Minutes of the 114th WP2 Meeting held on 16/01/2017

Participants: A. Androula, S. Antipov, G. Arduini, X. Buffat, F. Carlier, J. Coello de Portugal, R. De Maria, S. Fartoukh, D. Gamba, M. Giovannozzi, P. Hermes, G. Iadarola, N. Karastathis, S. Kyriacos, E. Metral, Y. Papaphilippou, S. Redaelli, E. Todesco, R. Tomas, F. Van der Veken

AGENDA:

1 GENERAL INFORMATION (G. ARDUINI)

The minutes of the previous meeting have been circulated and approved without comments.

2 OPTICS CORRECTION STRATEGY, CYCLE OPTIMIZATION AND IMPLICATIONS FOR POWER CONVERTER AND MAGNETIC MEASUREMENT PERFORMANCE (R.TOMAS)

Rogelio presented a first draft of his Chamonix talk. First, he reviewed the HL-LHC performance limitations coming from the power converter (PC) noise and proposed ways of mitigation together with cost estimates. One of the limitations arises from the tune ripple, where the 4 dipoles in the ATS arcs feature the largest contribution. An upgrade of PC controllers to the class 0 with an estimated cost of 600 kCHF reduces the ripple by 35%. If the arc dipole PCs are not upgraded the luminosity imbalance between ATLAS and CMS would increase to ~20% from the current 5%. Upgrading the PCs to class 0 brings the imbalance down to ~12%. Further investigation is required to reach the target value of 5%.

The ramp-down time is limited by the PCs of the triplet quadrupoles in IR-2 and IR-8. Their upgrade (estimate of 80 kCHF, to be checked) would lower the turn-around-time by 15 min, leading to a 2-3% increase in the integrated luminosity.

Concerning challenges for optics control in HL-LHC, the beta-beating will be harder to control in HL-LHC compared to LHC and a peak value of 10-20% is expected for HL-LHC. Presently, the round optics can be controlled better than the flat one, for which so far the best results show a peak beta-beating of 25%. Rogelio emphasized that more MDs are needed in order to learn correcting HL-LHC optics in general and the flat optics in particular.

ADT measurements at LHC have observed a slow tune jitter with a ~ 100 s period of an unknown source, which could become an issue for HL-LHC. The jitter might come from the temperature fluctuations or the orbit feedback system. The tune jitter was studied separately with another technique using the AC dipole that can only sample the tune at 1 minute rate. Obtained this way dependence of the tune jitter on β^* shows a general agreement with the predictions from power supply measurements but cannot disentangle the arc and the IR contributions due to the large uncertainty of the measurement. More data is needed to establish a correlation.

Triplet multipole corrections in the LHC differ from the values expected from magnetic measurements by up to a factor of 3, and some b3 corrections have an opposite sign. Due to nonlinear errors the DA in HL-LHC reduces to 5σ for β^*=15 cm without correction. This might even pose a challenge for linear optics measurements. An iterative scheme of linear and non-linear corrections will be required

- **Gianluigi** suggested checking the options of upgrading the triplet power converters in IR-2,8 with Jean-Paul Burnet.
- **Davide** inquired where the largest deviation of beta-function is localized for the flat optics. **Rogelio** replied that it is located in the arc of IR5, to be confirmed.
- Regarding the tune jitter, **Riccardo** inquired about the source of the noise and suggested that it might be caused by the orbit feedback. **Rogelio** added that the temperature fluctuations could also be the source. **Stephane** proposed adding to the analysis the data for β^*=35 cm, obtained during the ATS MDs. **Gianluigi** pointed out that the two presented measurement sets, obtained with ADT and AC dipole respectively, were done at different frequencies and may have different nature. It is thus important to try separating the contributions.
- **Stephane** raised a question why the situation with nonlinear error corrections in IR1 is different from IR5. **Rogelio** replied that this is not known at the moment. **Gianluigi** noted that it is necessary to quantify the error in terms of its magnitude, putting it in familiar units (Amps or b_n units, for example), to see if it is relevant or not. **Ezio** also reminded that the LHC has a unique feature of having a strong systematic b4 error (not present in HL-LHC), which affects the MDs, and suggested emphasizing its impact.
- **Stephane** mentioned that the magnetic field errors were measured in hard to control conditions which cannot guarantee the sign of b3/a3 components or even the swap between the a3 and the b3 components.

ACTION (Rogelio): Examine the options and cost for upgrading the triplet PCs in IR2 and 8. The need to provide exact cost estimates in the slides for Chamonix should be verified with Lucio and Oliver.

ACTION (Rogelio): Analyze the MD data at β^*=35 cm.

ACTION (Rogelio, Ezio): Analyze how the measured nonlinear errors compare with the precision of magnetic measurements.

ACTION (Rogelio): Check and synchronize the presentation with Lucio concerning the general introduction concerning the baseline items

3 LONG RANGE BEAM-BEAM EFFECTS IN THE HL-LHC (Y. PAPAPHILIPPOU)

Yannis provided an update on the impact of the long-range beam-beam interaction in the HL-LHC. He started with reminding the goal – to show a robust OP scenario for the HL-LHC during the luminosity production with respect to long-range beam-beam.

Measurements show a good correlation between lifetime and dynamic aperture (DA) for 8b4e and BCMS beams, justifying the use of DA as a measure of beam lifetime in numerical simulations. Yannis presented results of extensive numerical simulations of DA for different working points, and scans in β^* and crossing angle. A reduction of the crossing angle at a constant luminosity reduces the pileup and triplet irradiation. For the worst possible case the DA is greater than 5σ, including the effect of multipole errors.

Yannis also showed an optimization of the crossing angle for collision and levelling and an analysis of the impact of nonlinear errors on DA. According to the numerical studies, the 15 cm β^* requires a crossing angle larger than that allowed by the aperture for the ultimate luminosity and if the relaxed DA settings are considered.

A wire compensation method can be used to target and suppress specific beam-beam multipole components. Recent MD measurements show an increase of beam lifetime with the wire compensation ON when targeting the octupole component of the long-range interaction. A gain of 30 urad in the half-crossing angle is estimated for the HL-LHC. The plan for 2018 is to continue the research on long-range beam-beam compensation with experiments in IR1 and IR5.

- **Rogelio** asked if the HL-LHC burnoff would affect the correlation between the dynamic aperture and the beam lifetime. **Yannis** relied that this is likely. **Gianluigi** asked to indicate the HL-LHC burnoff lifetime.
- **Stephane** asked if the cases studied in the numerical simulations of DA are OK from the coherent stability point of view. **Elias** replied that the presented cases are consistent with what was studied for the new OP scenario. **Gianluigi** suggested adding the β^* = 15 cm case in the slides (20 cm was shown).
- **Gianluigi** noted that if one starts the levelling with a smaller crossing angle, one might run into problems with beam stability due to long ranges earlier in the cycle. **Yannis** assured that the presented aperture estimates show the combined effect of the head-on and long-range interactions. **Gianluigi** suggested it would be beneficial to uncouple the two effects and determine which of the two is more detrimental.
- **Riccardo** raised a question whether a margin in the crossing angle should be taken into account, reminding that the present aperture estimations are based on the worst case scenario. **Stefano** pointed out that, at the moment, there is no margin for the 590 urad full crossing angle without

the alignment system and suggested putting together a table of the most critical cases. **Gianluigi** proposed stating explicitly the limit without the alignment and the potential gain, both in β^* and in the crossing angle, that could be achieved if the alignment is available. These numbers should be consistent between the talks of Yannis and Riccardo.

- **Stephane** noticed that the potential gain from the wire compensation, demonstrated in the MDs, might be reduced with the ATS. **Stephane** also pointed out that the wire compensation scheme is more useful for the flat optics, since for the round one there is a tested option of the octupole compensation, which might not work for the flat optics. **Elias** asked if a full compensation has been achieved in the wire compensation MDs and could a higher degree of compensation be expected in future. **Yannis** replied that the full compensation has not been achieved yet.
- **Riccardo** suggested optimizing the beta-function at point 8 in order to operate at a larger separation and reduce the contribution of IP8 to head-on tune spread. **Gianluigi** emphasized the importance of concentrating on the baseline, showing whether it is sufficiently robust, and identifying the margins and unknowns and the backup solutions that we have (e.g. wire). For the ultimate scenario a lower lifetime can probably be accepted.

ACTION (Yannis): Account for and clarify the impact of HL-LHC burnoff.
ACTION (Yannis): Study the separate effects of long-range and head-on on the dynamic aperture

4 EXPERIENCE WITH ATS OPTICS IN 2017: LHC NOMINAL OPERATION AND MD'S (S. FARTOUKH)

Stephane presented the motivation and principles of the ATS optics, showed the results of 2016/17 MDs and the 2017 LHC run with ATS, and finally discussed the limitations expected from ATS in LHC/HL-LHC.

The chromatic correction does not limit the β^* reach but several chromatic aberrations have to be taken care of at low β^*: off-momentum beta-beating, nonlinear chromaticity, spurious dispersion from the crossing angle. These effects where not limiting the performance of LHC in 2016.

Overall, the ATS increases the efficiency of the octupoles in HL-LHC by a factor of four. In a series of dedicated MDs the full HL-LHC telescope has been tested with probe beams, the loss maps have been obtained with a large telescope index of 3, a good lifetime has been observed with a large tele-index, and long-range beam-beam compensation with ATS and octupoles has been demonstrated. For flat beams, the telescopic squeeze has been demonstrated, but the optics correction remains a challenge, especially at large telescopic indexes: a beta-beating of up to 25% has been observed.

The new IR6 optics with MKD/TCT phase advance optimization allowed implementing the ATS optics in operation in 2017. The same level of control over the beta-function has been achieved with ATS in 2017 as in 2016. The MD plan for 2018 is to finish the validation of the ATS for the round optics, continue development of the flat optics, and identify the gain of ATS with the flat optics with respect to the round optics.

There are several limitations for the implementation of ATS in HL-LHC. First, some RSD circuits need over 600 A of current which might be above their limit. Second, for the flat optics, Q5.L6 requires 3700-3900 A when only 3610 A is available.

- Concerning the current in RSD circuits, **Riccardo** mentioned that the circuits are commissioned only up to 590 A. **Stephane** replied that there is a margin of 10-15 A that can be used. **Elias** suggested showing the maximum current explicitly. **Gianluigi** proposed clarifying the difference between LHC and HL-LHC in the slides. He suggested clarifying that the HL-LHC baseline includes the sextupoles in Q10 and is compatible with the Ultimate energy, requiring less than 550 A in the sextupole circuits.
- **Riccardo** noticed that the presented flat optics differs from the optimized one. **Gianluigi** suggested that the results should be presented for the official optics and pointed out a request from the management to guarantee that the circuits work at 7.5 TeV. During the discussion that followed **Stephane** emphasized the existence of a limitation already for 7 TeV and stressed the importance of knowing the circuit limitations for MQY magnets as soon as possible. **Ezio** replied that several magnets have achieved the current of 4000 A in tests at 1.9 K.

ACTION (Stephane): Make sure that the distinction is made between the situation before and after LS3 with respect to limitations for Q5 in point 6 and Chromaticity sextupoles.

5 DIGESTING THE LIU HIGH BRIGHTNESS BEAM: IS THIS AN ISSUE FOR HL-LHC? (G. IADAROLA)

Gianni presented a draft of his Chamonix talk for discussion within the WP. He reviewed various aspects of beam stability, electron cloud heat loads, and emittance preservation. Gianni presented several arguments in favor of having at least a factor two safety margin in the octupole threshold in HL-LHC. The need for safety margin is supported by current operational experience at LHC, the possible interplay between impedance and electron cloud (not fully understood yet) and the outcomes of the recent LHC MDs, including the TMCI measurement.

The results of the first TMCI measurements in the LHC have been presented. The test shows a clear improvement of the TMCI threshold for the upgraded low-impedance collimators that were simulated by retracting the TCSGs in IR-7, but there is still a discrepancy between the measured and expected threshold for the tight collimator settings.

Gianni explained that, for the high-load sectors, the present heat load from electron cloud is not manageable in HL-LHC due the increase of other contributions and discussed possible options of reducing the EC heat load. It is important to check the 8b4e scheme with a high intensity of ~ 1.7e11 p to see if it can work as a back-up for HL-LHC by studying the heat load dependence on bunch population. Several mixed filling schemes were presented; they offer a better performance in terms of the required cooling power, allowing a higher number of bunches for the same cooling capacity. The performance of the filling schemes have been analyzed both for different scenarios including some where a limited reduction of the SEY after scrubbing and/or the scaling of the heat load with the bunch population does not correspond with the present simulations.

The present emittance blowup in LHC is higher than that assumed for HL-LHC performance estimates. Studies to be done in 2018 to identify the source. The blowup has low effect on the integrated luminosity, provided that the emittance blow-up is such to give a significant reduction of the lifetime at constant DA, since it can be partially compensated by β^* levelling.

The transverse feedback might pose an issue for the emittance preservation in HL-LHC. According to Xavier, the damper noise has to be reduced by a factor of 4.

In the end, Gianni presented a back-up filling scheme BCMS (240b.) that has a benefit of requiring less time at SPS flat-bottom and is less demanding for protection devices.

- **Elias** suggested emphasizing the progress of the group in understanding of the coupled-bunch instabilities at LHC. **Gianluigi** asked to clarify in the slides why a factor two safety margin is important (with examples). **Elias** replied that the outcome of the TMCI measurement clearly shows the need of the safety margin. **Gianluigi** posed a question if the discrepancy in the TMCI threshold could be indicative of the incompleteness of the impedance model, i.e. geometric impedance, and (together with **Elias**) proposed to emphasize that the measurement clearly shows we are addressing the right equipment with low impedance collimators and therefore have good chances of succeeding in the end.
- **Elias** advised to be prepared to mention the destabilizing effect of the damper and low Q' in case there are questions during discussion.
- Regarding the electron cloud instabilities, **Gianluigi** pointed out the importance to test the high-intensity scaling of the heat loads during Run 3. **Gianluigi** asked if the model includes the triplets. **Gianni** replied that they are not included at the moment. **Gianluigi** suggested that this is explicitly mentioned in the slides and that this needs to be verified in particular for IR1 and 5.
- **Gianluigi** suggested that the slides on the emittance blow-up are checked with Yannis (according to whom there is a sufficient margin in the nominal OP scenario) in order to deliver a coherent message. He also proposed stressing that while we have a back-up scenario, we have to understand the origin of the emittance blow-up.
- **Gianluigi** proposed putting in the conclusion a list of high-priority items: understanding of the emittance blow-up, checking the intensity scaling of the electron cloud heat loads, and the verification of 8b4e scheme with a high bunch population.

ACTION (Gianni, Elias): Verify the 8b4e scheme with high-intensity beams in 2018.

ACTION (Impedance team): Identify the source of discrepancies between the measurements and the impedance model predictions observed during the TMCI test.

ACTION (Gianni, Yannis): Make sure to deliver a coherent message on emittance preservation and its impact on the machine performance at Chamonix

6 POSSIBLE FURTHER SIMPLIFICATION OF THE MATCHING SECTION (R. DE MARIA)

Riccardo presented two options to reduce the number of corrector magnets in the matching section, discussed the differences of the two approaches, presented orbit corrector budgets and alignment scenarios for each option, and, finally, review the apertures. Option 1 involves removing existing and adding extra correctors. Option 2 involves a full remote alignment system usable with safe beams, but does not need extra correctors. The remote alignment, required for this option, is yet to be demonstrated. The 2nd option does not involve the installation of the flexible bellows in the crab cavities (which are not in the baseline at the moment). Option 2 is preferable from the aperture point of view, both in the round and in the flat optics.

New data received from Rama on the tolerances of beam alignment in crab cavities. In the non-crossing plane the tolerance on beam position with respect to RF center is 5 mm. The question is if, under this tolerance, the transverse HOMs could lead to emittance blowup or have an effect on the beam stability.

An inconsistency in the baseline has been identified: the crab cavities need special flexible bellows for the remote alignment. The bellows are not in the baseline. The estimated cost for their implementation is roughly 1MCHF. The issue needs to be discussed at the technical committee.

- **Gianluigi** made a general comment regarding both presented options, asking to first put the numbers for the scenario with two crab cavities, and then quantify the additional corrector strength needed for four CCs. **Massimo** noted that if the crab kissing is not used, then the crossing planes are frozen, and this fact has to be reflected in the design of the corrector scheme.
- **Gianluigi** proposed emphasizing the benefits of the second option: a larger aperture, no need for a warm corrector, more flexibility in case the two additional crab cavities are installed. **Riccardo** mentioned that while the 2nd option does not require the flexible bellows, if they are not installed, it may limit the max crossing angle. **Gianluigi** doubted it is worth putting an additional constraint on the crossing angle. **Riccardo** pointed out that the bellows are still in the design stage and have not been studied from the impedance point of view.
- During a discussion on the alignment scenarios, **Massimo** questioned the need to perform a proof of principle test in LHC or SPS. **Gianluigi** agreed that the demonstration can be done in the foreseen String Test.
- **Ezio** suggested calling the Option 2 the first option, since it seems preferable.
- **Gianluigi** proposed is good to include a margin in the crossing angle (as Riccardo proposed earlier). It should be consistent with the aperture though. **Davide** estimated that one could recover 590 urad crossing angle with less than 1 mm orbit error in the crossing plane, to be confirmed.

ACTION (Elias): Study beam stability as a function of the beam offset in the crab cavities in the crabbing and non-crabbing planes.

ACTION (Riccardo): Add a margin in the crossing angle, consistent with the aperture.

ACTION (Riccardo): Lower the density of the material on the slides and synchronize the presentation with Paolo.

7 ROUND TABLE