182\textsuperscript{th} WP2 Meeting
Tue 13\textsuperscript{th} Oct. 2020, 10:30 – 12:30

	extit{Chairs:} Gianluigi Arduini, Rogelio Tomás

	extit{Speakers:} Frederik Van der Veken, Riccardo De Maria

	extit{Participants (zoom):} Roderik Bruce, Xavier Buffat, Juan Carlos Perez, Davide Gamba, Jesús A. García Matos (CIEMAT), Hector García Morales, Massimo Giovannozzi, Gianni Iadarola, Sofia Kostoglou, Ewen Hamish Maclean, Michele Martino, Carla Martins (CIEMAT), Elias Métral, Nicolas Mounet, Yannis Papaphilippou, Konstantinos Paraschou, Stefano Redaelli, Ezio Todesco, Fernando Toral (CIEMAT).

\textbf{AGENDA}

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\textbf{MEETING ACTIONS}

\begin{tabular}{l|l}
Frederik, Massimo & Perform the DA study on the MCBXF with random errors, without the MCBRD, for the nominal case. \\
Ezio & Provide field quality measurements for the MCBXF in a grid of working points consistent with the operational scenarios \\
Riccardo & Check with machine protection the possibility to use the FRAS as an orbit corrector; also check the interlocks on the FRAS. \\
\end{tabular}
**GENERAL INFORMATION (GIANLUIGI ARDUINI)**

Gianluigi reviewed the minutes of the 181th WP2 meeting, which were circulated (no comments were received). The first talk, by Riccardo, introduced the optics versions and scenarios. Then Thibaut Lefevre provided the point of view from instrumentation, and showed that the requirements are met, at the possible exception of the BGV for beam 1 - investigations regarding possible locations are ongoing. One action has also been assigned to him, concerning the impact of dispersion on emittance measurements. Wolfgang Höfle then discussed the optics as seen from the point of view of the transverse damper, and showed that requirements are also met. Two actions are assigned to the damper experts, regarding the impact of the increased beta functions in Q9 and Q10, and on the computation of the pick-ups figure of merit during Run 2, considering the optics evolution along the run. Besides, these figures of merit will also have to be computed by Riccardo for future optics scenarios. The talk of Sofia then provided DA estimates with the new operational scenarios, including beam-beam effects. The option with the positive octupole polarity, without telescopic index during the ramp and squeeze, seems to provide sufficient margins from the simulation point of view (with relaxed collimator settings). The idea now is to study this configuration for Run 4, also considering the case without MS10. A plan has been discussed between Yannis, Rogelio, Massimo and Gianluigi for next year, where it will be checked if we can go down to β*=15 cm without MS10 (which could be installed during LS4). The last talk was from Nicolas, as a follow-up on an action regarding the collimator geometric impedance, in particular in an attempt to understand better the discrepancy between two different measurements on a specific primary collimator. In the end, it turns out the measurements are quite consistent between each other for this collimator, and the discrepancy with the model (of around a factor 3) is rather constant throughout the years. An action was assigned to Elias, to collect a list of measurements during Run 3, aiming at a better understanding of such discrepancies.

The schedule of the meeting was then announced. A talk by Riccardo was added after the Task leaders' meeting that took place last Friday and the presentation by Ezio during the HL-LHC collaboration meeting last week, showing in particular that the MCBXF corrector cannot operate at maximum field in both x and y at the same time. Riccardo will discuss the issue, and assess if we can use the Full Remote Alignment System (FRAS) to operate.

Finally, an announcement was made by Stefano on the 11T magnets. A meeting took place on Monday within WP11, with the CERN/TE management, and it was recommended not to install the 11T dipole magnets during LS2, as there are a number of issues discovered only when the long magnets were produced. If the recommendation is followed the installation is postponed until LS3. As a consequence, Oliver Brüning mentioned we have to accelerate on the plan B for ions, i.e. the crystal collimators. For the magnets, the main focus is now on the quadrupole program, to have everything available for LS3. There will be an ATS management board next Monday where a final decision will be taken and the plan for crystal collimators will be presented to the directorate. Gianluigi also mentioned that this means a full set of Nb$_3$Sn magnets will be installed during LS3, with potentially unknown consequences in terms of flux jumps: the installation of dipoles only was not deemed to have an impact on machine availability because of beam losses, but the situation is less clear for the triplets, as the exact characteristics of the flux jumps
are not known, as well as the exact impact of those in the operation of the nested power converters of the triplets. Gianluigi concluded that we need additional measurements for the qualification of flux jumps.

1 DA WITH THE FIELD QUALITY SPECIFIED IN THE HL-LHC MAGNETS ACCEPTANCE CRITERIA DOCUMENTS (FREDERIK VAN DER Veken)

This presentation studies the effects of random multipole errors in the MCBRD and MCBXF, on dynamic aperture (DA), the idea being to probe with high statistics the range encompassed by the acceptance criteria listed in the corresponding official EDMS document. It is a follow-up of a number of previous presentations during the 180th, 175th, 172th and 166th WP2 meetings. Multipoles up to the seventh order are taken into account, with two types of errors considered (and added together): a systematic error (as already implemented in the existing error tables), and a new random error of ±3 units for the MCBRD and ±5 units for the MCBXF, corresponding to the respective acceptance criteria. The random errors are generated through a Gaussian distribution, identical for all multipoles (the higher acceptance criteria on a_3/b_3 are taken into account by the systematic error on them). The study was performed with v1.4 round optics at the minimum β* (15 cm), without octupoles, with low chromaticity, with all other magnets at their nominal settings and errors, and using BOINC.

Regarding the MCBRD, the beta-beating from b_2 remains perfectly manageable (around 0.5%) - feed-down from b_3 is negligible as the orbit due to the separation and crossing bumps is very small at this location. The DA is increased by systematic errors through internal compensations, but random errors remove this effect. When looking at the impact of each order separately, multipoles from 2nd to 5th order create compensations and increase the DA, but not the 6th and 7th orders. Overall, the impact of MCBRD on DA seems under control, but still requires further investigations to fully understand the compensation effects.

To evaluate the impact of the MCBXF field quality, the reference field, which depends on orbit bumps in principle, is here set at its maximum. Non-negligible beta-beating is created both by pure b_2 and by feed-down effects from a_3/b_3 errors (the latter being about double as strong as the former), and are much stronger than the MCBRD (around 6%), but still manageable. To investigate the impact of the MCBBF field imperfections on DA, a comparison is made against a baseline where for all other magnets the nominal errors are assigned (and only the systematic ones for the MCBRD). The addition of the MCBXF systematic errors (from error tables provided around 5 years ago) decreases strongly the DA (as already shown in previous presentations), but this effect is not worsened when adding the random errors on top. Looking at the impact of each order separately (with the caveat that the baseline shown is only for 60 seeds), the a_3/b_3 multipole errors are confirmed to be the main contributions to the DA decrease, while other orders are not an issue. Overall, the MCBXF has a strong impact on DA, and mitigation measures have to be found.

As a possible mitigation for the MCBXF field quality, one should take into account the use of the FRAS, i.e. that it could correct for triplets misalignments and hence allow to set the reference field of the MCBXFs to what is needed to generate the crossing and separation bumps, which is about half of the magnets.
maximum value. The beta-beating is then halved, and the DA improves strongly: it is almost fully recovered for Beam 1, while for Beam 2 half of the decrease is recovered. No strong effect is seen when adding the random errors, as previously. Moreover, as the reference field is now deterministic, the MCBXF $a_3/b_3$ multipole errors could potentially be corrected by using the CP magnets. The impact of multipole errors on DA remains to be investigated order by order under the assumption of using the FRAS.

In the future, the impact of the MCBXF at higher $\beta^*$ will also have to be analysed, as well as the acceptance criteria for the non-linear corrector package (CP).

- **Gianluigi** asked why a uniform distribution of errors is not used. **Frederik** answered that it could be done, but it requires revising the routines, and is also less representative as errors for all other magnets are assigned in this way as well. Gaussian distributions are both convenient and consistent with what is done usually.

- **Gianluigi** asked what “nominal” means in slides 7 & 8. **Frederik** answered that it is everything except the MCBXF and MCBRD. **Gianluigi** then asked if the other magnets were assigned the errors, as in previous studies. **Frederik** answered in the affirmative. **Gianluigi** then wondered if there are similar intervals for the multipoles of the other magnets. **Massimo** answered that for the other magnets, i.e. triplets, D1, and D2, the acceptance criteria are based on error tables that are always used in our tracking studies. He added that if we have intervals up to the $a_6/b_6$ multipoles, they will be absorbed by the corrector package. **Gianluigi** argued that we have symmetric acceptance criteria around zero. **Massimo** replied that the systematic is corrected by the CP. Preset values of the CP will be based on magnetic measurements that should be accurate (in the document we also have the accuracy of the field quality measurement for the triplets). Also, even on top of a small systematic error there is a random error at a given value, which is corrected by the CP. **Frederik** mentioned that for the MCBRD/MCBXF, they did not get precise values for the multipoles, as in the past, hence they have to look at the impact on DA when sampling a full range considered as acceptable; this is a change of paradigm. **Gianluigi** insisted on the quality of the measurements. He concluded that “nominal” means that for every seed the corrections are computed and applied with the non-linear CP. **Frederik** answered that it’s indeed the case; this is done seed-by-seed. Nominal is the starting point for the tracking.

- **Rogelio** asked if $a_2$ means actually $a_2+b_2$ (slide 8). **Frederik** answered it is really only $a_2$. **Rogelio** mentioned that in the past, an increase of DA with sextupoles was indeed observed, as in slide 8. **Frederik** answered he is not sure what is happening; the same takes place with other low order (both $a$ and $b$ multipoles). After the meeting, **Massimo** mentioned that all this indicates the need to revise the way the CP package is used, as it is not for sure that the current strategy for defining the strength of the CP magnets maximizes the DA.

- **Gianluigi** asked if the interval of random errors is around the value given by the systematic error $\xi_M$. **Frederik** answered in the affirmative.

- **Gianluigi** commented that the beta-beating depends on the settings and operational conditions. **Frederik** answered that indeed the impact is very different depending on the settings. **Rogelio**
then added that a RMS around 6% implies there is a significant imbalance between the luminosities in IP1 and 5.

- **Gianluigi** asked what “nominal” means in slide 12, and wondered about the high DA there. **Frederik** answered that it is actually with the MCBRD systematic errors included (also in the next plots). Hence the compensation effect is included (see the second point in the plots of slide 7). **Gianluigi** commented that the “nominal” in slides 7-8 and in slide 12, are not the same. **Frederik** confirmed, and claimed that it would be unfair to compare without the MCBRD. **Massimo** said they will review the slides. **Gianluigi** insisted that it might be good (for e.g. the TCC talk) to present the results with respect to the first “nominal” (without MCBXF/MCBRD), at least until the cancellation is understood. **Frederik** said that changing the nominal means doing again the full study. The point was to study each magnet separately. **Gianluigi** insisted that with the MCBRD and MCBXF, one should add one corrector at a time, the baseline being only with the triplets and other magnets. The idea would be to check that the effect of each corrector magnet is not large. **Frederik** replied that one would just see all curves shifted down (Action: Frederik, Massimo).

- **Rogelio** said that in the TDR update, there is a new target of minimum DA without beam-beam (8 σ). **Massimo** said that indeed one can highlight this target. **Frederik** argued that the high number of seeds, as used for this acceptance study (240), necessarily decreases the DA with respect to a study with 60 seeds. Hence one should always use the standard of 60 seeds in order to compare with the target.

- **Massimo** mentioned that the maximum order at which we can apply the acceptance criteria was discussed with **Ezio**; it was decided to go up to the 7th order - this is quite conservative.

- **Rogelio** asked what the assumptions are when using the FRAS. **Frederik** said they stick to half the strength of the orbit corrector. **Rogelio** argued this is a huge constraint: the FRAS is not curing the problem, and yet we are assuming we will not use the full strength of the magnet. (After the meeting, **Massimo** mentioned that one does not want to limit the strength of the MCBXs, but rather to limit it to what is needed for the separation and crossing bumps. If one would propose bumps needing the full MCBXFs strength we would review the situation in terms of DA, but this is not the case now. With this approach, the strength of the MCBXF is always optimized, i.e. used only for the bumps, which has a beneficial effect on the DA. Moreover, the fact that the strength would be set in a deterministic way, opens the possibility of correcting the MCBXF FQ by means of the CP magnets, using pre-defined corrections based on magnetic measurements). **Gianluigi** said the idea is to measure the magnets in all the phase space in which we can operate. **Rogelio** commented that the measurement of the magnets happens well before we use them in the machine, and they should be measured on a grid (Action: Ezio). **Gianluigi** also asked if the assumption from **Frederik** is that they can correct perfectly, i.e. they have nominal settings without errors from misalignment or orbit errors. **Frederik** answered the errors are relative to the reference frame which comes from the optics. There is no orbit error. **Massimo** mentioned that one can use the FRAS to reposition the triplets, while outside IRs the orbit is taken care of by other orbit correctors. **Gianluigi** asked if we are assuming that the FRAS works perfectly. **Massimo**
answered in the affirmative. Gianluigi concluded that then there is no tolerance on the residual error from the FRAS. Frederik argued that this is somehow within the random error from the MCBXF. Later in the meeting (after the third talk), Rogelio came back to this discussion and argued that the order of magnitude between residual triplet misalignments and random errors from the acceptace, is very different. Frederik said he had assumed that the excursion from the reference frame is of a few percent. Gianluigi mentioned that indeed, the triplet misalignment is non-negligible w.r.t to the systematic part (see Riccardo’s next talk and discussion thereafter), even if it is reduced by a factor 2. Frederik asked if it is an uncertainty. Gianluigi confirmed it is, as it will evolve during the year (from zero after correction, to half of the value after some time). Frederik said that for a stricter assessment of the MCBXF, one should do a more computationally intensive Monte Carlo study on the reference field, but they would need a precise range for it. After the meeting, Massimo concluded that all this should be reconsidered once the questions raised about the new needs for the FRAS have been answered and we know exactly what FRAS can do and what it cannot do.

- Gianluigi concluded that there will be a learning curve for the MCBXF, with implications on how to get there.

As the discussion moved toward the use of the FRAS, it was decided to go right away for the talk of Riccardo, and move the second talk of Frederik to the end of the meeting.

2 MCBX CORRECTOR BUDGET AND POTENTIAL USE OF THE FRAS TO REDUCE IT (RICCARDO DE MARIA)

This presentation was triggered by Ezio’s talk at the HL-LHC collaboration meeting on Oct. 6th, 2020, in particular slide 13, showing that retraining is needed for the MCBXF in combined mode, to get more than 25% of the torque, whenever the torque sign is changed. This limits the operation of the MCBXFA in the non-crossing plane to 1.5 T.m, and of the MCBXFB to a circle (in the x-y plane) of 1.15 T.m, hence missing around 1 T.m of the corrector budget for both magnets.

For the MCBXFB and the non-crossing plane of the MCBXFA, at least half of the budget is taken by the 2 σ correction from triplets transverse misalignments - in the other plane, the MCBXFA budget is mainly used for the crossing (MCBXFB are also used for crossing angle with small strength, however the strengths increase for presqueeze optics with β* > 50 cm). Other important contributions to the corrector budget are the IP offset correction, and the crab cavity motion. The triplets misalignments could be partially taken by the FRAS, for which the 2.5 mm budget is currently mainly assigned to the IP shift following the ground motion of the detectors (2 mm) and the yearly alignments of all elements in the tunnel following ground motion (> 0.5 mm). In principle, 1 mm of this budget could be used to compensate for the 1 T.m missing in the MCBXFs, if it is proven that it can be used frequently with high reliability, and if it safe to operate it as an orbit corrector for safe beams. Both conditions are not given for granted according to the FRAS specifications (written in the EDMS document no 2166298). In particular the need to requalify the system.
after each movement larger than a few tenths of mm, could be an issue. In the case of quadrupoles, the need for such a re-validation is questioned, as the beam gives the most accurate measure of the offset.

If FRAS is used for orbit correction, one needs to redistribute the FRAS budget (1 mm for ground motion and orbit correction, 1.5 mm for IP offset), review separately other possible usages of the FRAS (e.g. for triplet misalignment for radiation purposes), and make sure the remote alignment range can be recovered with re-alignments in the tunnel (the issue might be the machine activation).

- **Ezio** asked if the $2\sigma$ correction corresponds to a 0.5 mm offset in the center of the triplets. **Riccardo** answered in the affirmative.

- **Gianluigi** asked if for the MCBXFB, the strength is the same in both planes (see slide 5). **Riccardo** said that in principle it can, but we cannot anticipate exactly the strength needed at the end of the squeeze as it depends on random components.

- On slide 5, **Gianluigi** commented that the part of the corrector budget taken by the IP crossing and separation (respectively yellow and red bars in the histograms), is systematic and would bring us to a point that is predefined in the diagram on the left. **Riccardo** confirmed. **Gianluigi** then asked if one can reduce the triplet misalignment and crab-cavity parts using the FRAS (resp. violet and grey bars in the histogram). **Riccardo** confirmed, and added that one can also remove part of the IP offset (in green). **Gianluigi** asked if we can halve the triplet misalignment after re-validation of the FRAS during a technical stop. **Riccardo** answered in the affirmative. He mentioned that there can be errors because of some mechanical plays (there is a 50 µm uncertainty whenever something is moved); overall one probably cannot do better than a 200 µm precision. But using the beam, the precision can be increased a lot (down to 10 µm). **Gianluigi** commented that it is reasonable to assume that we can decrease the grey bar (triplet misalignment part), assuming we can gain confidence in re-correcting at every technical stop. He asked then where we would be in the left plot of slide 5. **Riccardo** answered we would still be around 1.5 T.m, so above the limit for the MCBXFB - one actually should rather get everything halved. Still, the true mechanical response is unknown (one fights with the elasticity of the structure of the cryostats), hence it remains difficult to compensate with manual adjustment. It is better with the FRAS, but without feedback from the beam, it’s difficult to be better than a few hundred microns, hence the success of this procedure has a lot to do with the fact one can do it with beam. **Gianluigi** asked if this should be right after technical stops. **Riccardo** answered it should take place during beam commissioning, not necessarily after technical stops (this is specified in EDMS no 2166298, written by Hélène Mainaud Durand and Paolo Fessia). **Gianluigi** said we would need pilot beams. **Rogelio** asked if the specifications are for LHC or HL-LHC. **Riccardo** answered they are for HL-LHC. **Gianluigi** said one can probably decrease the grey part of the histogram by a factor of two, assuming one has well mastered the operation of the FRAS. **Riccardo** argued that the exercise to realign by a few mm already occurred and worked rather well (but they were asked not to do it anymore). **Gianluigi** argued that anyway one cannot fully get rid of the triplet misalignment. **Riccardo** said the grey part of the budget correspond to around 1 mm, so if one assumes we can compensate 0.5 mm in a year, then we can indeed correct half of it. But with beam, this could happen every
two months and one could gain a factor as large as 4. Gianluigi asked how much operational time this would cost. Riccardo answered it would cost one single ramp each time - provided we do not have to re-qualify the alignment. Gianluigi mentioned that machine protection also has to be consulted. Riccardo replied that since the quadrupoles are very sensitive (contrary to the absorbers or dipoles), the beam will give us the information we need, which should convince machine protection. Gianluigi argued that one would need to use the FRAS quite often. Riccardo confirmed but said it is about the same when compensating the ground motion. Gianluigi concluded that one should discuss with machine protection people and check interlocks on the FRAS budget (Action: Riccardo), and ultimately report back to Markus Zerlauth.

- **Ezio** concluded that one requirement is reduced, as one never thinks of using the MCBXFA in horizontal (non-crossing) at more than 2.5 T.m. Then, part of the corrector budget can be compensated by FRAS to some extent, but it is non-trivial - there will be more discussions and interactions with the various teams implied. Gianluigi said that completely eliminating triplet misalignments with the FRAS would be extreme (as one would need to do it almost every day).

- **Ezio** said that the requirements have also changed from a square to a cross; one can remove regions that will never be needed (in the left plot of slide 5). Frederik insisted that it is magnet dependent. Gianluigi wondered if one would need retraining when moving from one direction of the cross to the other one. Ezio answered that the problem is only when we go beyond the hyperbola.

### 3 Issue with SixTrack Post-Processing (Frederik Van der Veken)

This presentation follows from the discovery of a bug within SixDB, one of the post-processing tools used for SixTrack. The bug can be traced back to one feature of Sixtrack, namely the fact that it does not store particles that are lost abruptly. The issue then appears in the case of “walls”, which occur when the stability goes abruptly from a finite value to zero at a given amplitude, and is related to the fact that SixDB considers the DA to be the amplitude of the first unstable point, instead of the last stable one. Currently, in the case of “regular walls”, meaning that islands are present at high amplitudes, the first unstable amplitude is considered to be after the last island because of the absence of data on all the particles lost for smaller amplitudes. This can lead to DA overestimation up to 2σ or more in extreme (but rare) cases.

The fix (implemented in SixDB by Riccardo, and soon to be put in SixDesk as well) includes using the last stable particle (instead of the first stable one) as the DA definition. This is not back-compatible and leads most of the time to a reduction of DA by one amplitude step. This removes the problem on “regular walls”, but creates a new one for “double walls”, which are numerical artefacts consisting of spurious loss of particles at low amplitude while higher amplitudes are back to stability - this is normally removed when running again SixTrack at this amplitude. Therefore, to fix this remaining issue one needs to detect such double walls and re-run the simulation there. A bash script is provided to detect all walls in DA simulations (note that bash scripts lack reliability on AFS and may occasionally fail).
Finally, previously run simulations were screened for the issue. Not considering the systematic difference between “last stable” and “first unstable” points, it was found that the impact on the average DA is negligible, while 2% of the studies have overestimated the minimum DA by 0.5 σ or more. Note, still that most probably the extreme cases are due to “double walls” issues, potentially fixed by running again the simulations.

- Gianluigi asked if the latest study on the MCBXF & MCBRD (see first talk) was done before or after the fix. Frederik answered it was performed after the fix.

4 ROUND TABLE (GIANLUIGI ARDUINI)

Gianluigi concluded the meeting by mentioning that we have to think again about the strategy we want to adopt for the MCBXF as far as field quality is concerned.

The next WP2 meeting will be on October 27th, with the following agenda:

- Update on the field quality of the HL-LHC magnets (Ezio Todesco),
- Update on the expected lifetime increase thanks to the possible triplet shift attainable using the margin of the full remote alignment (Marta Sabate Gilarte).

Reported by N. Mounet