WP2 Meeting #172

Tue 7 Apr 2020, 10:00 – 12:30

Chair:	Gianluigi Arduini
Speakers:	Ezio Todesco, Frederik Van der Veken, Riccardo De Maria, Giovanni Iadarola
Participants:	Gianluigi Arduini, Xavier Buffat, Barbara Dalena, Riccardo De Maria, Paolo Fessia, Hector Garcia, Massimo Giovannozzi, Giovanni Iadarola, Clement Lorin, Ewen Maclean, Elias Métral, Nicolas Mounet, Yannis Papaphilippou, Konstantinos Paraschou, Tobias Persson, Thomas Pugnat, Stefano Redaelli, Marta Sabate Gilarte, Galina Skripka, Kyriacos Skoufaris, Guido Sterbini, Ezio Todesco, Rogelio Tomás, Frederik Van der Veken

AGENDA

MEETING ACTIONS

Frederik	Study a possibility to use feed-down cancellation to increase the DA
Gianni, Rogelio	Give a detailed characterization of the burn-off, looking iteratively at the burn off properties of the partner bunches

GENERAL INFORMATION (GIANLUIGI ARDUINI)

Gianluigi briefly went through the minutes of the previous meeting. Serge presented the constraints in cryogenics when going to maximum peak luminosity: it is currently not possible to reach it in one step. At present $2.5*10^{34}$ $cm^{-2}s^{-1}$ can be reached in a step, which is then followed by a 10 minutes pause and a ramp to maximum peak luminosity. This strategy is now used to redesign the operational scenario. Rogelio presented the scenarios for luminosity ramp-up over the years of HL-LHC operation. There was an action for Rogelio to evaluate the effect on integrated luminosity in IR1&5 in case LHCb will be operating at higher luminosity ($1.5*10^{34}$ $cm^{-2}s^{-1}$ instead of $2*10^{33}$ $cm^{-2}s^{-1}$). The effect was estimated by Luis Medina Medrano and is in the order of 2% for the nominal case. **Rogelio** will do the estimation for the ultimate case. Davide presented the impact of flux jumps in the operation with ions. **Davide** will present at the next TCC on Thursday the summary of the flux jumps study and sum up what needs to be studied/measured for the triplets.

Today, there is an update on the b4 correction by Ezio. Then, Frederik will present the results of a new study on the effects of feed-down from b3 in D1, D2. After that, Riccardo will give a talk on D1 aperture optimization to avoid designing a new beam screen. Finally, a short update on filling schemes, considered for operational scenarios, is given by Gianni.

1 THE ENIGMA OF B4 CORRECTION IN IR5 (EZIO TODESCO)

This is an update on b4 in LHC, previously discussed in FiDeL meetings. The amount of b4 in the IR triplet can be measured via the detuning with amplitude. The octupolar sources in IR are MQXA, where a systematic b4 comes from the mechanical structure with dipolar symmetry, MQXB, where a small systematic b4 is enhanced by the large beta functions, and the beam screen due to its dipolar symmetry gives additional 0.12 units (with a change of sign in IR5&1 due to installation in H/V direction).

Today the modeled and measured corrections are in very good agreement in IR1 but in IR5 there is a large discrepancy of 0.5 m^{-4}, which is about 20% of the maximum correction (1 m^{-4} corresponds to 1.6 units of octupolar error in MQXA and zero in MQXB. The total correction range provided by corrector octupoles in IR is 2.4 m^{-4}).

To understand the origin of discrepancy it was proposed to decompose the correction in individual contributors. Considering the contribution of only the MQXA it was found in between the two measured values of IR1&5. Then, the contributions of MQXB and beam screen were added individually. The beam screen orientation is vertical in IR1 and horizontal in IR5, thus, the b4 contribution of 0.3 m^{-4} has different signs. This results in an exact match between the model and measurement in IR1 and a jump in the opposite direction in IR5. It was observed that if the sign of the beam screen contribution in IR5 is changed, the model corresponds well with the measurements. However, it is absolutely impossible that the beam screen was installed in the wrong orientation in IR5 (N. Kos and vacuum group). There is no physical indication that the sign is wrong.

To conclude, the agreement between the beam based measurements and model is in very good agreement in IR1. The discrepancy in IR5 is still present and cannot be explained by changing the sign of the beam screen contribution, since it would be unphysical. A hypothesis proposed by Massimo suggests CMS solenoid leaking an octupolar component in MQXA.

- **Barbara** commented that currently an estimate of the 3D distribution of the field in the triplets is ongoing. She asked what is the origin of the different sign when the beam screen has different orientation. She also asked how this could possibly be added in ROXIE simulations. **Ezio** replied that b4 is the first harmonic excited due to not fully symmetric chamber (rect-ellipse shape). The two orientations of the ellipse give two different signs. The beam screen contribution is difficult to measure, so it is computed by ROXIE.
- **Clement** asked if only the nominal yoke was taken into account in ROXIE simulations of magnets, or were deformations considered. **Ezio** replied that the magnets are measured. The producer did simulations of the magnet and no deformation of the yoke was considered. **Gianluigi** asked if the measurements were done at nominal field. **Ezio** replied that it was done at cold and nominal fields.
- **Rogelio** added that the welding in the beam screen has to be taken into account. **Ezio** replied that computations were done but this needs to be checked. **Rogelio** asked if for HL-LHC there is a plan to measure the field quality with the beam screen. **Ezio** replied that this is planned for both types of the beam screen. It is expected to give contribution only to b6, from symmetry considerations. **Gianluigi** added that the welding breaks the symmetry. For HL-LHC the effect of the beam screen has to be estimated and presented (**Action: Ezio (same as on WP2 meeting #169)**)

2 EFFECTS OF FEED-DOWN FROM B3 (FREDERIK VAN DER VEKEN)

This presentation covers the study of possible impact on the beam quality from the b3 component feed-down in D1, D2/MCBRD and MCBXF. For this study a dedicated script cancelling the feed-down from higher-order errors was created and then used to analyze the impact of feed-down on β-beating, tune shift and β^*-beating.

To calculate the reference orbit, the script temporarily removes the errors for which the feed-down will be corrected (errors are reapplied afterwards). Then, the feed-down correction is added as an extra contribution to the multipoles. The typical feed-downs resulting in β-beating are b3 → b2 and a3 → b2, and resulting in coupling are b3 → a2 and a3 → a2. The full derivations of the cancellations of feed-downs are given in backup slides of this presentation.

To test the script, firstly, the b3 error was set to 1 unit in a single slice of one MBXF magnet and the β-beating was calculated with and without feed-down cancellation. Cancelling the feed-down almost completely removed the β-beating. The small impact on the orbit distorting the correction comes from the second-order feed-down of b3 to b1 and a2. When these are cancelled the β-beating is completely removed. In the second test the b3 error was set to 1 unit in all D1 magnets, still keeping the other errors at zero. The effect of cancelling the feed-down was found to be much less efficient. A possible explanation is the b3 feed-down to a2, which creates coupling, thus, influencing the orbit and distorting the correction. When this feed-down is cancelled (in addition to b3 →b1 and b3 → a1) the β-beating was completely removed again. In the final test, all the nominal errors were assigned to D1 magnets. In this case the β-beating could not be removed completely, especially in vertical plane. This effect can be explained by the feed-down of other orders onto b2, a2, b1, and a1. Detailed analysis of the error strengths shows that the feed-down from a3 into b2 explains the large β-beating in the vertical plane. By cancelling all feed-downs up to b6, it was possible to remove the β-beating completely.

The effect of the feed-down on β-beating was estimated for realistic magnets using the newly developed script. In MCBXF β-beating could be reduced from 5% to about 1% by cancelling feed-down from b3 and a3. Concerning the errors, The MCBXF is dominating the β-beating. For D2 magnets the errors of MCBXF are not assigned, to be able to see the smaller effect, not covered by the MCBXF contribution. Cancelling the b3 and a3 feed-down in D2 had very little effect on the β-beating. No effect was observed for MCBRD as well. For the D1 the impact of the feed-down cancellation is under investigation.

The effect of the feed-down on the tune shift was studied. In MCBXF there is a significant reduction from both b3 and a3 cancellation. No effect was observed in D2/MCBRD. The impact on the β^*-beating is not as pronounced as on the tune shift or β-beating, but overall behavior for different magnets is similar.

In summary, the dedicated script for cancellation of feed-down was developed, tested and applied to the D1, D2/MCBRD, and MCBXF magnets. The study has shown that the impact of the feed-down from b3 and a3 on β-beating, tune shift and β^*-beating in MCBXF is substantial and in D2 and MCBRD is negligible. The effect in D1 is not yet well understood. Possibility to use feed-down cancellation to increase the DA will be studied. In case of positive results, an application of feed-down cancellation in real machine will have to be investigated.

- **Gianluigi** asked how the errors are cancelled when calculating the reference orbit. **Frederik** replied that for example b3 in MCBXF can be zeroed, then orbit calculated, and then b3 is assigned back to MCBXF. The orbit in this case was calculated with all the other errors.
- **Gianluigi** asked if for the MCBXF the error table provided by Ezio is used. **Frederik** confirmed.
- **Gianluigi** summarized that the feed-down from b3 and a3 (-16 and 20 units) in the MCBXF has an impact on DA, which is dependent on the exact settings of the magnet that varies slightly, and a non-negligible impact on β-beating. **Frederik** added that the effect of the MCBXF is strongly influenced by the strength of the reference field and the sign of it. This study was done just for one sign configuration. **Gianluigi** added that this is another argument to reduce the b3 or at least to have an accurate measurement as a function of the MCBXF settings.
- **Massimo** commented that it is not yet clear whether the loss in DA due to the b3 component is the result of the beta beating.
- **Paolo** recalled that b3 and a3 were linked to saturation of the iron and rotation of the fields, due to the position of the heat exchangers to match the other magnets. If it is still the case, it is extremely difficult to correct. **Massimo** commented it would be good to improve the field quality but the reasonable goal values for b3 and a3 have to be determined. **Paolo** said that is was impossible to improve.
- **Gianluigi** added that this should be reported to the TCC.
- **Gianluigi** asked to report on the effect on the DA **(Action: Frederik).**

1 D1 APERTURE OPTIMIZATION (RICCARDO DE MARIA)

This is a short update on the D1 aperture optimization. In HL-LHC design one of the main criteria was minimization of β^* reachable. For this the apertures were designed making the triplets the aperture bottleneck by giving margins in near by structures (D1, TAN, D2, Q4-Q5). D1 was never a bottleneck until it was decided to extend the service module and the length of the beam screen.

In case of round optics, at the location of D1 the beam sizes decrease and the horizontal separation increases, thus, creating an aperture bottleneck towards the end of D1. There are two strategies to address the problem: to increase the size of the beam screen by 1.5 mm at the end of cold mass or to displace the end of D1 by rotating it (shift the end by 1.5 mm towards the outside of the machine). The two mitigation options can be applied separately or together.

The apertures were explored at four different locations (end of D1 body, end of the beam screen with nominal size, short transition of beam screen, end of beam screen) for the four scenarios: for the baseline, for the new beam screen, for the rotated baseline and for the rotated new beam screen. In the baseline scenario the aperture bottleneck 13.17σ is at the end of the beam screen. With the new beam screen the aperture bottleneck is 13.36σ and shifts to the end of the beam screen with nominal size. This shows that the location of the start of transition is not optimal, but still improves the aperture. In case of rotation of the baseline the bottleneck aperture is improved to 13.7σ and stays at the end of the beam screen. Combination of the new beam screen and rotation results in the aperture of 13.88σ that is located at the start of the transition.

Comparison of the apertures for the flat and round optics was presented. Rotation improves the situation for the round optics, however, for the case of flat optics, rotation resulting in more than a 2 mm shift at the end of the beam screen reduces the aperture. The value of 2 mm shift from rotation gives a trade-off between the round and flat optics. Identical values for the apertures, acceptable for both the round and flat optics, can be achieved by, either rotating (1.5mm shift) a new beam screen, or rotating (2 mm shift) the old beam screen. In both cases there is about 1σ margin between the aperture in the triplet and in D1.

- **Gianluigi** asked what happens when rotating the new beam screen by 2 mm. **Riccardo** replied that 0.2σ is added in the flat optics case.
- **Gianluigi** asked if 2mm displacement if feasible for D1. **Paolo** replied that 2 mm shift has a very small impact on the bellows and is not problematic. He asked why not to optimize for the round optics (preferred scenario) and ask the vacuum group for 2.5 mm rotation. **Gianluigi** replied that one could further optimize after construction if needed.
- **Riccardo** added that, if the triplet will be displaced for radiation reasons, the apertures in the triplet may overshadow the situation in D1.
- **Gianluigi** stressed that starting with 2 mm will be good for understanding what would be the situation in reality (best case or worst case optics) and deciding if shift of 2.5 mm is needed. **Paolo** added that the Remote Alignment can be used for that.
- **Gianluigi** suggested presenting this as a possible solution to TCC asking for a 2 mm case. **Massimo** and **Paolo** proposed to present this to the WGA beforehand.

3 HL-LHC FILLING SCHEMES (GIOVANNI IADAROLA)

This presentation summarizes constraints that are assumed in the design of the filling schemes and the results obtained for HL-LHC. The new filling schemes for different operational scenarios are now uploaded on the WP2 webpage.

The filling schemes are generated with the LPC tool using the following assumptions: kicker gaps and abort gap lengths are the same as used in Run 2, the kicker pulse lengths are more than 8.55 μs (determined by 8b+4e scheme), the first injection is of 8 or 12 bunches for machine protection reasons (non-colliding in IP1&5), all other bunches are colliding in IP1&5. The filling schemes are as close as possible to four-fold symmetry, to maximize collisions in IP8. The generated filling schemes are analyzed with the FillingPatterns python package.

The baseline scheme includes a second train of 12 b (as was done before) and is made of up to 4 trains of 72 bunches. Following the request by Rogelio, additional information on burn-off was calculated for the colliding/non-colliding bunches in IP8 and their IP1&5 partners colliding/non-colliding in IP8. There are about 10% of bunches that either do not collide in IP8 or have a IP1/5 partner that does not collide in IP8.

In the BCMS scheme the four-fold symmetry cannot be fully enforced and the portion of bunches in a different burn-off regime is almost doubled. With this filling scheme there are bunches that do not collide in IP8 and have collisions with other bunches also non-colliding in IP8. The 8b+4e scheme in terms of burn-off is similar to the baseline scheme.

The beam-beam pattern for the baseline scheme shows that only a small amount of bunches is not colliding in IP8. In the BCMS scheme there is about 10% of bunches that are not colliding in IP8.

The OMC team has requested a special filling scheme to measure coupling during physics fills. The main requirement was to have a small number of bunches which have no beam-beam encounters. A modification of a 48b scheme (with a loss of 9% of the total number of bunches) was made to get 8 bunches with the required characteristics. The loss in the total number of bunches is considered acceptable and should not affect much the integrated luminosity if the scheme is used only once every ~20 fills.

- **Gianluigi** asked if the tools for the filling scheme analysis could be shared with the Operation and the LHC Program Coordination colleagues. **Gianni** replied that the tools are public and he will inform the LPC**.**
- **Gianluigi** asked if in the BCMS scheme the non-colliding bunches with a different burn-off are colliding in IP2. Gianni replied that this is most likely the case and can be easily checked. Rogelio added that a more detailed characterization of the burn-off could be done, looking iteratively at the burn off properties of the partner bunches **(Action: Gianni, Rogelio)**.
- **Gianluigi** asked how often the scheme dedicated to the coupling measurements would be required. **Tobias** replied that this would be done as often as possible (in the order of every second week). **Gianluigi** asked if this should be done on bunches with long-range and head-on as well. **Rogelio** said that it is not clear weather it is possible to measure the coupling with the long-range. **Xavier** added that, if possible, measuring on bunches with beam-beam encounters could give more information on beam-beam.

4 AGENDA OF NEXT MEETING (GIANLUIGI ARDUINI)

The next WP2 meeting will be on Tuesday, April 21th, starting at 9:00. The agenda will be:

- Measurement of collimator block irradiated samples - status and plans (Nicolo Biancacci)
- Beam-beam induced crabbing (Xavier Buffat)
- Tune separation along the bunch train (Carlo Zannini)
- Short update on the difference between old and new impedance model (Nicolas Mounet)
- Short update on the HL-LHC octupole and TeleIndex requirement with the new impedance model (Xavier Buffat)
- Beam stability with e-cloud for bunch intensities below 2.3e11 (Gianni Iadarola)

Reported by G. Skripka