Minutes of the 109th WP2 Meeting held on 31/10/2017

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General Information (G. Arduini)

The minutes of the previous meeting have been circulated. Gianluigi summarises the actions from the previous meeting. In particular he recommends to everybody to carefully read the paper collecting the parameter update, which is being finalised by Elias.

11T Dipole Integral Field, Transfer Function and Coil Length (S. Izquerdo Bermudez)

Susana explains that the requirement is 119.2 Tm at 11.85 kA. The original design was updated reducing the outer radius of the yoke by 5 mm; in addition some of the magnetic laminations have been replaced by non-magnetic laminations to reduce the peak field at the extremities.

The final coil length will be fine-tuned according to the measurements performed in order to match the integral field. Short coils models (1.7 m) and prototypes (5.3 m) have been assembled; six apertures have been measured for the short coils and three for the prototypes. A large variance of 25 units has been observed in the short coils, but it reduces to less than 10 units in the long magnets. In addition, on average, the measured integrated field is 24 units weaker than the requirement.

The final measure of the integrated field necessitates installing the cryostat which has not been done yet. The current best estimate shows a deviation between the required integrated strength and the measurements at low temperature. Two options have been identified to compensate: modify the coil length making it longer by 33-48 mm compared to the prototype, or rely on the trim circuits with currents up to 100 A.

The proposed strategy is to go for 40 mm coil elongation, which can easily be achieved without major interventions. If the integrated field is too large, then magnetic lamination can be replaced by non-magnetic laminations to reduce it; in alternative the trims will be used.

Massimo asks about the behaviour of the transfer function with the trims. Susana shows an explanatory plot in the spare slides. Rogelio asks about the origin of the difference in integrated field. Susana replies that it is more difficult to control the coil length than the magnet length. Gianluigi asks if this discrepancy was expected. Susana replies that it was known before producing the prototype, the decision to continue was made to avoid delays. Frederic adds that the tooling was already in place and they decided to go nevertheless in production to gain experience, postponing the adjustment to when detailed measurements were made available.

Gianluigi points out that the spread between different apertures, which cannot be corrected by trims, reaches about 10% of the corrector strength. He asks if, for this reason, sorting is envisioned. Susana replies that for the long magnets the variation is expected to be smaller.

Gianluigi asks if the difference in field comes from the difference in coil length or if the iron yoke contributes more. Susana replies that the coil length is dominating; the iron length only allows for tuning, she adds that the tuning acts on both apertures in the same way. Frederic confirms.

Stephane asks if the insulation layer for the high order multipoles could be used, Frederic replies that its contribution to the main field is very limited.

Frederic is confident that the right magnetic length will be achieved, but there will be some variation which will not be compensated by construction.

Susana asks if operating the trims at 20 A is acceptable as nominal scenario. Gianluigi replies that the smaller the trim current, the smaller would be the risks in case of trims failure in stable beams. In addition he is worried by the increased strength at the ultimate energy. He concludes that 20 A could be acceptable, but the closest to zero, the better. Massimo confirms.

Validation of the operational scenario: beam-beam including DA response to the swap of the crossing angle (D. Pellegrini)

Dario points out that a large part of the work was done by Nikos who is on duty trip. The DA studies have been updated to HLLHC V1.3 taking into account the new settings collected by Elias for octupoles and chromaticity. LHCb is now levelled at 2e33 Hz/cm², Alice is separated at 5 σ.

Roderik says that due to the e-lens the separation in Alice will be smaller (e.g. 3.5 σ). Riccardo asks whether the present Alice separation is compatible with Gaussian tails. Yannis replies that it is possible to look into this. Stephane comments that the impact of HO tune shift coming from reducing the separation in Alice, could be comparable to the one obtained when going from the good to the bad LHCb polarity. Dario recalls that the impact of separation on DA was already checked for IP1/IP5 and for IP8 finding almost no dependency in all the considered cases.

Dario presents the tune scans at the end of levelling. The optimal tunes are the same as previously found for the beginning of the fill (62.320, 60.325). He stresses that the nominal working point does not allow reaching 6 σ DA. Stephane points out that there seems to be somewhat more space below the diagonal, as found for the ATS MD with negative octupoles. Dario replies that it is anyway quite limited and it is not clear if one can cross the diagonal. Stephane suggest injecting below the diagonal. Dario points out that there are also plans for MDs with tune close to half integer which should make the situation significantly better. The HV and the VH crossing schemes do not provide significant differences in terms of DA.

Sergei asked whether the working point changes with intensity. Dario replies that although this could be expected, it has been observed that this is not the case.

Dario explains how the levelling process at constant DA is investigated with several crossing angle vs beta* DA scans at different intensities. The final step is consists in an intensity vs crossing angle scan at 15 cm beta* which allows to pinpoint the exact intensity for the end of levelling. The burn-off process is then integrated in time taking into account the so determined crossing angle as function of the intensity. Although the gain of integrated luminosity is limited compared to a scenario with crossing angle fixed at 500 µrad, big improvements are observed in terms of pile-up density.

Stephane comments that reducing the crossing angle has an impact on the tune spread and therefore one can reduce the octupole strength. Dario replies that the choice of octupoles is as presented in the document, the extra strength is required to stabilise the non-colliding bunches. Elias clarifies that the non-colliding bunches could be stabilized with -400 A taking into account the latest estimates, although margins are kept.

Gianlugi asks about pacman effects. Dario replies that they have not yet been investigated in the HL-LHC case. For the LHC extensive studies have been performed for the 8b4e considering different classes of bunches and it was observed that the missing long ranges result in better DA also for the common working point. Stephane warns that some pacman might be close to the third order resonances.
Gianluigi asks if one could trade some crossing angle to increase the possible working point area. Dario replies that if the working point is not well optimised there is no chance to recover 6 sigma DA by acting on the crossing angle.

Dario presents the error studies performed by Nikos. Few relevant points are selected at the beginning and at the end of the levelling. The general conclusion is that the current tolerances appear adequate to maintain the errors in the shadow of beam-beam, with a limited DA spread of a fraction of a sigma across the various seeds. Gianlugi asks to study the ultimate case also at the end of levelling. Dario replies that Nikos is already working on it and it will be ready for Madrid.

Stephane remarks that for negative octupoles the tune spread will decrease with beta* as a result of the increasing beam-beam tune spread and it might be required to anticipate the telescopic part of the squeeze. Dario asks if it would be better to have constant tele-index during the levelling. Stephane replies that one would like to work with constant spread. Elias notes that it might be good to review the choice of the sign of the octupoles as for transverse distributions without tails (this is what has been assumed taking into account of the possible implementation of the electron lens) the octupole current required to stabilize the beam (in the absence of beam-beam long range effects) is similar for both signs of the octupoles. Gianluigi asks to determine the tune spread required to stabilize the beam before going in collision and then determine what is the current evolution of the octupoles for both signs to obtain and maintain that up to collision (for both the nominal and ultimate scenarios) for the crossing angle of 500 µrad and during levelling. **Action: Xavier for the parameters of the operational scenario.**
Rogelio points out that we should verify the DA with the new working point before going in collision with separated beams and in the presence of errors to verify the feasibility of operation with the new working point both for the nominal (beta*=64 cm) and ultimate scenario (beta*=40 cm) with a crossing angle of 500 µrad and nominal bunch population. In other words it would be important to complement the data with scans of the DA for the new tune working point, Q'=+15 and crossing angle of 500 µrad as a function of the octupole current (from -570 A to +570 A) and beta* both for colliding and separated beams for the nominal bunch population and for colliding beams also for the levelling steps. **Action: Dario and Nikos.**

Gianluigi asked how the picture changes for the different classes of bunches (different number of HO and long range encounters).Some additional cases for tune scans are identified: octupoles at -400 A, re-check of the beginning of the fill with V1.3 and pacman bunches (worst case with all the LR and no HO). **Action Dario and Nikos.**

Impedance model and stability (S. Antipov)

The parameters used for the studies are presented. Roderik comments that the tight settings are not realistic and could be updated according to what has been collected in the paper on the operational scenario. **Action: Elias, Sergey**.

Sergey show the main contributions to the impedance in terms of required octupole current to maintain the beam stability. This is widely dominated by the collimators. Stephane asks what falls under the label of "other collimators”. Sergey and Elias replies that these are the collimators in LSS3 and the injection protection collimators. Stephane notes that the contribution appeared to be large. Probably tighter than nominal settings have been used. **Action: Sergey to verify.**

The resistivity of the collimators for different coatings has been measured. The molybdenum-graphite coating reduces the tune shift by a factor 2, as predicted by the model. The molybdenum coating shows a reduction by a factor 3, while the model predicts 5. The cause has been found in the surface roughness contributing to the inductive impedance. Gianluigi asks if the roughness comes from the coating or from the substrate. Sergey replies that the coating process is known to produce extra roughness, although the substrate can contribute as well.

The required octupoles for various coatings are shown. Dario asks if the quoted values take into account the effect of beam-beam on the tune spread. This is not the case. Stephane points out that if the tele-index is raised from zero in presence of negative octupoles, at some point the spread will cross zero. Gianluigi suggests considering the same frequency spread in DA and stability studies.

The possibilities to reduce the impedance are identified in terms of coating and geometry of the collimators. In order to further reduce the contribution from the geometry, the CST model is being used aiming at gaining a better understanding.

Gianluigi suggests checking what the main contributors of the geometric impedance are. He asks how the geometry contribution is computed for the time being. Sergey replies that a semi-analytical model is used. Gianluigi asks if the geometric model developed by Zobov and Frasciello is considered. Elias replies that this should be verified. **Action: Elias**.

Concerning Crab Cavities most of the HOMs are observed around 1 GHz. As the transverse feedback is ineffective above 20 MHz, some octupole current is required. In particular few modes at around 2 GHz require attention. Sergey shows that 30A of octupole currents are enough to stabilise the single-cavity single-mode scenario for all the considered modes and positive chromaticity. If more crab cavities are present the frequency spread will contribute in positive way. If one cavity hits a coupled-bunch mode the contributions of all the others become less relevant, even in the unlucky case where more of them hit the same mode.

The maximum transverse mode shunt impedance to have a negligible impact on the operation is identified in 1 MOhm/m.

Gianluigi comments that the updated settings of the collimators will reduce the octupole requirements from 420 to about 300 A. **Action Sergey to check and update the corresponding values.** He adds that it is important to get a better understanding of the geometric part. **Action Elias.**

Roderik asks if there should be an effort from the collimation side to reduce the impedance. Gianluigi suggests that a better understanding of the contributions should be achieved first.

Beam stability with realistic longitudinal profiles and contribution from space charge (A. Oeftiger)

The activity was started after Elena’s presentation at the 82nd WP2 and aimed at getting a better understanding of the impact of a realistic synchrotron frequency distribution on the transverse stability. Adrian recaps the main findings of Elena's presentation highlighting the hole in the synchrotron frequency distribution which hints at a depletion of the bunch core.

Adrian explains the details of the tomography and how it is used to reconstruct the macro-particle distribution. A small dip in density of the bunch core is enough to reproduce the hole in the synchrotron frequency spectrum.

Chromaticity scans were performed showing the dependencies on bunch length. Gaussian, q-Gaussian and hollow distribution are all considered. Different rise time and modes are observed for the different distributions. The hollow distribution presents less stability in the presence of the damper.

Stephane asks if there is a correlation between rise time and required octupoles for stability. Elias replies that is linear. Gianluigi is puzzled and wonders whether the significant dependence on chromaticity and distribution is still present when the effect of the octupoles is included It is suggested to compute the growth rates by adding the effect of the octupoles with values estimated by DELPHI simulations. Riccardo suggests testing on the machine by going close to the stability threshold and then validating the limit by changing the distribution.

Yannis points out that by keeping constant FWHM, the RMS is changing and this affects the luminosity.

The impact of space charge has been studied at injection energy without chromaticity and damper. Space charge was included in a self-consistent way and resulted in a suppression of the mode coupling instability. The instability was observed again for emittances above 20 um, where space charge is highly diluted.

Gianluigi concludes that it is important to check the contributions of the octupoles by including them in the tracking. **Action Adrian.** Adrian adds that the turn number is also important in spotting instabilities.

Reported by Dario, Gianluigi, Riccardo and Rogelio.