Field Maps

4.2 The Magnet-Magnetometer Yaw Angle Peak Shift

5. Post Processing

5.1 Lidar Scans

5.2 Coil Induction Analysis

5.3 Bessel-Fourier-Fourier Series Fitting

5.4 Estimating the Magnet-Magnetometer Yaw Angle

6. Discussion

6.1 Metrological Characterization

6.2 Future Design Considerations

Units

H Henry, Unit of magnetic inductance.. i

References

[1] Stephan Russenschuck. *Field computation for accelerator magnets: analytical and numerical methods for electromagnetic design and optimization*. John Wiley & Sons, 2011.