# MEMORANDUM ABOUT HMS FIELD MAPPING IN HALL C

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January 28, 1991

Just thought about the complete commissioning procedure of HMS, it is necessary to put our previous discussion and different opinions togerther and to try to get through from optically predictable performance to practical operation procedure of the spectrometer. I emphasize here some very unique characteristics of HMS in order to set a reasonable technical demand for field mapping project, save time, money, and labor to meet fundamental requirement of initial HMS operation, to make sure commissioning HMS for the first experiment in 1994.

## 1 SPECIAL CHARACTERS OF HMS

- Moderate momentum resolution $\Delta P/P = 10^{-3}$.
- Simple configuration of magnetic elememts. Dipole magnet is a flat pole pieces magnet with tilt straight boundaries at the entrance and the exit. That could simplify mapping process by taking only the transversed field component instead of three components measurement.
- Correction windings for high order **Geometric Aberrations** will be installed in Q1, Q2, and Q3.
- Cold iron and large bore configuration of HMS quads causes a big change of effective magnetic length versus different excitations in the range of 2 - 5 cm. The first order focusing property of HMS directly asks for an accurate data of effective length.
- A wide positioning tolerance have been applied to Q1, Q2/Q3, and Dipole. We may image that each magnetic element of HMS is a rigid body which has three translation and three rotation freedom.

| | Δx(cm) | Δx'(mr) | Δy(cm) | Δy'(mr) | Δz(cm) | Δz'(mr) |
|---|---|---|---|---|---|---|
| Q1 | ~~0.08~~ 1.00 | 2.0 | 0.2 | 0.8 | 0.2 | 2.0 |
| Q2 | 0.10 | 2.0 | 0.2 | 1.0 | 0.2 | 2.0 |
| Q3 | ~~0.10~~ 1.0 | 2.0 | ~~0.2~~ 1.0 | 1.0 | ~~0.2~~ 1.0 | 2.0 |
| D | 0.20 | 2.0 | 0.2 | 2.0 | 0.2 | 2.0 |

Those reference data can be found in the HMS manual [1].

# 2 THE OPTICAL PARAMETERS EXTRACTED FRO HMS MAPPING

- The effective magnetic length of each HMS element
- Changes of effective length versus excitations
- Homogenuity of the uniform field in dipole magnet
- Fringing field distribution of the dipole magnet
- Fringing field distribution of the quadrupole magnets
- Integral harmonic components of the quadrupoles
- Changes of those parameters versus excitations

Those parameters are the necessary magnetic parameters used in optical evaluation of the HMS performance. The most important data is the **effective length** which determines the first order tuning of HMS, unfortunately, in our case those values are very dependent with field excitation not like other low rigidity spectrometers with few cm gap. Therefore, we have to know precisely the relation between effective lengths and excitations, and an accurate curve is very necessary for operating the HMS.

RAYTRACE assumes that a uniform field dipole magnet possesses an absolute homogenious field [2]. Due to the momentum resolution of HMS is in the order of $10^{-3}$, only $10^{-3}$ uniformity in the dipole magnet is requested. If the mapping result really reproduces the designed data, no point-to-point field value implantation is necessary and the whole commissioning procedure can be greatly simplified.

Fringing field distributions in dipole and in quadrupoles do not affect the first focusing property of HMS but have an influence on high order terms which appear in reconstruction coefficients. For HMS data processing we only truncate the fitting at 3-rd order, therefore, we actually allow a large tolerance on the shape of fringing field. Simple fitting program will be used to get fringing field coefficients, LASFIT [3] will be used for fitting off-median plane data.

# 3 MAPPER FOR HMS QUADRUPOLES

Two alternative devices can be used as the mapper for HMS quadrupoles: Rotating coil and Hall probe. As shown in Fiqure 2 and Fiqure 3, both of the planar coil and a cylindrical coil can be used for quadrupole mapping. The planar rotating coil is a traditional Halbach geometry [?]. At CEBAF there is such a mapper used for mapping beamline quadrupole and multipole in Test lab (Jeffry Karn) The modification of planar rotating coil is a set of bulking rectangular coils embeded in a cylindrcal body and each order coil picks up corresponding harmonic signals. The absolute accuracy of rotating coil mapper is about $10^{-3}$. Several parameters can be obtained from rotating coil mapper system:

- Determine the actual magnetic axis of quadrupole, this data will quide the mechanical alinement of quadrupole magnet.
- Determine the effective length of quadrupole - the original Halbach rotating coil is not able to get this data. Steve Lassiter suggests to use a short pick-up coil in the middle of large rotating coil to extract effective length data. Let us go back to review the definition of effective length. In Figure 3, taking the origin of z at the center of quadrupole magnet we can define an effective length $L_{eff}$ by the relation:

$$g(0)L_{eff} = \int_{-\infty}^{\infty} g(z)dz$$

  g(0) = B(0)/R is the gradient at the center of quadrupole, B(0) is the field at the pole tip and R is the radius of quadrupole aperture. I really don't know if an enough accuracy of g(0) can be obtained by short rotating coil.
- Integral high order harmonic components can be obtained from analytical calculation based on planar rotating coil's data or directly from cylindrical coil measurement.
- Effective length and the integral harmonic components versus excitations. In the whole operation range to say 0.5 Gev/c to 6 Gev/c, those data will be installed in the HMS setting program to guide users operating correctly.
- The main advantage of rotating coil mapper is the fastest speed, within few days we may complete all necessary measurement on an installed quadrupole.

- The disadvantage of this method is : integral measurement only and no information about fringing field at all, if we really need the data of fringing field distribution the rotating coil mapper is not a suitable solution . The magnetic parameters of several different type of quadrupole magnets were compared and no obvious difference of fringing field coefficients has been found, therefore, the data of fringing field of HMS quadrupoles is not very important for us, either theoretical coefficients or semi-empirical coefficients can be used in RAYTRACE calculation.

Another mapping setup for quadrupole magnet is a single Hall probe mounted in intermediate plan, that is a bi-coordinate mapper like x-y single-pen plloter. If we can borrow ZIPTRACK from FNL it is easy to build a planar mapper for quadrupole. The scan pattern of single Hall probe mapper is shown in Figure 5. Due to the symmetric distribution about a quadrant of cross section and the high precision of Hall probe it is easy to find the actual magnetic axis as well as the real intermediate plane.

- Measure $B_y$(x,z) versus r at each z coordinate, we can obtain local z gradient value.
- Measure $B_y$(x,z) versus z at each y coordinate then we have the gradient distribution along z in diffrent plane.
- From previous data the effective length can be extracted by the formula:

$$L_{eff} = \frac{\int_{-\infty}^{\infty} B_y(z) z dz}{\int_{-\infty}^{\infty} B_y(z) dz}$$

- Fringing field distributions
- Extract harmonic components from integral $B_y$(x) versus x data, from the integral field distribution along x the high order harmonic components can be analytically calculated by using

$$\phi = \sum_{n=1}^{5} (n+1)^{-1} B_n R^{-n} r^{n+1} sin(n+1)\theta$$

and

$$G_n = \frac{B_n}{R_n}$$

$B_n$ is the value of the field of the 2(n+1)-pole contribution at the aperture radius R.

- Those parameters versus excitations
- The absolute accuracy of Hall probe measurement is 0.02 Gauss that has be guaranteed by GMW/group 3 on DTM-141 digital teslameter plus MPT-141 miniature Hall probe which we ordered in last December. The sensitive area of MPT-141 probe is only 1.0×0.5 $mm^2$ that is suitable for the use in a field gradient.

- The main advantage of Hall probe median plane mapper is simple- mechanical configuration of the moving parts that can be even made with manual coordinate read out and the absolute accuracy is pretty high. One thing that I have to emphasis here is that point-to-point mapping is not necessary for HMS, therefore, both of rotating coil and Hall probe single plane scanner are all suitable for the use.

- Assume the speed of mapper is 0.25cm/s (driving automatically or manually) Step size is 5 cm, data requisition time is 5 second for Hall probe and the corresponding interface, for Q1 mapping **1.72 hrs per excitation** and for Q2/Q3 **4 hrs per excitation**.

# 4 MAPPER FOR HMS DIPOLE MAGNET

That is still a single Hall probe positioning by mechanically movable carriage. Ziptrack may be the best way to drive the sensor. The parameters and the performance provided by this mapper are:

- The homogeneity of uniform field region $V = 326 \times \pi \times 30 \times 20 = 6.15 \times 10^5 cm^3$

- Fringing field distributions at the entrance and the exit of dipole, fringing field region is definded from 150 cm outwards EFB to 100 cm inwards EFB and the mapping volume $V = 250 \times \pi \times 30 \times 20 = 4.72 \times 10^5 cm^3$ at each side.

- Those parameters versus excitations

- Advantages: Directly provide readout field values; One planar measurement is enough to give all necessary parameters. Assume step size is 5 cm, 25 seconds for one field point data taking, scaning area $S = 766 \times 30 = 22980 cm^2$, **Mapping time is 6.5 hrs per excitation.**

- Why I prefer to use a single Hall probe? Each Hall probe should have its own interface and no way to place a multiplexer between probes and an interface. For one planar single probe measurement 6.5 hrs is necessary and for complete mapping we have enough time. The DTM-141 probe is the best one with precision temperature calibration as well as an automatic compensation of temperature effect.

# 5 WHAT WE HAVE ORDERED ALREADY

## 5.1 High Resolution NMR Teslameter

- Metrolab PT 2025 NMR teslameter includes three transverse flexible probe: a 1060R5 0.7 to 2.1 tesla, a 1060R3 0.17 to 0.52 Tesla and a 1060R4 0.35 to 1.05 Tesla.

- 2031 probe multiplexer amplifier for up to 8 probes
- 1011-10 cable, connect mainpart of teslameter PT 2025 to the probe multiplexer amplifier 2031.
- 2025 high resolution teslameter: resolution - $10^{-7}$; relative accuracy better than 5 ppm; absolute accuracy better than 1 ppm.
- no field regulation option has been ordered.

## 5.2 DTM Hall Digital Teslameter

- Group 3 DTM-141-DG digital teslameter, 16 bit output; 15ppm resolution, IEEE 488 interface.
- MP-141-7 miniature Hall probe; full range 0.3, 0.67, 1.2 and 3 Tesla; temperature automatically corrected to 10ppm/degree; absolute accuracy 0.01
- probe holder

## 5.3 Group 3 Hall Probe and Analog Interface

- Probe 11000027-7m
- 15000021 Hall Probe Analog Board: current putput 100 mA peak; input level 2 to 150 mV; standard Eurocard size; temperature analog output; output impedance 1K; drift 10 mV per degree at output and 5 ppm per degree.

## 5.4 LBL precision programmable bipolar V/f instrumentation module - to be ordered or copied

For the use of rotating coil [5]. Circuits, design of printed board, specification ... are gethered already.

# References

[1] C. Yan, P. Brindza, R. Carlini, S. Lassiter, D. Mack, J. Napolitano, R. Thorpe, S. A. Wood, *Preliminary User's Manual for the High Momentum Spectrometer at CEBAF*, CEBAF-R-92-002

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[3] H. A. Enge, *RAYTRACE and the real world*, Proceeding PILAC Optics Workshop, Los Alamos, August 12-13, 1991

[4] K. Halbach, *The Hilac Quadrupole Measurement Equipment*, Engineering Note, Lawrence Radiation Laboratory - University of Califonia, March 3, 1972

[5] W.E.Hearn, M.I.Green, D.H.Nelson, D.J.Rondeau *A Precision Programmable Bipolar V/f Instrumatation Module*, LBL-13417, October, 1981