Quadrupole Information for the Møller Polarimeter in Hall A

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June 5, 2020

Abstract

This is intended to be a summary of the existing information for the Hall A Møller quadrupole magnets.

1 Introduction

The Hall A Møller polarimeter was originally designed with a magnetized Fe-foil target followed by a 3-quadrupole + dipole spectrometer focusing events onto a detector. Over the years modifications have been made to the target, the spectrometer and the detector package. The focus of this note is a summary of the quadrupoles. The information for this summary comes largely from https://hallaweb.jlab.org/equipment/moller/spectrometer.html and is meant to clarify what can be confusing and sometimes apparently conflicting information.

2 History

The original quadrupole magnets used in the Møller polarimeter for Hall A came from LANL. Photocopies of documentation found at
https://hallaweb.jlab.org/equipment/moller/magnets/Moller_quads2.pdf state that at least two of the quadrupoles were mapped originally in 1972, so we aren't dealing with new magnets. Four quadrupoles given the names Patsy, Jackie, Tessa and Felicia, were provided to Jefferson Lab by LANL for the Hall A Møller polarimeter. Only 3 were used in the original design since that was sufficient for the 6 GeV program. Jackie was in the worst shape and was put in storage. In 2012 a new fourth quadrupole magnet was designed to allow for the beam energies of the 12 GeV upgrade. Looking through the documentation can be confusing since these magnets were referred to differently depending on when the document was written and where they were placed on the beamline at the time. For example quadrupole 1 refers to Patsy in the 6 GeV era but generally is used to mean the new quadrupole after 2015. Some documents refer to a quadrupole 0. Table 1 is included to provide nomenclature reference.

Table 1: Reference table providing changing nomenclature for the spectrometer quadrupoles. "Eugene's Ref." refers to Eugene Chudakov's summary on the following webpage https://hallaweb.jlab.org/equipment/moller/magnets/quad_summary_simul.html.

12 GeV position	ID	Name	Eugene's Ref.
Q1	QO1H01	New	Q4
Q2	QM1H02	Patsy	Q1
Q3	QO1H03	Tessa	Q2
Q4	QO1H03a	Felicia	Q3

Patsy and Jackie were identical magnets as were Tessa and Felicia. The new fourth quadrupole was designed to be similar to Tessa and Felicia, although it turned out to have larger contributions from higher multipole moments and. The physical information for the 4 quadrupoles (excluding Jackie) is provided in Table 2.

Table 2: Physical parameters of the four quadrupole magnets.

	New	Patsy	Tessa	Felicia
Manufacturer	?	MagnaTek	Indust. Coil	Indust. Coil
Height (in)	?	14 1/8	22 1/8	22 1/8
Width (in)	?	14 1/8	22 1/8	22 1/8
Length (in)	?	16	12	12
Effective Length (cm)	36.58(2015)	44.77 (1996) 44.73 (2012)	36.74(1996)	36.6(1996)
Bore/Aperture (in)	4.0	4.0	4.0	4.0
Max Current (A)	280	300	280	280
Pole tip field @ 300 A (T)	– (2015)	0.5801(R=4.96 cm 1996) 0.5604 (R=4.6 cm 2012)	0.6029(R=5.00 cm1996)	0.6135(R=5.00 cm1996)

Here are key points in the history I was able to piece together.

- 1972: Tessa and Felicia are mapped at LANL.
- 1996: Patsy, Jackie, Tessa and Felicia are all mapped at LANL before being given to JLab. Quadrupole and higher order multipoles are measured. The multipole measurements are recorded in an LANL document apparently first copied into a document at UK which was then poorly photocopied into the first 6 pages of document MiscQuadInfo.pdf. It appears pg.1 was written by someone at UK. Pages 2-6 contain photocopies of a LANL document with measurements recorded from 1996 and including some information on the plots on page 6 from 1972. Page 14 (labeled pg 1 of a document by Sirish Nanda made in 2000) appears to simply replicate the information in the tables of the LANL data in pages 2-3. It is not clear where the effective length values come from.
- 1997: Magnetic fields of Patsy, Tessa and Felicia remeasured by the University of Kentucky. Multipole components do not appear to be remeasured. The measurements at UK are not clearly labeled so it is difficult to know which ones they are. Perhaps the hysteresis curves shown on pages 15-19 of MiscQuadInfo.pdf. It is not clear what the information is on pages 7-12 of this document. Is it a UK measurement? There is a hand-written note saying these are from EPICS field maps. Not sure what to make of this. Regardless, pages 7-12 don't provide much additional information except to say the quads are essentially linear at the parts per thousand level up to 150 A or about half max.
- 1998: Møller polarimeter commissioned.
- 2012: Patsy removed from beam line and mapping performed by magnet group at Jefferson Lab. Multipoles and gradient measured.
- 2012: New 4th magnet (now Q1) manufactured similar in design to Tessa and Felicia.
- 2013: Four quadrupole configuration installed.
- 2015: 11 GeV beam tested in Hall A Møller

Insights and questions from this history:

1. All our information for the two most downstream quadrupoles are from decades ago. To what accuracy were they mapped and can we still trust the decades old information?
2. Patsy was remeasured in 2012. How consistent were those results with the 1996 and 2000 maps?
3. The new quadrupole was mapped most recently. How well do we know that mapping?

We will address these questions individually in the sections ahead.

3 New quadrupole map(Q1 or QO1H01)

The new quadrupole was mapped in 2012. The raw data is found in the spreadsheet QO1H01_Summary1.xlsx. Four (at least) different data sets were taken.

3.1 Effective length

Effective length was measured moving a Hall probe along Z at R=4.035 cm. The effective length was found to be 36.58 cm and the value at the center (Z=0) was 0.51404 T. The data are shown in Fig. 1.

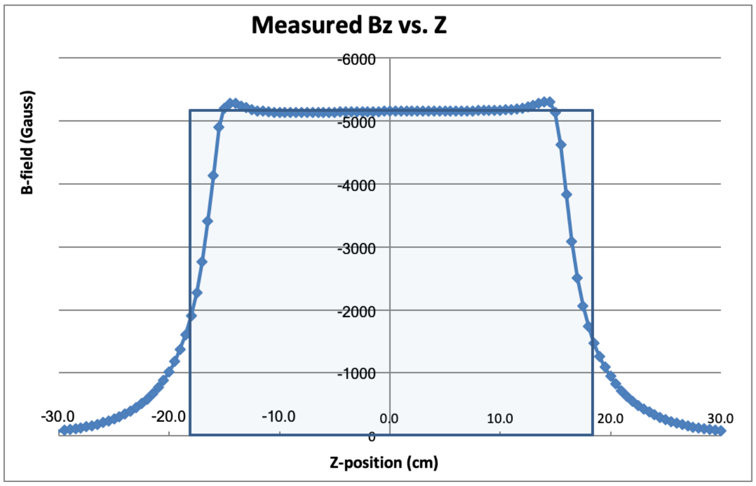

Figure 1: Hall probe measurements taken along Z for QO1H01 at r=4.035 cm. The effective length, 36.58 cm, is shown as the shaded region.

3.2 Harmonics: multipole expansion

The magnetic field in a region free of current can be approximated in a truncated multipole expansion. For cylindrical coordinates the radial,$B_r$and azimuthal, B_ϕ components of the field can be expressed in terms of sines and cosines as

$$B_r = \sum_n A_n \left(\frac{r}{r_0}\right)^{n-1} \sin\left(n\phi - \alpha_n\right), \qquad n = 1, 2...$$
$$B_\phi = \sum_n A_n \left(\frac{r}{r_0}\right)^{n-1} \cos\left(n\phi - \alpha_n\right),$$

where A_n are constant coefficients dictating the relative strength of the contributions. α_n is an offset term in case the coordinate system has an offset azimuthal angle relative to the field axes. The index n gives the multipole order. $n = 2$ gives the quadrupole term with 2 negative and 2 positive poles in the azimuth and is proportional to r. To determine the harmonics of the magnetic field a wire coil of radius 3.699 cm rotating at a fixed frequency was used. The signal from the coil was analyzed using a lock-in amplifier to pick out the harmonics. The coil had a radius of 3.699 cm whereas the pole tip is at 5.08 cm. Only the n=2 (quadrupole) and n=6 (dodecapole) contributions were measured to be significant as can be seen in Table 3. The n=6 contribution was found to be 1.44% of the quadrupole at R=3.699 cm. Since the dodecapole depends on the r^5 whereas the quadrupole on r this translates into a n=6 contribution of 5.12% at the pole tip.

Table 3: Newest quadrupole (QOH01) showing the harmonic multipole contributions relative to the quadrupole contribution measured at $r = 3.699$ cm. Multipoles up to n=20 were measured. Shown here are all harmonic contributions above 0.01% of the quadrupole.

Current (A)	n=2 (arb)	n=3 (%)	n=4 (%)	n=5 (%)	n=6 (%)	n=7 (%)	n=10 (%)
100.0	44217.253	0.035	0.035	0.114	1.438	0.012	0.056
200.0	87505.650	0.035	0.036	0.116	1.439	0.012	0.056
300.0	118079.471	0.035	0.036	0.116	1.441	0.012	0.056

3.3 Gradient-length (GL)

GL measurement versus current from -300 A to 300 A using a stretched wire.

Table 4: Newest quadrupole (QOH01) offset and n=6 multipole fractional component as determined from fitting the gradient-length versus X-position data at 22 different currents. These are extrapolated to the pole tip at R=5.08 cm. The average dodecapole contribution is about 12%, more than double that assessed by the rotating coil analysis (see https://hallaweb.jlab.org/equipment/moller/magnets/quad_summary_simul.html). I was not able to replicate the results shown on the previous webpage either even when fixing the n=6 contribution to 4.8%. I assess a negligible offset of 0.02 mm as opposed to 0.4 mm.

Current (A)	Offset (mm)	Dodecapole Coeff (frac)
300.0	-0.06	-0.114
270.0	-0.04	-0.114
240.0	0.04	-0.091
210.0	0.05	-0.091
180.0	0.08	-0.082
150.0	-0.04	-0.111
120.0	-0.05	-0.114
90.0	-0.03	-0.114
60.0	-0.04	-0.117
30.0	0.12	-0.071
0.0	0.31	-0.289
-30.0	0.57	-0.196
-60.0	-0.02	-0.123
-90.0	-0.06	-0.118
-120.0	-0.06	-0.112
-150.0	-0.05	-0.115
-180.0	-0.05	-0.115
-210.0	-0.06	-0.115
-240.0	-0.06	-0.115
-270.0	-0.06	-0.117
-300.0	-0.06	-0.116
-330.0	-0.08	-0.117
Average	0.02	-0.121