186th WP2 Meeting

Tue 8th Dec. 2020, 10:00 – 12:00

Chair:	Rogelio Tomás, Gianluigi Arduini
Speakers:	Riccardo De Maria, Frederik Van der Veken, Ezio Todesco
Participants (zoom):	Roderik Bruce, Ilias Efthymiopoulos, Hector Garcia Morales, Massimo Giovannozzi, Michele Martino, Elias Métral, Nicolas Mounet, Yannis Papaphilippou, Konstantinos Paraschou, Tobias Persson, Stefano Redaelli, Benoît Salvant

AGENDA

MEETING ACTIONS

Ezio	Write an EDMS document summarizing the D2 corrector naming conventions.
Ezio, Frederik	Define a realistic 2D model for the field imperfections in the MCBXF.

GENERAL INFORMATION (ROGELIO TOMÁS)

Rogelio reviewed the minutes of the 185th WP2 meeting. The first of the four talks was devoted to the impact of a crab cavity non-closure on the dynamic aperture, showing a quite comfortable situation from this point of view. In conclusion, only the luminosity will determine the tolerance on crab cavity non-closure, and an action was attributed to **Ilias** on this aspect. The rest of the meeting had been devoted to electron cloud, starting with two talks by **Lotta Mether**: on coupled-bunch tune shifts, showing no

concerns, and the other one on simulations of 16L2-like events, with large gas densities and a solenoid, which are getting close to the observations. On the tune shifts, one action is on **Hannes Bartosik** and **Gerd Kotzian**, to devise tests in the SPS to measure e-cloud tuneshift of single excited bunches. The last talk was made by **Kostas**, showing the impact of incoherent effects when adding e-cloud lenses (in one dipole per half-cell), in SixTrackLib. The issue is at low intensity, while the situation is more relaxed at high intensity. Studies are ongoing to e.g. increase the number of e-cloud lenses.

On the subject of crab cavity non-closure, **Riccardo** mentioned that he made a proposal to **Rama Calaga** on crab cavity monitors to check non-closure, with an optimized location (with the present phase advance).

From the 185th WP2 meeting an additional action was attributed to **Riccardo**, about a non-optimal transition between the TAXN and D2. **Riccardo** was ready to present a couple of slides right away, hence the meeting started with this short talk. Then the schedule followed as foreseen, in particular with two presentations by **Riccardo** and **Frederik** in preparation of the next TCC meeting on Thursday, and a report on new field quality measurements by **Ezio**.

1 AOB - Beam Aperture for TCT/TCL between TAXN and D2 (Riccardo De Maria)

This is a short report on an issue discussed already during the 185th WP2 meeting, itself following up a presentation on the TAXN aperture during the 184th WP2 meeting. The issue concerns the bellow between the TAXN and the collimator, for which the aperture (80 mm) is smaller than that of the stroke of the vertical TCTPXV collimator (84 mm). A similar (but less critical) issue occurs right before the horizontal TCTPXH collimator. One proposal is to increase the aperture of the bellows to 85 mm; the situation would then be ideal, the TAXN staying the aperture bottleneck.

Discussions already took place with **Stefano**, **Roderik** and **Luca Gentini**, who argued that this modification arrives relatively late for the horizontal collimator, but possibly still in time for the vertical one.

- **Rogelio** asked if the proposed change (80 to 85 mm) requires an engineering change request (ECR). **Riccardo** answered he is not sure; some numbers are anyway still not defined (they are not in drawings). **Stefano** added that independently of the ECR, the design of the collimator prototype is completed (it is built at CERN), and it needs to be installable. Hence the preference is to not change the design now. On top of that, the issue will become a limitation only later, and the gain will be extremely small because we are limited by the tank anyway (the dimensions of which should not be changed). Hence, he would not consider it as a strong priority, unless WP2 gives a strong request. **Roderik** added that the limitation arises only for flat optics, and not for the baseline; moreover, the triplet being at 12.3 σ one needs to lose 1.7 σ for this to become a real limitation. **Rogelio** argued that it is still not ideal to have a bellow of 80 mm when there is 84 mm in the stroke. **Stefano** asked **Riccardo** what the limitation becomes if the bellow aperture is increased. **Riccardo** answered the numbers are in the table shown (slide 3). He asked **Stefano** whether it is feasible to change part of the interface to the jaws, and if for the vertical one the

cost is minimal. **Stefano** answered that it is possible for all of them; indeed, for the vertical collimator, which is not being prototyped now and the closest to the transition, it's only a matter of time - one essentially has to redo the drawings, which could be done without any issue. **Riccardo** then mentioned that the horizontal one is not a strong issue, and a modification is not strictly needed. **Rogelio** concluded with the proposal to do the modification for the bellow before the vertical collimator only.

- **Ilias** commented that the TAXN is a massive object assembled from block and not easy to align, hence the efforts made by the TAXN design team to improve its alignment procedure and method (new support, improved tools etc.), and proposed to have a discussion/presentation to cross-check. **Rogelio** said this has to be checked. **Riccardo** mentioned that the latest tolerances are included - the tolerance set is being finalized and will be presented on Dec. 9th at the alignment working group.

After the meeting, a discussion took place between **Riccardo**, **Stefano**, **Roderik**, **Federico Carra**, **Luca Gentini** and **Inigo Lamas Garcia**. **Luca** stated that 1) it is possible to reach 85 mm for the three collimators - it is actually beneficial to use one size for all collimators; 2) the change of drawings is limited to the interfaces and most of the collimator design is unchanged; and 3) it will take about three weeks to update the drawings. **Inigo** and **Federico** did not see any significant risk in changing the design, but mentioned that it is important that the prototype has the same design as the final one. Delay due to the update of drawings could be partially mitigated by advancing the checks and starting the price inquire of the parts that will not be modified to advance the procurement process. It was then agreed to propose the increase of the interface from 80 to 85 mm. **Oliver Brüning** will be informed, as well as the vacuum and impedance teams.

2 IMPACT OF MCBXF STRENGTH LIMITATIONS ON ORBIT CONTROL AND POSSIBLE MITIGATIONS (RICCARDO DE MARIA)

This presentation reviews the strength limitations of the MCBXF and its possible mitigation using the Full Remote Alignment System (FRAS), in preparation for the next TCC meeting on Dec. 10th. It follows a number of previous presentations at the HL-LHC collaboration meeting on Oct. 6th, 2020 (talk by **Ezio**), at the 182th WP2 meeting (talk by **Riccardo**), and at the alignment working group (WGA) meeting #40 on November 25th.

The two main limitations of the MCBXF are 1) it may require training to reach combined nominal current when the sign of the torque is changed; and 2) the field imperfections specified for MCBXF (±20 units range for a3 and b3) provoke a non-negligible reduction of dynamic aperture. A potential solution for both problems would be to re-align the straight sections with the FRAS more often than once per year as initially foreseen. More specifically, the FRAS could be used for 1) triplet misalignment compensation during the year due to ground motion (0.5 mm expected), saving up to 1 Tm in MCBXF strength; 2) IP shift correction during the year (0.5 mm expected), saving up to 0.5 Tm; and 3) crab-cavity adjustment (0.5 mm expected), saving up to 0.2 Tm. Only beam-based alignment would be able to reach very precise alignment targets,

much better than the 0.5 mm initially foreseen. The proposed scenario is therefore to decide before each technical stop whether or not to use the FRAS to re-align (based on the movements observed so far and the impact on performance), and to use the MCBXFs for fine tuning the orbit.

During the WGA on 25/11/2020 meeting a number of considerations were discussed. A review of past LHC experience by **Jorg Wenninger** ended up with the following proposal: at injection, once the reference orbit is defined, one could "zero" the settings of the MCBXF through re-alignment, using a probe bunch and an iterative procedure (move a step with the FRAS, observe the orbit change, and follow with the correctors). If the HL D1/D2 magnets transfer functions are well known, additional trims at high energy could be minimal - a second straightforward iteration might be necessary to also zero the settings at flat top. Such a setup could hold for an entire year if the HL inner triplet region is as "stable" as the LHC one, applying minor trims occasionally (during technical stops).

According to machine protection, it is acceptable to perform alignment on pilot beams at injection. On the other hand, the powering of the motors of the FRAS needs to be interlocked, and the FRAS cannot be used as an operational knob - it requires re-validation with loss-maps and intensity ramp-up.

As far as hardware requirements are concerned, no major change is requested, and it may even be beneficial to the motors to be moved regularly. On the other hand, the reliability of the alignment systems become crucial (as also raised during the Cost & Schedule Review in November 2019). Hence additional redundancy would be recommended by installing a second wire stretched between Q1 and D1 (removing other sensors) - integration and costs are under study.

In conclusion, there are no fundamental limits to use the FRAS more often than once a year to mitigate potential MCBXF limitations, but re-qualification procedures from machine protection are essential to quantify the impact on performance.

- **Ezio** said that the last statement of slide 5 is actually incorrect: the MCBXF field imperfections do not depend on the powering history. The fact that one powers one or two magnets is important for the b3 multipole, but once we know the two currents, it is deterministic. **Riccardo** asked if it is possible to get measurements on a 2D grid, for several ratios of the two currents (for instance with a total of 200 points). **Ezio** answered that they have 16 lines today in the plot, with a few measurement points for each of them. **Riccardo** said this is a radial mesh. **Ezio** mentioned that there are some changes in a3/b3, while for the other multipoles, changes are practically negligible. He said he will show the data (Action: **Ezio** - see action in 182th WP2 meeting).

- **Rogelio** wondered if the fact we will not need to move the FRAS throughout the year, is really applicable for HiLumi. **Riccardo** answered that the IP orbit stability of the last years was excellent (20-30 µm). The amplitude of the parallel separation and lumi scan knobs were enough to compensate for the ground motion. The MCBXs were not used. If everything stays at this level, the orbit will be perturbed by 50 µm at maximum, so if the LHC stability is confirmed this is not an issue. **Rogelio** asked if we are not more sensitive in HiLumi. **Riccardo** answered in the affirmative, in terms of luminosity. **Rogelio** wondered if it is not also the case for the displacement of the IP. **Riccardo** answered that the order of magnitude is the same. If one does not correct for

it, indeed HL-LHC is more sensitive.

- Regarding the proposal to align with the FRAS at injection, **Rogelio** asked about the residue at top energy. **Riccardo** answered that part of this residue is coming from the transfer function errors in D1 & D2. He added that there is no feedback (nor feedforward) in D1 & D2. The idea would be that if the transfer function errors are important, one needs to compensate for them, which can be done with a couple of iterations. He also mentioned the tilt, which could be corrected (to a certain extent) by the FRAS.

- **Stefano** wondered if this discussion was not triggered too early. If there is no impact on hardware, he wondered whether we can actually wait for the run to take place. **Rogelio** said the main motivation is the non-conformity which limits the MCBXF strength. We need to decide if it is ok or not; one possible mitigation is the FRAS, so we need to check if it is OK to use it in the proposed way. **Ezio** said that he initially asked WP2 what would happen if all magnets are torque-limited, as the first prototype measured. **Stefano** said he doesn't know to what extent we can use the FRAS to mitigate issues on other hardware - it sounds optimistic and ambitious. **Ezio** said the point is to explore this possibility. **Stefano** also wondered how much can be assessed before Run 4, regarding the re-validation process after the FRAS. **Rogelio** said that we don't know yet if this will be adopted, but there is a potential issue and this is a potential mitigation - this is the message to give to the TCC. **Massimo** mentioned that the outcome of the WGA was to say that the FRAS can be used for this extended scope. The point is indeed to understand what validation would be needed and its time overhead - this will tell us if it is feasible or not. He also stressed the other motivation to use the FRAS, namely to mitigate the impact of the field imperfections for this magnet by keeping the reference field below the nominal level, hence removing the random component of the imperfections (b3/a3) - see the talk of **Frederik**. **Gianluigi** confirmed that there is a potential issue and WP2 has been asked to look for alternatives, both for the field quality and regarding the maximum field available.

- **Ezio** commented that the presentation of **Riccardo** gives the impression that the MCBXF magnets are all limited, and that this limitation cannot be overcome. Actually, the results shown on slide 5 were obtained only on the first prototype, and they are still working to improve the situation - the problem can still be solved. One should not overreact. **Rogelio** confirmed the importance of stating this clearly, and that the best solution is still to solve the issue on the magnet side.

3 UPDATE ON IR MAGNETS FIELD QUALITY: NESTED CORRECTORS AND SPREAD OF TF IN QUADRUPOLES (EZIO TODESCO)

This presentation provides an update on the field quality of the magnets of the triplet region in HL-LHC, following-up on the last talk on the subject during the 183th WP2 meeting. Results for the D2 corrector (MCBRD), the MQXFA transfer function and the MCBXFB are shown.

First, the naming convention of the D2 corrector is reviewed, as a wrong naming was sometimes used in

old slides. The convention is that from the connection side, the aperture 1 (Ap. 1) is on the left (and gives an horizontal kick) while Ap. 2 is on the right (vertical kick). The multipoles are normalized to the main field absolute value, and the angle is referred to the reference system (x radial, y vertical), hence there are 10 units of systematic b3 in Ap. 1 and -10 units of systematic a3 in Ap. 2. An EDMS document will probably be written to summarize these conventions.

For the D2 corrector, all data confirm the ±10 units of geometric b3/a3, which is at the edge of the specification. For Ap. 1, the saturation is beneficial to the b3 (it goes to -5 units) while for Ap. 2, the powering of Ap. 1 pushes a3 towards 15 units - hence the ongoing effort to try to center the geometric around zero (in particular via the iron shape); results should come in the first months of 2021.

For the MQXFA transfer functions (TF), the data of four magnets are shown to be within a band of 0.46% (46 units), which is large but within the specification of 50 units (acceptable maximum difference between any pair of magnets).

Finally, for the MCBXFB the data of the second prototype is reviewed, showing that b3 is well centered while a3 has 10 missing units to compensate for saturation. Both a3 and b3 are within the 20 units range specified by beam dynamics. b3 is particularly well centered, giving a ±10 units range. The b3/a3 multipoles for any combination of signs in the two apertures, is summarized in a table. Higher order multipoles are all within the specifications (b5/b7 within 10 units, and all the multipoles that are not allowed within 5 units).

- **Rogelio** mentioned that there are simulations with 50 units of difference between the MQXFAs TF, and results were looking ok.
- **Rogelio** asked if the MCBXFB is the shorter magnet. **Ezio** answered in the affirmative. After the meeting Ezio clarified that the potential improvement on the b3 by centering also applies to MCBXFA.
- **Frederik** asked for a confirmation regarding the MCBRD conventions, in particular regarding the horizontal kick which should be given by the left magnet. **Ezio** confirmed. **Frederik** then said that his routines should be modified accordingly. **Ezio** confirmed that this is important, and the need to write an EDMS document. **Frederik** said it is even implemented in the other way in the sequence (up to optics version 1.4 at least). **Riccardo** said this is indeed a known issue which is being addressed for optics v1.6. **Ezio** confirmed that on the right, the dipole is horizontal, hence the kick is vertical. **Gianluigi** insisted on the need to write an EDMS document on the subject (Action: **Ezio**).
- **Ezio** pointed out that the dependence on powering is not utterly complex (see discussion during the previous talk). **Riccardo** agreed. Regarding the use of the FRAS to mitigate the MCBXF issue, he added that the key is the commissioning time. **Ezio** said that one should also avoid triplet quenching when the corrector is quenching, which depends on the level of energy extraction. A WP3 meeting is organized around this subject on Dec. 9th.

4 MCBXF FIELD QUALITY IMPACT ON DA (FREDERIK VAN DER VEKEN)

This presentation is reviewing the key aspects of the impact on dynamic aperture (DA) of the magnet field quality, in preparation for the next TCC meeting on Dec. 10th. It follows a number of previous presentations at the 166th, 172nd, 175th, 180th and 182th WP2 meetings.

The core aspect is that the impact on DA of the field imperfections in the triplet region is very detrimental and dominated by the MCBXF, more specifically the b3/a3 multipoles of the MCBXFA, which alone gives almost the same DA decrease as all multipoles from both the MCBXFA and MCBXFB combined - a drop of 2.5 σ on the average DA for Beam 1 and of 3.5 σ on Beam 2. The DA decrease comes from the pure multipole error rather than the beta-beating via feed-down effects. The corrector package (CP) can fully correct the error, but this remains theoretical as the size of errors is relative to the reference field, itself related to the actual powering which can be largely unpredictable because of potential triplet misalignments.

There are three possible mitigations to the DA drop: 1) improving the magnet field quality; 2) using the CP while tracking the dependence on powering (this might be difficult and time-consuming, with potential compensation effects); or 3) keeping the operation as close as possible to the nominal powering cycle, e.g. using the FRAS to re-align the triplets. With the third aforementioned option, and assuming an ideal FRAS, the reference field of the MCBXF becomes deterministic and there is no remaining decrease of DA for Beam 1; however, a large DA drop remains for Beam 2, which might be recovered by a phase advance optimization. Moreover, without beam-beam, the DA is almost acceptable. There is also a decrease of DA with the crossing angle, visible already at low angles, that could potentially be solved by correcting the errors (assuming the FRAS is used). Note that at large β*, the DA is much larger and the MCBXF imperfections pose no issue, thus ensuring a smooth beginning of operation even in the absence of multipole corrections from the CP.

As a side note, the sensitivity of DA on the signs of the individual reference fields of each magnet, is underlined. The impact of signs on DA is rather unpredictable because of possible compensation effects. Monte-Carlo simulations are needed to understand better the effect of the sign configuration.

In conclusion, in the absence of field quality improvements, or without using the FRAS, the DA is below specifications. Even with the FRAS, Beam 2 remains marginally acceptable. One still needs to verify the reliability of the correction algorithm (assuming the FRAS) and see if the drop of Beam 2 DA can be recovered by using the CP. Also, one has to check if the DA improvement is sufficient when applying the correction obtained for the middle value of the half crossing angle, to all crossings (during levelling).

- **Rogelio** agreed with the general message. He underlined that without action, the situation is not comfortable. Among the three possible mitigations, the ideal one is the improvement of the field quality. The second ideal solution is the local correction, and the third is to use the FRAS, which will not be enough anyway. **Frederik** pointed out that following the reference field by use of FRAS might be possible with efficient measurements of the powering, and then the second solution might be very good, but in combination with FRAS.

- **Ezio** asked if in the simulations, 20 units were taken for the a3/b3. **Frederik** answered it is 18 or

19 units (values given by **Ezio** some years ago). These values are multiplied with the choice of reference field (with a factor 1e-4), represented by the green dot in slide 2. **Ezio** asked if this is a systematic error. **Frederik** answered in the affirmative; there is no random error. Simulations with random errors were also shown (see 182th WP2 meeting) - their impact is small. **Ezio** asked if there is full power in one plane, while the other one has only half the power. **Frederik** answered in the affirmative - this is the configuration with a full crossing plane. **Ezio** said that one can do better. **Frederik** answered that the best would be to do a Monte-Carlo study. **Rogelio** asked what "better" means, in particular if **Ezio** meant that a better field quality can be achieved for that particular setting. **Ezio** suggested producing a two-parameter model for field quality in the MCBXF (depending on H and V currents) - this has never been done, and a few weeks would be needed to find the right way. **Frederik** agreed (Action: **Ezio**, **Frederik**) and said the idea here was to test the corner cases, to be conservative. He mentioned the small Monte-Carlo study he performed a few years ago, which showed that results are very sensitive to how the magnets are powered (from 0 to 4 σ), hence he chose to stay on the pessimistic side. **Rogelio** agreed that a more refined model for the field quality would be nice, adding that now only a linear scaling was used. After the meeting **Ezio** added a preliminary 2D field quality model to his slides in indico.

5 ROUND TABLE (ROGELIO TOMÁS)

This meeting was the last WP2 meeting where **Gianluigi** acted as chairman - a few retrospective slides were hence shown by **Nicolas** and **Rogelio** at the end of the meeting.

The next WP2 meeting will be a Special Joint HiLumi WP2/WP5 Meeting, devoted mainly to impedance of collimators, at a date that has not been decided yet. The agenda will be the following:

- Longitudinal impedance measurements and simulations for the crystal collimator in HL-LHC (Danilo Quartullo),
- Transverse impedance of the crystal collimator (Benoit Salvant),
- Status of new smaller H011 cavity and RF measurement of irradiated samples (Adnan Kurtulus),
- Comparison of DC and RF measurement for ion irradiated samples at GSI (Carlotta Accettura).

Reported by N. Mounet & R. De Maria