Joint WP2/WP3 Meeting

Tue 30 June 2020, 10:00 – 12:30

Chair: Gianluigi Arduini

Speakers: Lucio Fiscarelli, Susana Izquierdo Bermudez, Andrea Musso

Participants: Gianluigi Arduini, Barbara Dalena, Riccardo De Maria, Ilias Efthymiopoulos, Lucio Fiscarelli, Hector Garcia, Massimo Giovannozzi, Giovanni Iadarola, Susana Izquierdo Bermudez, Glyn Kirby, Ewen Maclean, Elias Métral, Michele Modena, Nicolas Mounet, Andrea Musso, Yannis Papaphilippou, Galina Skripka, Kyriacos Skoufaris, Guido Sterbini, Ezio Todesco, Rogelio Tomás, Frederik Van der Veken

AGENDA

MEETING ACTIONS

Lucio Compare measurements with integrals of simulations over the coil length for the present data and possibly do that also with finer shifts of the probe for future measurements

Ezio Give first estimates on the fringe fields in correctors (MCBRD and MCBXF)

Susana Present comparison of simulations to measurements of beam screen impact on field quality in LHC (triplet, main magnets)

Susana Update on the beam screen impact on field quality in HL-LHC (with data measured on short model)

Susana Summarize the impact on the main field in the quadrupoles and dipoles

Susana Check the relative impact on the field from the quadrupole cooling channels, depending on their size and distance form the center

Massimo Check the impact of b2, a2 on the MCBRD on beta beating.

Ezio Check the tables for the acceptance criteria for D2, MCBX and MCBRD

GENERAL INFORMATION (GIANLUIGI ARDUINI)

Gianluigi briefly went through the minutes of the previous meeting. An update on the impact of fringe fields on corrector strength was presented by **Barbara** Dalena, both for LHC and HL-LHC. Some of the effects could explain discrepancy between the beam based measurements and the magnetic measurements in the present triplets of the LHC. **Ezio** was asked to provide data on field components for MQXB and already some data exchanges were made between Susana, Ezio and Barbara.

Hector presented on beam halo measurements using collimator scans, interesting for understanding the impact of noise on beam lifetime. This is found to be dependent on beam profile. There is a discussion between **Hector** and **Ilias** regarding the report to the experiments working group about the need to check past luminous region data, in particular regarding the tail population, and the need for better luminous region measurements.

As a follow-up there was a short presentation by **Nicolas** where he clarified some points on longitudinal impedance.

Today is a Joint WP2/WP3 meeting with talks dedicated to field quality and magnetic measurements. There is a presentation by Lucio on possibilities for measuring the fringe fields, then, a presentation from Susana, concerning available simulations of beam screen impact on field quality in HL-LHC triplets, and an update on the field quality of the MCBRD by Andrea.

1 MEASUREMENT OF FRINGE FIELDS (OF MQXF TRIPLET QUADRUPOLES) (LUCIO FISCARELLI)

The fringe fields are the fields at the magnet end-regions where a large variation in the longitudinal direction is present. These fields are not affected by magnetic center shift or by changes is magnetic length. The rotating-coil probe is a standard tool used to measure the integral of the field harmonics over the sensor length. The measurement resolution depends on the probe length but with decreasing probe size the accuracy is degrading (*e.g.* positioning is more difficult). Another complication in measuring the fringe fields is the integration of harmonics: it is complicated when the field has *z*-variation (2d harmonic expansion is not valid anymore). The measurements can be affected by the systematic error given by the *z*-component of the field. The best setting is to use a coil length spanning over the whole length of the fringe field to place ends in the regions with zero *z*-component.

Using different measurement setup (different probe lengths) the fringe fields were measured at CERN and by colleagues in US. At CERN the measurements on long magnets at cryogenic temperature are currently ongoing.

Fringe fields in the MQXFS3c, MQXFS4a and MQXFS6a short magnets were measured at CERN using the scanning along z-axis with 130 mm probe at room temperature. The measured main field b2 is in good agreement with simulations, even though the measurement resolution is limited. For the b6 and b10 components the fast variation of the fringe fields could not be measured again due to the limited resolution.

The MQXFAP2 full-length magnet prototype was measured in US using the scanning along z-axis with 110 mm probe both at room and at cryogenic temperatures. The measured main field b2 is in good agreement with simulations. Resolution is better because of the shorter coil length. The field profile is slightly different at room and cryogenic temperatures due to iron saturation. For the b6 the situation is similar: good agreement with simulations and small difference depending on a temperature.

The MQXFBP1 fill-length magnet prototype was measured at CERN using the scanning along z-axis with 600 mm probe (spanning over the full length of the fringe fields) currently only at room temperature. In these measurements higher multipoles across the ends were measured (normalized to central field) and no large variations were found (max b3 of -4 units). On skew multipoles variations in the order of 10 units were measured for a3 and a4.

In current strategy for the measurements of series magnets at CERN it is planned to use a 600 mm probe (13 integrated measurements) at room temperature and 1300 mm probe (6 integrated measurements) for the measurements at cryogenic temperatures.

- **Barbara** asked if it is possible to use a finer shift of the probe to resolve the field variations. **Lucio** replied that it was tested before and this method has large errors because relying on a deconvolution. In addition, it does not solve the problem of systematic errors from the *z*-component of the field. **Gianluigi** asked if integrated simulations could be better for comparing to measurements. **Lucio** replied that, instead of deconvolution of measurements, the integration of the calculations is better, but fast variations would be smoothed giving loss of spatial accuracy. **Gianluigi** replied that it would still be good to compare measurements with integrals of simulations over the coil length for the present data and possibly do that also with finer shifts of the probe for future measurements. (**Action: Lucio**).
- **Rogelio** asked if the effect of the rotating coil be included in the model to account for the systematic errors from *z*-component. **Lucio** replied that there is no straightforward way to do this and it requires some development.
- **Riccardo** commented that it is not clear how to compare the measurements to simulations in the case when there is a contribution from *z*-component. The definition of harmonics becomes different. **Lucio** agreed and said that in the model the *z*-component is neglected to compute the harmonics whereas in reality it is impossible. The rotating coil, depending upon the specific design, is in general sensitive to *z*-component when in the fringe. Lucio also added that, in the fringe fields, model is giving reliable results but the measurements could have limited accuracy.
- **Rogelio** asked if there is any experience for the fringe fields in the correctors. **Lucio** replied that 3D simulations, though heavy, could be done if needed. **Rogelio** added it is necessary to know if they are of concern and have some estimation MCBRD and MCBXF. Before, correctors were neglected assuming b3 to be zero, but now it is known that there is a contribution. **Ezio** said that a first approximation estimates can be calculated with ROXIE to decide if it is worth to make a more precise model. **Rogelio** said that it has to be checked (**Action: Ezio, WP3**).

2 IMPACT OF BEAM SCREEN IN FIELD QUALITY MQXF, D1 AND D2 (SUSANA IZQUIERDO BERMUDEZ)

This is an update on the effect of the beam screen on the field quality. The materials considered in the first studies in 2016 include High-Mn Austenitic Steel for the beam screen and cooling channels, Tungsten for absorber and Austenitic Steel for the cold bore. For the magnetic properties of the steel the data measured to characterize LHC was used. For tungsten the magnetic properties were measured at cold. Using the available numbers for permeability the impact of different components (including beam screen) on the field quality was simulated for b6, b10, b14 and b18. The beam screen and the cooling channels were found to contribute to the harmonics the most.

In 2018, measurements aiming to characterize different tungsten samples were done. Following these measurements the material specification for the tungsten absorber were defined ($\mu_r < 1.0003$ at $H > 6 \cdot 10^6$ A/m), setting the impact on the b6 at collision limited to 0.2 units. The first pre-series measurements in 2020 show that tungsten properties are well within specifications and it should give a very little contribution to the field errors.

Based on the new measurement data the ROXIE models were updated. Simulations were done for two beam screen geometries: "Thick Tungsten" Q1 and 'Thin Tungsten" Q2, Q3, D1. An additional modification in the model was also considered: the new cooling channel in the "Thick Tungsten" model is 6 mm smaller in diameter than before. ROXIE simulations were done for Q1, Q2, Q3 and D1 and tables summarizing the impact on different field components at injection and top energy are summarized in the tables. For the D2 the beam screen design is still in discussion with the aperture team and the study of the impact on field quality will be estimated when it is finalized.

- **Gianluigi** commented that D2 design is ready. **Riccardo** added that currently there is iteration on-going to make it bigger.
- **Gianluigi** asked if any comparison between the simulations and measurements is planned or was done before. **Susana** replied that the beam screen was installed only in one of the short models and not measured yet but this is planned. **Ezio** added that simulations are reliable with 10-20% relative error (based on LHC experience) and the numbers are small. **Gianluigi** commented comparison of simulations to measurements in LHC (triplet, main magnets) should be shown (**Action: Susana**). **Ezio** added that for HL-LHC this comparison is in the pipeline. Once the short model is measured an update will be given (**Action: Susana**).
- **Rogelio** asked if the impact on the main field in the quadrupole was studied. Susana replied that it was but not reflected in the tables. **Gianluigi** added that it should be summarized for the quadrupoles and dipoles (**Action: Susana**).
- **Rogelio** asked which measurements are planned. **Susana** replied that one short model will be measured but not in the long. **Ezio** agreed.
- **Rogelio** asked if the welding (or any other asymmetry) is taken into account. **Susana** said that no. **Massimo** commented that if the symmetry is broken more multipoles will appear. **Susana** replied that there were studies with different details breaking the symmetry (support rings etc.). The contribution was found to be very small. **Massimo** said that any change of the beam screen position would have an impact as well. **Susana** replied that a very preliminary study on the tolerances on the assembly was done, no significant impact was found, but more detail studies could be preformed.

- **Massimo** pointed out that in the Q1 and Q3 the cooling channels have different size and also are at a different distance from the centre. The effect of the field is different. Which of the components is more important the distance or the diameter? **Susana** replied that this should be checked (**Action: Susana**).

3 UPDATE ON THE FIELD QUALITY OF THE MCBRD (ANDREA MUSSO)

The MCBRDs are orbit correctors in the same cold mass as D2. The specifications can be found in the EDMS 2085323. The magnet has two apertures, one with horizontal and one with vertical field. For connecting the aperture to the iron, two types of keys are used (hybrid and SS304L). They are installed depending on the field orientation (hybrid along the field orientation and SS304L in orthogonal plane).

Three apertures (red, blue and violet) were produced at CERN and assembled in two prototypes for testing. Prototype 1a (with red and blue apertures) showed no issues in reaching goal parameters for the red aperture. The blue aperture had long training but no retraining after thermal cycle. It was decided to produce a 3rd aperture, violet, and test it in the prototype 1b assembly with the red aperture. The violet aperture had fast training in virgin conditions. A second prototype was produced by WST in collaboration with IHEP (China) and tests are on-going.

L. Fiscarelli did magnetic measurements for the red aperture with and without iron at room temperature and at cold. The b3 component in measurements with iron (both at room temperature and at cold) was measured at ~10 units which is close to the specifications limit. This is not present in measurements without iron. For all three apertures produced at CERN the b3 component measured at 1.9 K is close to 10 units.

ROXIE simulations were done to identify the origin of 10 units of b3. In simulations without keys the b3 is ~2 units. With keys placed as designed the b3 is ~3 units as expected. In simulations with hybrid keys inverted the b3 component is in the order of the measured values. Simulations performed so far show that the increase in b3 is caused by something close to the edge of the iron yoke. However, this is still in the analysis stage.

In conclusion, preliminary results show b3 value of ~10 units, close to the limit of specifications. Simulations do not confirm the measurements, however, investigation is ongoing. The discrepancy on b3 is compatible with iron edge at 83 mm radius and hybrid keys inverted. Measurement results from the prototype in IHEP should give more information.

- **Massimo** commented that the a2 and b2 components should not be underestimated since the measured values are non-negligible (3-4 units). **Andrea** replied that the spread is rather large and new measurements from IHEP should give more statistics. **Massimo** asked if the observed a2 could be due to alignment. **Lucio** replied that the angle was measured but not the centering of the coils into the iron and that could contribute to b2 and a2. **Ezio** added that the specifications are 10 units for b3 and 3 units for others so this should not be an issue. **Massimo** replied that the impact of nonzero a2 and b2 was never checked. **Ezio** added that it will be difficult to reduce it much below 3 units. (**Action: Massimo)** to check the impact of b2, a2 on the MCBRD on beta beating.
- **Gianluigi** asked for the set of tables for the acceptance criteria in a singe document giving numbers to use in simulations. **Ezio** replied that each magnet has acceptance criteria and tables in a separate document approved by the management, and to project guideline are to

avoid duplication. **Gianluigi** then asked to check the tables of D2, MCBX and MCBRD. **Ezio** replied that it is not yet approved and the final version is being edited tor D2 but he will check (**Action: Ezio**).

- **Glyn** commented that just the first set of measurements is being taken on the prototype in China. At room temperature the measurements are not enough precise, and we have to wait for measurements at 4.2 K to have reliable results. **Gianluigi** replied that there was an acceptance criteria document quoting maximum value of 3 units for b2. If it is different, the new value should be given. **Ezio** stressed that the tables are given in the acceptance criteria but, if there are discrepancies with the table after the measurements are done, corrective actions should be discussed.

4 AGENDA OF NEXT MEETING (GIANLUIGI ARDUINI)

The next meeting will be on Tuesday, July 7, starting at 09:00. The agenda will be:

- Update on GPU beam-beam simulations - follow-up (Konstantinos Paraschou)
- Linearized method for e-cloud instabilities (Giovanni Iadarola)
- E-cloud in the IR BPMs (Galina Skripka)
- E-cloud in triplets with Cu-LESS SEY curves (Galina Skripka)

Reported by G. Skripka