Minutes of the 116th WP2 Meeting held on 13/03/2018

Participants: C. Accettura, S. Antipov, G. Arduini, R. Bruce, X. Buffat, F. Carra, R. De Maria, D. Gamba, F. Giordano, M. Giovannozzi, P. Hermes, G. Iadarola, N. Karastathis, K. Skoufaris, A. Mereghetti, E. Metral, S. Redaelli, B. Salvant, G. Sterbini, E. Todesco, F. Van der Veken

AGENDA:

1 GENERAL INFORMATION (G. ARDUINI)

The minutes of the previous will be circulated shortly. A follow up on the flux jumps with **Ezio** is planned later during the week. The next meeting will take place on the 20th of March and will be devoted to electron cloud studies of TDIS. The date and time of the meeting on noise, emittance blow-up, and power converter upgrade is to be decided.

2 TRANSVERSE KICK FACTOR OF HL-LHC CRAB CAVITIES (S. ANTIPOV)

Sergey presented an analysis of kick factors for the HL-LHC crab cavity higher order modes (HOMs). The study was made in response to a question raised at the WP2 114th meeting whether the HOMs can lead to instabilities or emittance growth through amplification of the noise. Crab cavity HOMs should be treated in comparison with other sources of impedance and the damper. A kick factor is a measure of noise amplification. A preliminary study done by **Nicolò** showed that the kick factors of the HOMs are at least on order of magnitude lower than that of the collimation system. For the present HOM design the noise amplification from the HOMs is 3 orders of magnitude smaller than the damper gain, both for RFD and DQW, making the impact of the HOMs on the beam emittance negligible.

- **Riccardo** asked where the transverse offset of the beam orbit at the cavity enters the analysis. **Sergey** replied that the offset is accounted for in the definition of the kick factor. **Riccardo** raised a question if the nonlinearity of the HOM impedance has been taken into account and whether it could affect the results. **Gianluigi** asked to clarify whether the linear impedance is assumed. **Sergey** replied affirmative. **Benoit** commented that the change of the kick due to nonlinearity of the impedance is unlikely to be large, since the maximum orbit offset, 5 mm is relatively small compared to the cavity aperture; also from his experience the nonlinearity typically decreases the kick. **Gianluigi** and **Elias** proposed checking with **Rama** whether the HOMs can be highly nonlinear, noting that according to the analysis there is plenty of margin.
- **Xavier** pointed out that what is computed for the estimate is the amplification, in order to obtain the emittance blow-up one has to know the noise source. It is unlikely to have noise at the high frequencies of crab cavity HOMs (500 MHz and above), since the usual sources, such as power converter ripple and ground motion, are low frequency.

ACTION (Rama): Check how large the variation of crab cavity HOM impedance with the offset is and if it can be considered linear within 5 mm.

3 MAXIMUM TOLERABLE A4 AND B5 ERRORS ON THE TRIPLETS BASED ON THE AVAILABLE CORRECTOR STRENGTHS (M. GIOVANNOZZI)

Following up on Yuri Nosochkov's talk in Madrid, **Massimo** presented an extended study of the effect of a4 and b5 field errors in the inner triplet on the dynamic aperture (DA), their effect on corrector strength, and maximum tolerable errors. Tracking simulations show a large, up to 2σ variation of minimum DA with the multipole errors. A region has been identified where the impact on DA is relatively small. Effects of the D1 separation dipole a4 and b5 errors on the maximum corrector strength are within 10%. Maximum random uncertainty in a4 that can be corrected is 1.9 units and in b5 – 0.9 units. Comparison with magnetic measurements shows that, although the magnetic errors are within corrector specifications, the margin is very thin: 13% for a4 and 15% for b5.

- **Ezio** raised a question on the seeding of magnetic errors, asking whether only one b_u error is extracted for magnet family was used. **Massimo** replied that was the case. **Ezio** also pointed out that in the end there will be two producers. **Gianluigi** asked whether it is necessary to have two components b_u and b_r and whether one would be sufficient. **Ezio** objected that this may not be enough since due to an uncertainty of the production line the average might not be centered at the design ideal systematic value. **Massimo** pointed out the limited number of magnetic measurements preventing from estimating the spread and the more realistic values for the uncertainty and random components.
- **Massimo** stressed that currently the expected error tables feature a zero systematic b5 component for D1. **Ezio** noted that we could assume a b5 systematic error in D1 of the order of 0.1 unit: this will be taken into account in a future revision of the analysis.
- **Ezio** noted that for the purpose of determining the margin, the worst of the measurements has been taken. While it is impossible to get an accurate estimate of uncertainty based on just two

samples, **Ezio** is confident future magnets will perform better, since the results of the measurements will be taken into account. **Gianluigi** pointed out that, based on the available measurements, the safety margin is only 10%, which is unacceptable. **Ezio** agreed that we are at the limit.

4 ITERATION ON LENGTH OF HIGH ORDER CORRECTORS (E. TODESCO)

In response to the problem posed by in his talk by **Massimo**, **Ezio** presented two options for improving the margin. Option 1 involves increasing corrector current by 50%. Due to saturation the gradient increases by only 30%. The 2nd option involves increasing corrector length by 30%, which would yield an additional 50% of gradient. This option still leaves the possibility of the current increase on the table, should it be required. A decision on the change has to be made by the end of April. All engineering drawings need to be redone, but no significant cost increase is foreseen (~5%).

Ezio also raised a question whether the current skew quadrupole corrector is not too strong. Based on his estimates, the skew quadrupole corrector is strong enough to compensate a 5 mrad tilt of the triplet which exceeds significantly the expected alignment accuracy.

- **Massimo**, **Jaime**, and **Rogelio** will check the data, verify the required corrector strength, and provide a follow up study on this topic.
- **Massimo** pointed out that the Option 1 is not compliant with the present choice of power converters (PCs) and has to be discussed with Integration. The current increase would require switching to 600 A PCs. **Ezio** replied that the option can still remain in case of an emergency, then special PCs could be procured, if necessary.
- **Massimo** inquired whether an increase of a6 and b6 strength is also possible. **Ezio** replied that there is no need in that since the corresponding errors are well under control. **Massimo** requested a clarification whether the magnetic shimming remains the baseline to deal with b3. **Ezio** confirmed that the magnetic shimming stays.
- **Gianluigi** asked if there is any magnetic interference between the multipolar correctors. **Ezio** replied that the fringe fields have been studied and the interference is not an issue. **Gianluigi** stressed that although having the corrector strength a margin is important, the field errors have to be well under control because the LHC experience indicate that beam-based correction are not always consistent with the measured magnetic errors. **Ezio** assured that all magnets are to be tested and measured at CERN
- **Gianluigi** asked Ezio for which energy the optimization of the field quality of D2 has been performed. **Ezio** replied that this has been done for 6.75 TeV. **Gianluigi** noted that given the requirement of operating up to 7.5 TeV it would be preferable to do the optimization for 7 TeV. **Ezio** agreed and will verify what the implications are.

ACTION (Massimo, Jaime and Rogelio): Verify the required strength of the skew quadrupole, a2 corrector.

ACTION (Ezio): Check the implications of optimizing the D2 field quality for 7 TeV

WP2 considers Option 2 as preferred solution.

5 EFFECT OF COLLIMATOR COATING THICKNESS ON HL-LHC OCTUPOLE THRESHOLDS (S. ANTIPOV)

Sergey studied how the thickness of the coating and its material affect the octupole threshold. The thickness was scanned from 1 to 5 µm, two coating materials: Molybdenum (Mo) and Copper (Cu) and two materials of the jaw bulk: Molybdenum-Graphite (MoGr) and CFC were studied. The choice of bulk collimator material has little effect on the machine impedance and hence on beam stability if the coating is sufficiently thick. For Mo coating 5 µm thickness provides a significant safety margin in terms of the octupole threshold. For thinner coatings the increase of octupole current is relatively small for most chromaticities Q', but can be significant – up to 100% - near Q' = 15. For Cu coating no significant effect of thickness is achieved for 3 µm and thicker coatings. In any scenario, the octupole current shall not exceed 300 A in the range of chromaticities Q' = 5-20.

- **Stefano** mentioned that the team has been asked to also consider a Copper coating option. Both Mo and Cu were tested in HighRadMat; Cu coating features a slightly worse, but still acceptable performance in terms of resistance to beam impact. At the moment, there is a problem with Mo coating of MoGr, where the coating seems to be contaminated by methane. It is not clear if the contamination depends on the coating material, but in order to have a backup a Cu coating on MoGr is also being tested as a possible alternative. **Gianluigi** summarized that it is not so obvious which one of the coatings is easier to do and reminded that in terms of impedance Cu is better. **Stefano** replied that the collimation prefers Mo due to its lower energy absorption and proved highest robustness against beam impacts.
- **Federico** noted the Cu resistivity is a factor 4-5 better than that of Mo, but in the table presented there is only a factor of 2. **Sergey** replied that for Cu a pessimistic value is considered, which is based on the measurements done for TDIS. **Gianluigi** asked to clarify what value is used for Mo. **Sergey** replied that a bulk DC resistivity is used. **Federico** asked why the approach is different. **Sergey** replied that no reliable measurement of the resistivity of Mo coating is available and pointed out that, according to beam measurements, the resistivity could be up to five times higher than that of the pure bulk. Other mechanisms, such as surface roughness and the microstructure of the coating could also explain the observed discrepancy in the tune shift; a detailed study of the coating resistivity is needed.
- **Gianluigi** requested performing a comprehensive study of coating resistivity. **Stefano** emphasized the importance of understanding the resistivity discrepancy in Mo. If in the end, the resistivity of the coating turns out to be higher than expected, that could be a strong argument in favor of Cu coating. **Federico** mentioned that the purity of the coating is unlikely to be the source, since no oxide formation has been observed in the TCSPM sample. Some surface roughness of the MoGr substrate (around 1 µm) is required for a good adhesion of the coating though. There is a coated block with 6 µm of Mo on MoGr available for studies. **Sergey** proposed that a flat ceramic sample is coated in order to confirm or rule out the effect of surface roughness. **Federico** replied that such a sample has already been tested, but the measurement can be redone. He also recalled that an extensive measurement campaign was carried out in the past and suggested that he could look

back at the results that are already available. **Elias** pointed out that the samples are needed to do the measurements.

- During a discussion on the thickness of the coating for LS2 upgrade **Federico** pointed out that for Mo there are no problems to achieve 5-6 µm, but for Cu coating more than 2 µm might be challenging. **Federico** suggested to check the limits with **Mauro** Taborelli. **Sergey** mentioned that 2 µm would probably work, since it is still larger than the skin depth at the frequencies around 1 GHz that are relevant for single-particle dynamics. **Elias** emphasized that the skin depth is the physics behind the increase of the octupole threshold for thinner coatings and concluded that to effectively screen the bulk of the jaw 2-3 µm of Cu or 3-4 µm of MoGr is needed. **Gianluigi** suggested supplementing the study with a 2 µm Cu coating and summarized that 3 µm for Cu and 5 µm for Mo respectively appear to provide adequate octupole current reduction for any value of the chromaticity.

ACTION (Vacuum team): Provide the samples for impedance measurements

ACTION (Impedance team): Measure and compare the resistivities of Mo and Cu coating on flat insulating substrate and on a real block of MoGr with 6 µm of Mo and 2 µm of Cu.

ACTION (Sergey): Study if the reduction of Cu coating thickness from 3 to 2 µm affects beam dynamics

ACTION (Federico): Check the upper limit of Cu coating thickness

6 ROUND TABLE

In conclusion, **Gianluigi** proposed an AOB on the kick factors at one of the next meetings.