Measurement Procedure for CBETA Magnets

Stephen Brooks 2017-Aug-17 CBETA machine note #nnn

# Pre-requisites

## Magnet Measurement

In all cases, magnets will be measured:

* With water cooling attached, at the equilibrium temperature of 85F, which may be achieved by running the chiller through the magnet for 1 hour\* before testing;
* With the window-frame corrector for the magnet type attached to the Halbach core.

\* It is possible this time could be reduced if necessary, magnet warm-up is fairly fast. Data on this is available for both QF and BD types.

Currently, there is a “glitch” with the BNL rotating coil that means the first measurement after switch-on comes out ~6e-4 different. Thus until this is resolved, suggest a dummy run first thing on each day.

## Magnet Survey

The following must be included in the survey:

* The roughly 8 magnet fiducial points, located on the front and back faces of the aluminium body of each magnet;
* At least 3 points on the rotating coil base plate, to define the “bench frame”;
* An accurate model of the rotating coil cylinder relative to the base plate.

For the rotating coil, Animesh Jain suggests taking sets of points on the surface of the coil either side of the magnet, at multiple orientations as the coil rotates about its axis. This should be accurate and repeatable relative to the base plate to within 10 microns (although needs checking). So the detailed coil survey measurement can be done only once per day (or week?) with small sets of surface points on the coil during each measurement as a check.

Sometimes a magnet must be remeasured and surveyed in the reversed orientation. This survey (and all magnet surveys) must be treated as independent measurements of different sets of points, with no “pre-survey” of the magnet nor fitting to an assumed model of the magnet. The base plate fiducials and latest accurate coil position should be in the survey model, however.

It may be useful to install a “foot” for the Faro survey arm on or near the rotating coil bench.

## Magnet Orientation

The CBETA magnets will be marked with two sides called “A” and “B”, as well as which part of the magnet is the “top” vertically. The significances of these sides are given in the table below.

|  |  |
| --- | --- |
| Side A | Side B |
| Beam-downstream (DS) | Beam-upstream (US) |
| Faces the rotating coil motor | Faces away from the rotating coil motor |
| The “front” in any 2D magnet design drawings |  |

# First Measurement of Magnet (without Tuning Rods)

This measurement does not need survey, it is mainly to determine the required tuning rod arrangement (or if there is a major error that is not tunable).

1. Place magnet on rotating coil
2. **If first measurement of the day**, take a dummy coil reading (~10 reads)
3. Attach chiller hoses, switch on chiller
4. Wait 1 hour (or other specified thermal equilibration time)
5. Take a rotating coil reading (~20 reads)
6. Calculate tuning rod arrangement using software from Stephen Brooks, with input being the rotating coil “.dat” file
7. Fill two tuning rod cartridges with wires of appropriate lengths (may be automated)
8. Ensure the rods are glued securely in place and will not move when placed into magnet

# Magnet Measurement after Tuning

The first and any subsequent tuning iterations will also be surveyed because they have a significant likelihood of being of acceptable field quality, so the survey data of each magnet needs to be available.

1. **If not already there**, place magnet on rotating coil
2. Insert tuning rod cartridges for this iteration, being careful of orientation
3. In parallel, starting from now, survey can take measurements of magnet fiducials relative to coil and bench
4. **If first measurement of the day**, take a dummy coil reading (~10 reads)
5. **If magnet is not already at thermal equilibrium**, switch on chiller and wait for thermal equilibration time
6. Take a rotating coil reading (~20 reads)
7. Software from Stephen Brooks will verify if magnet meets CBETA figures of merit and also suggest a further optional tuning rod iteration, with input being the rotating coil “.dat” file
8. **If first surveyed measurement of the day**, need to determine coil angle with reversed measurement as follows:
   1. Retract rotating coil
   2. Unbolt magnet from base and reattach to the same base rotated 180 degrees about vertical axis
   3. Perform again steps 1 through 6 above

# Software Packages

There will be at least two software packages provided by Stephen Brooks for use with CBETA magnet measurement.

## Field Quality and Tuning Rod Calculation

This takes the rotating coil “.dat” file as an input and calculates:

* Multipole coefficients relative to the coil axis, including integrated dipole and quadrupole;
* Re-centered multipole coefficients where the magnet displacement and orientation is fitted to give closest to the nominal field and gradient;
* The displacement and rotation relative to the coil axis required to give the best fit above;
* Field quality figures of merit based on the above multipole coefficients and limits derived from CBETA-specific tracking studies;
* The lengths of tuning wire that must be inserted into each slot of the wire holder in order to correct the observed multipole and strength errors.

This program may also control an automated wire cutter robot to help with filling the tuning rod cartridges.

This program can generate output/log files in CSV (comma-separated) or LaTeX (hence PDF) form, which can be logged with systematic filenames.

## Magnet Survey: Magnet Axis to Global Coordinates

This takes as input:

* Survey file of magnet fiducials and rotating coil axis in bench frame;
* Displacements of the measured ideal magnet axis from the rotating coil position;
* Roll angle of the ideal magnet orientation relative to rotation coil zero;
* BMAD-generated survey file of ideal magnet axis in CBETA global coordinates.

This program outputs the positions that the magnet fiducials should have in CBETA global coordinates when installed. These positions will place the measured ideal magnet axis on the ideal magnet axis specified by BMAD.

## Magnet Survey: End-for-End Coil Roll Calibration

This takes as input:

* Two survey files of magnet fiducials and rotating coil axis in bench frame, one in normal orientation and one reversed;
* Two rotating coil measurements corresponding to the above surveys.

This program computes the ideal magnetic axis in both forward and backward orientations and uses the redundant information to calculate the roll angle of the coil itself (relative to the bench) as a best fit using the survey points and orientation of multipoles measured.

Once the coil roll angle is known, this may be input to the single-measurement magnet survey program and subsequent magnets will only require one measurement for as long as the coil roll angle is assumed to be fixed.

Periodically, the coil roll angle must be re-measured. If it has changed by a lot in an interval of time (e.g. more than the ±2mrad = ±0.11° roll angle tolerance in the CBETA spec), the magnets in that interval may have to be re-measured.