Minutes of the 126th WP2 Meeting held on 31/07/2018

Participants: S. Antipov, G. Arduini, X. Buffat, D. Gamba, M. Giovannozzi, G. Iadarola, S. Izquierdo, N. Karastathis, S. Kostoglou, E. Maclean, N. Mounet, Y. Papaphilippou, F. Plassard, K. Skoufaris, G. Sterbini, E. Todesco, R. Tomas, F. Van der Veken

AGENDA:

1 GENERAL INFORMATION (G. ARDUINI)

The minutes of the previous meeting are not ready yet, and will be circulated shortly. There will be no meetings during the next two weeks.

2 UPDATE ON THE TRIPLET FIELD QUALITY (E. TODESCO)

Ezio reported that for series production magnets a fine tuning of the field quality during the production is usually required. In LHC, for example, there were two iterations for the main dipoles, and one iteration for the main quadrupoles. For HL-LHC triplet due to a small number of magnets to build, the changes have to be done fast.

According to recent measurements, b6 errors are consistent between the 4 short models having the same cross section (MQXFS1 had a different cross section) within the expected random component of 1.1 unit but they show a systematic component of about -4 units significantly different from the expected systematic value of +1. The fine tuning is required, one has to act at the level of the fabrication of the coil. A discussion with the US colleagues is planned in the following days. In the fastest case the fine tuning of

the design can be implemented on MQXFA04 onward (AP1, AP2 are prototypes, AP1 is 4 m long while AP2 has the nominal magnetic length of 4.2 m but it has G10 spacers which have a poorer radiation resistance; A03-21 stand for series production units including three spares), MQXFBP1 and MQXFBP2 are prototype magnets in addition to MQXFB1 to 10 series production units (including two spares). The decision on the change should be taken before the end of August.

In the view of the measurement data, it also could be interesting to study the Dynamic Aperture (DA) with larger b6 errors. A scenario with all triplet magnets with b6 of -4 units, and another one with 1 or 2 Q2 with b6 of -4 units and 1 Q1/Q3 with b6 of -4 units are proposed

- **Gianluigi** inquired which magnet is the one tested in SM18. **Ezio** replied is the fourth short model MQXFS04. **Gianluigi** asked if the differences between the magnets explain the difference in the measured b6. **Susanna** noted that MQXFS1, S3, and S5 magnets were not shimmed in the same way. **Ezio** emphasized that a difference of this magnitude (5 units) is a systematic error that has to be reacted upon. The spread between MQXFS3 and the other ones within 1 unit of sigma is likely to come from the statistical distribution.
- **Gianluigi** asked whether one can proceed with the fastest tuning scenario if the decision is made by the end of August. **Ezio** confirmed and suggested he checks with Giorgio to see if the assembly of MQXFA04 has already started.
- **Massimo** noted that Frederik has already started to run simulations, considering all magnets with a systematic b6 of -6 units. Additional simulations have started for the case of -4 units - this is what is likely to happen if no action of fine tuning is taken. **Rogelio** asked about the other allowed multipoles. **Ezio** assured they are within the specifications. **Gianluigi** stressed the importance to check the sensitivity of DA with and without beam-beam interaction to the measured b6 errors. **Massimo** noted that one also needs to check if there is enough corrector strength, knowing that the length of these correctors has not been increased (only sextupole, octupole and decapole correctors' lengths have been increased). **Ezio** mentioned that in a couple of weeks the data for the assembly of another magnet MQXFBP1 will be available. **Gianluigi** proposed to review the results of the simulations at the next WP2 meeting on the 21st of August.

ACTION (Massimo): Check the sensitivity of DA to b6 errors in the HL-LHC triplet magnets and the implications of the measured magnetic errors on the needed corrector strength.

ACTION (Yannis): In parallel with Massimo, check the impact of the measured magnetic triplet errors on the beam-beam effects.

ACTION (Ezio): Provide an update on MQXFBP1 magnetic measurements and proposed strategy for fine tuning.

3 TRIPLET A3, B3 ERROR CORRECTIONS (M. GIOVANNOZZI)

Massimo presented the results of Yuri Nosochkov's work on the required strength of triplet a3 and b3 correctors. The study focused both on the old and the new specification values (the length of a3 and b3 corrector was increased recently).

The maximum a3 error strength that can be corrected is 6.2 units for the old specification, corresponding to an allowed uncertainty of 1.55 units, assuming a normal distribution cut at 4 rms. That leaves a factor 2 safety margin for the corrector strength. The maximum b3 strength is 9.0 units, corresponding to an uncertainty of 2.25 (vs 0.82 in the magnet specification) with a factor 3 safety margin.

For the new specification the maximum random uncertainty in a3 is 2.38 and in b3 - 3.48 units. Based on the recent magnetic tests of the MQXFS4 magnet, the a3, measured at 1.18, is compatible, while the b3 at 2.61 units might be incompatible with the old corrector strength values, but not the new ones.

- **Ezio** inquired why the a3 and b3 strength requirements are different. **Massimo** replied that while the coil strength limit is indeed the same, the impact on the beam is not as one needs consider the effect on the relevant resonance driving terms. **Rogelio** pointed out that the β-functions are different in the two planes.
- **Ezio** emphasized that while the measured b3 error MQXFS4 is above the threshold for the rms deviation, it may still be compatible within the requirements, since it is impossible to measure a random component and guess the maximum deviation within the whole set of magnets based on one sample. **Ezio** proposed extracting a more precise estimate of the rms spread from the existing data on three magnets. **Massimo** commented that they look at rms deviation and not the maximum one, because this is what is used in the analysis. **Gianluigi** concluded that the final outcome of the study is that there is no problem with a3 and b3 error corrections.

ACTION (Ezio): Supply to the Work Package a Table providing the existing magnetic measurement data for all the measured MQXF magnets.

4 DA VS PHASE ADVANCE FOR V1.3 OPTICS AND BOTH BEAMS IN COLLISION. DA DEPENDENCE ON DP/P (F. VAN DER VEKEN)

Frederik presented numerical simulation results on DA dependence on phase advance and momentum deviation. The study was performed for a q-Gaussian distribution with a full width half maximum matching to that of a Gaussian. Tracking was performed for 10^5 turns with sampling points evenly distributed up to 2 σ of momentum deviation dp/p.

For momentum deviation, particle tracking shows that DA shrinks almost linearly with dp/p. The goal of the study was find the value of dp/p that reproduces the same DA as the weighted (over the longitudinal distribution) average, as this represents a realistic scenario. The new optimum settings are proposed:

$185*10^{-6}$ (instead of $750*10^{-6}$) at Injection and $65*10^{-6}$ (instead of $270*10^{-6}$) in Collision. Thanks to the linearity of the obtained dependence one does not need to redo the simulation for a different distribution, i.e. if one scrapes a part of particles.

An important challenge to overcome is the removal of the outliers. An automated algorithm has been developed that excludes statistical outliers based on a heuristic threshold. While the removal may significantly change the minimum DA, the average remains largely unaffected, making it a robust measure of the DA.

Finally, a phase advance scan has been performed to find the maximum DA and reduce the difference in DA between the two beams. The optimization is performed in several steps. Optimizing the phases allows increasing the min DA by ~ 2 σ and average DA by almost 3 σ for the case of no HL magnets; the difference between Beam 1 and Beam 2 DAs remains. With HL magnets one can gain up to ~ 1 σ in min DA and 0.3-0.4 in the average one. The optimal settings for the minimum and the average are not necessarily close to each other.

- **Gianluigi** asked why there is a large asymmetry in DA between -420 and +420 A of octupole current in collision. **Frederik** explained this is due to crossing of the 3rd order resonance. Gianluigi asked if the asymmetry remains for an average seed. **Massimo** replied this is likely to be the case, and pointed out that the asymmetry would have been less prominent with beam-beam, which is missing from the analysis.
- During a discussion of the average vs minimum DA **Gianluigi** suggested that the average DA might be not enough. **Massimo** agreed that while the presently used minimum DA might be extremely pessimistic, the average may be too optimistic. **Gianni** noted that the average DA is a more robust measure. **Massimo** pointed out that one needs to keep the old values of DA to compare with, and emphasized the importance of clearly carrying through the change in method used to compute the DA. **Yannis** suggested checking the situation in collision. **Gianluigi** proposed quoting both numbers – the one corresponding to 2/3 of the bucket height and that providing the weighted average of the DA – and noted that it would be beneficial to have a similar analysis done for the beam-beam interaction.
- **Yannis** inquired why one of the standard algorithms has not been used for outlier removal. **Frederik** explained that the algorithms are usually based on the normal distribution, which is not the case. **Massimo** emphasized the problem of a choice when removing the outliers: remove the seed from all angles (as a bad realization of the machine), or just the outlier angle as currently done in the analysis. **Yannis** suggested checking the behavior of a pair particle with infinitesimally close initial conditions
- For the phase advance optimization, **Fredrik** noted that future work may include studies of longer timescales and expanding the scan phase angle grid. **Rogelio** pointed out that there may be no margin due to fixed phase advances. Between IP1 and 5 the phase advance can be only changed by less than 0.1. **Gianluigi** suggested first figuring out the constraints before extending the studies.
- **Yannis** noted that the studies have been done for a nominal working point and suggested to perform an analysis of the choice of the working point. **Massimo** replied that the working point scan at injection has been done by Pascal.

ACTION (Yannis): Investigate the difference between the minimum and the average DA in collision.

ACTION (Fredrik): Verify with Riccardo what the maximum allowed tunability of the phase advance is.

5 DA FOR THE STABILITY SCENARIOS (N. KARASTATHIS)

Following up on Xavier's talk at the 123rd WP2 meeting, **Nikos** presented a study of the available DA before the collapse of separation bumps. The analysis was done for the Nominal and the Ultimate operational (OP) scenarios and telescopic indices of 1 and 3.33.

With the telescopic index of 1 a DA of at least 9 σ is achieved in both operational scenarios at the maximum octupole current of -570 A. A large reduction of DA is seen in collision with the high telescopic index of 3.33. For the Nominal scenario with the octupole current of -300 A in collision the DA reduces to ~ 7 σ for the tele-index of 1 and only 6 σ for 3.33. An optimization of the octupole current might increase the DA in collision.

- **Gianluigi** asked to clarify what the range of options for the telescopic index is. **Xavier** replied that with the LS2 subset 2.8 is enough to provide stability throughout the cycle; and with the full upgrade 2.3 is required. **Gianluigi** suggested creating an optics set for the Ultimate OP scenario and ATS index of 2.8 to add this case to the study. **Yannis** pointed out that DA is marginal already in the Nominal scenario. **Sergey** asked if the required telescopic index takes into account safety margin. **Xavier** clarified that the -570 A threshold assumes a factor of two margin, based on the past and present operational experience at LHC. **Nikos** noted that lower octupole strengths can also be studied.
- **Gianni** asked if it is feasible to ramp the octupoles fast enough to cross the critical region. **Xavier** replied that the octupoles are needed just before the start of Collision; after the beam-beam tune spread is plays the key role and the large octupole current is not required. **Xavier** noted that even the fast octupole ramp rate will not help. It is the last 10 seconds when the 1.5 σ separation is crossed that are the most critical. **Massimo** inquired if the speed of collapsing the separation bump has to be reviewed. **Xavier** replied that it does not seem to be a robust solution, because one needs to have a reproducible solution fill-to-fill.

ACTION (Riccardo, Nikos): Create an optics set for the Ultimate OP scenario and ATS index of 2.8 and extend the analysis to this option.

6 ROUND TABLE

Gianluigi presented an overview of the annual HL-LHC meeting that will take place on 15-19 October at CERN. The WP has two plenary talks: Gianni will present on the heat loads and Stephane – on the flat optics. A preliminary timetable can be found on this meeting's Indico page.

The next meeting is scheduled on the 21st of August.