

In Situ Measurement of the FA Solenoid Coil using Spin Precession

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Part 1 - Abstract

A somewhat novel approach was used to identify in situ the coil winding number (520 turns per coil) inside the FA type solenoid magnet by means of precession of the electron polarization.

Part 2 - Introduction

The CEBAF injector is populated with a variety of solenoid magnets. A recent assessment of collected reports and documents yields about 10% disagreement for the peak axial magnetic field of the FA type solenoid. This disagreement is, however, suspiciously similar to the 10% variation between two types of coil which may be used in the solenoid, 520 or 573 turns/coil.

Five such magnets are installed in the CEBAF injector (MFA0I01, MFA0I02, MFA0I03, MFA0I05 and MFA0I06). Precise knowledge of the magnetic field is desirable for simulation or analysis purposes; however, those installed are captured to the vacuum beam pipe and impractical to remove for inspection or field mapping. While different in situ methods exist to distinguish between types of coil a somewhat novel approach depends on precession of the electron beam polarization.

The longitudinal magnetic field of a solenoid precesses the transverse component of the electron beam polarization azimuthally, and the total precession is proportional to the integral of the longitudinal magnetic field through the solenoid. Generally, to preserve the electron beam polarization most injector solenoids, such as the FA, are of a so-called "counter-wound" type. This means there are two identical coils internal to the iron casing, connected in series, such that the magnetic field produced by one coil is opposite to that by the second coil. Consequently, while the magnetic field may be arbitrarily strong to focus the electron beam the integral of the magnetic field remains zero, independent of current.

The method described next, however, used *unequal currents* in the two coils. The resultant non-zero field integral and measured precession of the polarization is then used to infer the type of coil within the FA solenoid.

Part 3 - Measurement

Fortuitously, one CEBAF FA solenoid, MFA0I02, is configured with independently powered coils. For this measurement the Wien filter was set at 90.2 degrees, making the electron polarization nearly transverse before the solenoid magnet MFA0I02. Two cases were studied, with *only* the first or second coil powered at 950 mA. This approach eliminated the effect of any residual spin precession (offset) due to imperfections between the electron gun and polarimeter. It also improved sensitivity by using rather extreme cases, i.e., turning one coil off. In each case the beam spot at the Mott beam line viewer was determined to be of good quality and then the transverse components of the electron polarization (P_x , P_y) were measured using the Mott

polarimeter. Details of the measurements are documented in ELOG #1447328 on November 28, 2008. The solenoid settings, measured electron polarization and calculated azimuthal polarization orientation (Φ_z) for both cases studied are shown in Table 1.

Table 1. Measured conditions and calculated azimuthal spin angle for the two cases studied.

Case	MFA0I02AM	MFA0I02BM	File	Hor. Pol.	Ver. Pol.	Angle
Coils	I [mA]	I [mA]	Time	P_x [%]	P_y [%]	Φ_z [deg]
A=OFF B=ON	0.0	946.4	11:09:26	72.1 ± 1.5	-45.9 ± 1.6	32.5 ± 1.0
A=ON B=OFF	949.4	-2.1	11:16:24	75.9 ± 1.5	43.4 ± 1.5	-29.8 ± 0.9

Part 4 - Analysis

The azimuthal precession of the electron polarization by the axial magnetic field integral of a solenoid is given by $\eta_{\text{solenoid}} = ge\int(B_z dz)/2p$, where g is the gyro-magnetic factor of the electron, e the electronic charge, p the electron momentum and $\int B_z dz$ is the integral of the longitudinal magnetic field along the axis of the solenoid. For an electron at 100 keV the relation between magnetic field integral and azimuthal precession is 19.4 G-cm/deg.

Based upon the measurements summarized in Table 1 the difference in azimuthal precession is 62.3 ± 1.3 deg, meaning the difference in the longitudinal magnetic field integral between the two cases, to the precision of these measurements, is 1210 ± 20 G-cm.

Part 5 - Magnetic Model

The magnetic model for the FA solenoid was constructed using Poisson (see Appendix) per Drawing No. I0038D01 (3 sheets); note, the drawing agrees with the dimensions of the installed magnets. The magnetic model was used to calculate the axial longitudinal magnetic field integral for the cases studied, although done for the two different coil winding possibilities, either 520 turns/coil (see Table 2) or 573 turns/coil (see Table 3). The measured power supply current (Current) is listed alongside the modeled total current (Amp-Turns) used in the Poisson calculation.

Based on the model and experiment conditions the difference in axial longitudinal magnetic field should be 1195 G-cm using 520 turns/coil and 1316 G-cm using 573 turns/coil.

Table 2. Modeled field integral assuming 520 turns/coil.

Case	MFA0I02A		MFA0I02B		$\int B_z dz$
	Current [mA]	Amp-Turns [A]	Current [mA]	Amp-Turns [A]	Model [G-cm]
A=OFF B=ON	0.0	0.0	946.4	492.1	595.8
A=ON B=OFF	949.4	493.7	-2.1	-1.1	-599.0

Table 3. Modeled field integral assuming 573 turns/coil.

Case	MFA0I02A		MFA0I02B		$\int B_z dz$
	Coil Current [mA]	Amp-Turns [A]	Coil Current [mA]	Amp-Turns [A]	Model [G-cm]
A=OFF B=ON	0.0	0.0	946.4	542.3	656.5
A=ON B=OFF	949.4	544.0	-2.1	-1.2	-660.0

Part 6 - Conclusion

Using spin precession the axial field integral of MFA0I02 was measured in situ (1210 ± 20 G-cm) by powering only one coil at a time (950 mA) and measuring the electron polarization. Magnetic modeling of the FA solenoid type using two possible coil packages 520 turns/coil (1195 G-cm) or 573 turns/coil (1316 G-cm) supports the actual FA type solenoid coil package is most likely 520 turns/coil.

Part 7 - Appendix

The Poisson description of the FA type solenoid is listed below. In this example, both coils are powered at 1 Ampere using the 520 turns/coil configuration.

MFA COUNTER-WOUND SOLENOID

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$REG KPROB=0, XMAX=3.2, YMIN=-2.5, YMAX=2.5,
MODE=-1, NBSLO=0, ICYLIN=1,
DX=.045, DY=0.045, CONV=2.54,
XMINF=0., XMAXF=0., YMINF=-3.0, YMAXF=3.0,
LMIN=1, LTOP=401, KMIN=1, KTOP=1$
$PO X=0.0, Y=-2.5$
$PO X=3.125, Y=-2.5$
$PO X=3.125, Y=2.5$
$PO X=0.0, Y=2.5$
$PO X=0.0, Y=-2.5$
$REG MAT=2, NPOINT=9$
$PO X=0.752, Y=1.3125$
$PO X=0.752, Y=0.6725$
$PO X=0.94, Y=0.6725$
$PO X=0.94, Y=0.9995$
$PO X=2.875, Y=0.9995$
$PO X=2.875, Y=0.0625$
$PO X=3.125, Y=0.0625$
$PO X=3.125, Y=1.3125$
$PO X=0.752, Y=1.3125$
$REG MAT=2, NPOINT=9$
$PO X=0.752, Y=-1.3125$
$PO X=3.125, Y=-1.3125$
$PO X=3.125, Y=-0.0625$

```

\$PO X=2.875,Y=-0.0625\$

\$PO X=2.875,Y=-0.9995\$

\$PO X=0.94,Y=-0.9995\$

\$PO X=0.94,Y=-0.6725\$

\$PO X=0.752,Y=-0.6725\$

\$PO X=0.752,Y=-1.3125\$

\$REG MAT=2,NPOINT=9\$

\$PO X=0.752,Y=-0.25\$

\$PO X=0.940,Y=-0.25\$

\$PO X=0.940,Y=-0.0625\$

\$PO X=3.125,Y=-0.0625\$

\$PO X=3.125,Y=0.0625\$

\$PO X=0.940,Y=0.0625\$

\$PO X=0.940,Y=0.25\$

\$PO X=0.752,Y=0.25\$

\$PO X=0.752,Y=-0.25\$

&downstream-B (positive I is positive Bz)

\$REG MAT=1,CUR=+520,NPOINT=7\$

\$PO X=1.1875,Y=0.1555\$

\$PO X=1.1875,Y=0.9175\$

\$PO X=2.2375,Y=0.9175\$

\$PO X=2.2375,Y=0.1555\$

\$PO X=1.1875,Y=0.1555\$

&upstream-A (negative I is negative Bz)

\$REG MAT=1,CUR=-520,NPOINT=7\$

\$PO X=1.1875,Y=-0.1555\$

\$PO X=1.1875,Y=-0.9175\$

\$PO X=2.2375,Y=-0.9175\$

\$PO X=2.2375,Y=-0.1555\$

\$PO X=1.1875,Y=-0.1555\$