Questions and Answers from the CERN Magnetic Mapper Visit

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Abstract

A rough summary of my notes, and understanding, regarding the field mapping of the MICE magnets. These cover questions (and answers, where known) from meetings at Oxford and CERN.

1 Schedule Queries

- Do we have a *realistic* magnet schedule?

It is likely that both the Spectrometer Solenoids (SSs) and first Focus Coil (FC) will be ready for measurement at approximately the same time. If so, we may run into problems as we only have one measurement device (see Section 2). As shipping the device will take several weeks, we also need to know (a) *where* to send it first, and (b) *when* to send it.

CERN have asked that we forward on the magnet schedules to them. This way they can roughly arrange their travel plans for mapping the magnets. They have also asked that we inform them if it becomes likely we will need the mapper, or an additional disc (Section 2), available for use before December 2011.

- How much time will we have between the completion of the SS and it being turned on, ready for measurements?

Pierrick has expressed the concern that we may not have much time at Wang NMR to measure the SSs. This leads to the question of what we could do in a 24 hour period to convince ourselves that the SSs are 'good enough' for MICE to accept. We decided that we should be able to (a) identify the magnetic axis, (b) make sure that the measured field is sensible (*i.e.* it obeys Maxwell's equations), and (c) that the field is roughly in agreement with our expectations. The software requirements necessary for this are listed in Section 8.

2 The 'Need' for a Second Mapping Disc

- *Assumption:* The SS and FCs are all ready simultaneously

In the event that all of the magnets are available together, we want to avoid wasting time shipping the mapper to and fro. The sooner we are satisfied our magnets are as expected, the sooner we can install Step IV. Shipping the mapper's components across the Atlantic will take several weeks. However, since the SS and FC both use different *carriages* for the mapper it is possible that we could use two mapping discs (*i.e.* the part that holds the Hall probes) for this purpose.

- What are the costs and time involved in duplicating the mapping disc?

The first issue is that we would not just be duplicating the mapping disc itself. We would also have to duplicate the electronics and the motor that controls it. Felix has estimated that this would cost in the region of 10 kCHF, and at least a month of time to produce it.

The larger problem, however, is that we can only ever have one 'copy' of Felix and Pierre-Ange. Since they are the only people who know, reliably, how to operate the mapper we are restricted by their ability to fly where needed. This is a logistical problem to solve.

3 Miscellaneous Mapper Questions

- Who will actually *take* the mapping measurements?

Felix Bergsma and Pierre-Ange Giudici are the resident mapper experts. Once they have an idea of the measurement timescale, they will be able to arrange their own schedules for carrying out the measurements. I am unsure at this time how difficult it would be for an untrained person to acquire data, for example, if Felix and Pierre-Ange are unavailable.

- What is the mapper plugged into?

Although they expect to be able to provide their own laptop, the DAQ requires a PC running Windows XP. Additionally it must have both Microsoft Visual C and MINT (potentially available from Felix) installed.

- What type of output will we get?

We will get three files. One containing the raw ADC values from the mapper, the second containing the translated values in Tesla, and a final file containing the Hall probe calibration info. The actual format of this file is flexible and under discussion with Felix.

- How do they account for the Hall probe alignments and any skew relative to the magnet?

All alignment of the mapper carriage and Hall probes is done by survey. Their requirements are listed in Section 4.

- What is the longitudinal reproducibility of the mapper?

Longitudinally, the mapper can return to within 0.3mm of a set position.

- What is the approximate setup time for the device?

The mapper's setup time is dominated by its surveying needs, see Section 4.

4 Survey Requirements

The CERN mapper requires surveying at several points during its operation. First, relative to marks on the magnet itself to ensure it is properly centred within the bore. Secondly, with the mapping disc in two positions. Surveying with the disc close to the magnet and close to the motor allows any skew in the device to be adjusted. Finally, the position of each Hall probe is surveyed relative to the mapping disc and/or marks on the magnet.

A metal 'T' has been designed to fit in the same location as the Hall probes on the mapping disc. A survey mirror can be attached to the 'T', and a mirror & laser tracking arrangement can be used. If such survey equipment is not available, CERN should be informed as soon as possible so other arrangements can be made.

Surveying the mapper consumes the largest amount of time when taking data, especially for the FCs. In this case, one complete field map requires the mapper to be switched from one side to the other (because of the permanent flange). An accurate survey of each step is essential for the two field maps to be comparable. It will be important not to underestimate the time each survey takes when judging how long the field measurements will last – especially if the survey equipment must be removed and replaced when the magnet is powered (*i.e.* is survey equipment magnetic?).

The questions that must be asked of RAL and WangNMR/Berkeley are:

- Is laser tracking survey equipment available, and if not, what is available?
- Who would be able to survey the mapper at WangNRM/Berkeley?
- What is the availability of surveyors at each location?

5 Hall Requirements

- Are there any special installation requirements for the measurement area?

The mapper is supported on either end by two large (non-magnetic) tripods. Holes must be drilled into the floor so that they can be secured during the measurements. This may be tricky in R9 at RAL. I'm unsure of how difficult it would be at WangNMR/Berkeley and in the MICE hall.

- Are there any special running requirements?

There are two areas that must be controlled or monitored during the field mapping. The first of these is an accurate measurement of the current running through the coils. This is mostly important for the FC map, as it is carried out in two parts and we must be sure that they are comparable. A Direct Current Current Transformer (DCCT) may be what we need, but there is some disagreement about how accurate they are.

The second requirement is that the temperature in the bore of the magnets must be closely controlled. The Hall probes have been calibrated (Section 7) at 20 C, and their calibration is only valid in the range 15 to 25 C. We will encounter problems with the field maps if the temperature is not stable within this range along the whole of the magnet bore. This may mean we need to provide some ventilation to keep the temperature at 20 C. It also requires monitoring the temperature stability, as noted in Section 8.

- *Assumption*: All measuring areas have access to compressed air.

6 FC-Specific Mapper (Extension Disc)

- Is the support for the FC mapping carriage different from the SS?

The FC will be measured from both sides, with these measurements combined to create the field map. The first support is located approximately 70cm from the end of the mapper carriage. We will need to determine if the FCs dimensions interfere with this placement at all.

The FC mapper was also based on a bore diameter of 400mm instead of 470mm. Hence, it will be supported 'floating' inside the magnet bore. A survey will be essential to making sure it is centred and aligned with the bore.

- Do we want a longer extension disc?

The extension disc allows measurements to be taken beyond the permanent flange in the FC bore. It is currently supported by three 250 mm long carbon fibre rods. Pierre-Ange was dubious about extending this beyond 350 mm as they may flex and allow the extension disc to sag.

- How well will the Hall probes work in flip-mode?

As described in Section 7, the probes are calibrated between 2.5 and 4.5 T. However, in flip-mode, the field goes to zero at the centre of the magnet. Extrapolating the Hall probe calibration outside of this region is unreliable, hence Felix is unsure of how good the measurements will be in this case. He also points out that the NMR probe may not work, as the field gradient may be too high. The NMR probe requires a field gradient of < 50 ppm/cm.

7 Hall Probe Calibration

- Can Felix improve on the calibration of the Hall probes using the SS?

Felix has 28 MICE Hall probes, not including those on the mapper disc, that he would like to calibrate further using the flat field region of the SS. The probes were originally calibrated between 2.5 and 4.5T using a magnet in Grenoble, however, I gather that these measurements were difficult as it has a very small flat field region. No-one else has made a magnet with a flat field region as large as the SS who can offer Felix this opportunity. These measurements would take approximately $1 - 2$ days and he would prefer to do them before the FC mapping campaign. NB: The Hall probes in question were calibrated for the purpose of monitoring the magnetic field in the MICE hall.

- What does the calibration entail?

The Hall probe 'calibration' is approximately 1 kB of data in a table containing spherical harmonics (see Felix's talks at the International Magnetic Measurement Workshop $12 - 16$ for the precise details). When a particular Hall voltage is not found, it fits it to the data in this table. Extrapolating beyond this data is unreliable, as there is a *non-linear* variance with $|\mathbf{B}|$ (Planar Hall Effect). The calibration also depends on temperature (each Hall probe has a thermistor).

- What corrections need to be made to the data?

We will need to make some corrections (post-measurement) to account for small offsets in the Hall probes angles. They are each glued onto one side of a glass cube and can only be mounted to ± 0.5 mm.

- Conditions of field homogeneity:

The glass cube has sides of length 4mm. Is our field homogeneous over a 4mm region? This needs further investigation.

- *Aside*: How useful will the 28 external Hall probes be?

The probes intended for measuring the field outside the magnet are likely to see fields < 1 T, which is outside their calibrated region. Hence, I'm not sure how useful they will be beyond any information we would gain from measuring the currents in the coils as accurately as possible.

8 Field Analysis Software

I aim to have following software available prior to the mapping campaign:

- Reliable modeling of the coils in each magnet using the Biot-Savart law.
- Comparison/fit between the expected field model and the measured field map (*i.e.* a 'field quality' estimate).
- Identification of the magnetic axis from a field map.
- 'Online' plots of the field with position and the temperature variation measured by the thermistors, given a measurement file. This would equate to a short measurement being taken and then checked, before initiating a more detailed map.

I aim to have the following components available soon after:

- A minimisation routine to determine the most accurate magnet model that describes the data.
- A G4MICE/MAUS routine that provides field maps based on our measurements and improved understanding of the magnets.

9 Analysis-Related Questions

The following are all questions that require thought and/or simulation (to be done).

- What effect does the misalignment of the FC or Coupling Coil (CC) have on the field inside the SS?
- How well do we need to know the field in the *cooling channel* to be able to predict what would happen if we had 100 MICE.