Minutes of the 52nd Impedance Working Group meeting

Location: Zoom

Agenda of 52nd IWG meeting, November, 16th, 2021:
• Impedance of LHC buckled RF finger in 21L3 and related impact (B.Salvant, C.Zannini)

Present: Antuono Chiara, Nicolo Biancacci, Benoit Salvant, Christine Vollinger, Mike Barnes, Carlo Zannini, Fritz Caspers, Miguel Diaz, Giovanni Rumolo, Alexej Grudiev, Helene Guerin, Josef Sestak, Rui Franqueira Ximenes, Sergio Calatroni, Tina Griesemer, Miguel Valente Dos Santos, Kristof Brunner, Michael Sullivan, Freek Sanders, Marko Milovanovic.

This meeting has been organized on short notice to discuss the Impedance of LHC buckled RF finger in 21L3 and related impact since LHC management asked to ABP to present this at the LMC tomorrow and Carlo Z. agreed to represent the IWG there tomorrow.

Benoit points out that tomorrow there will be an introduction by Mike Lamont to motivate the decision that has been taken and a talk by TE-VSC on the outcome of the tomography by Giuseppe Bregliozzi (TE-VSC).

Impedance of LHC buckled RF finger in 21L3 and related impact (Carlo Zannini)

Carlo presents the work done on the 21L3 RF finger of LHC.
-First, he explains the simulated geometry showing that the finger shape was reconstructed from the information available in the two x-ray images and later confirmed by tomography. The RF finger is almost parallel to x-axis.
-Simulations have been performed with CST Studio and the goal is to evaluate the impedance in order to assess potential stability issues, beam induced power loss and electric field level on the finger.
-In the following slides, from the cross section view of the chamber with the RF fingers, we could see the electromagnetic interaction between the particle beam and the surroundings.
-Carlo presents three scenarios: the conforming one with all the fingers present and in the correct position, the one with the bent finger in contact with the other side, and the case with the finger deformed and tilted, that is the one closer to what was measured by aperture scans.
-He shows the results from eigenmode simulations, starting from the case of one finger deformed where we can clearly see a resonance, with a significant shunt impedance of 20 kOhm at a frequency around 710 MHz.
-Then he adds the case of one finger deformed and touching the neighbouring finger, where as expected, the resonances are shifted to higher values since we go from a lambda quarter resonator to lambda half resonator, while in the last case of deformed finger and tilted, there is no frequency shift, but it causes a reduction of 30 % of shunt impedance for the highest mode. From this study we can clearly see the significant impact of the deformed finger on the impedance.

-Carlo also shows the beam induced power loss of the dangerous mode and points out that, since the frequency of the resonance depends on the exact shape of the fingers, it is not possible to know exactly where it lies in the frequency spectrum, and one should consider

the worst-case scenario. Then if the mode falls on a main beam spectrum line, the power loss on the finger would be around 5kW with Run3 beams. If we consider the mean power loss for 10 MHz scan the value is 75W and the minimum power loss is 1 W.

-In order to explain where the computed power loss is dissipated, he shows the surface power loss density from CST simulation dissipated on the deformed finger.

-Concerning the simulated peak induced electric field, it is at maximum 1.8 GV/m corresponding to thermal losses of 1.6 MW and scaling to the maximum beam induced power loss of 5 kW, we get of the order of 100 MV/m. While scaling this to the minimum beam induced power loss of 1 W, we get of the order of 1.5 MV/m.

-Carlo describes also the impact of moving the beam, that could be a possible solution, but from the results turns out that the impedance reduction is almost linear with the offset showing to be not a magic solution for the issue.

-Afterwards he finally shows the impact of removing the deformed finger, that solves the problem since as shown from the plot, the dangerous impedance resonance is suppressed.

He concludes summarizing that:
➢A dangerous impedance mode is expected around 700 MHz due to the deformed finger
➢ Exact frequency of the mode depends on the exact shape of the finger.
➢ At least 10% uncertainty on the frequency value
➢ Large beam induced heat load on the deformed finger associated to this mode is possible
➢ 1W minimum and up to 5 kW on the finger, depending on frequency of resonant
mode and overlap with the beam spectrum lines
➢ Large beam induced peak electric field on the deformed finger associated to this mode is possible
➢ 1.5 MV/m to 100 MV/m, depending on frequency of resonant mode and overlap with
the beam spectrum lines.

-He has been asked to go through the spare materials and then he also shows the Wakefield simulations that confirm the large mode around 700 MHz with some frequency shift and shunt impedance reduction as the wake is not perfectly decayed, and the hexahedral mesh could lead to a different model compared to the tetrahedral mesh in Eigenmode simulations.

-Then he points out, with a comparison between the conforming case and the one with the finger missing, that the latter would solve the issue but not as mush as the conforming case.

-Carlo also shows the surface current flow through the deformed fingers at the mode frequency.

-He also includes some thermal behaviour simulation with body at 5K that he would like to remove from the slides presented tomorrow since a quantitative simulation should be done by experts.

-The following slides are from Elias, where he explains that the buckling could happen each time there is a warm up and includes some recommendations.

-Carlo shows also the superposition and agreement of the simulated geometry with the tomography and concludes the spare slides explaining how the frequency of the mode is sensitive to the different finger shapes.

Comments:

Alexej asks what the temperature of 5K on slide 21 is. **Carlo** answers that it is a qualitative study and probably he will remove the slides since they don`t know the temperature of the fingers. The main message of that slides is that what you lose will be dissipated on the finger. **Benoit** checked on NXCALS later that the temperature

measured on several PIMS when the machine is cold is around 15 to 20 K.

Alexej asks if the power loss is dependent on the material properties that may change with temperature, as in the case of conductivity and asks to check with someone which values of conductivity are involved. **Benoit** noted that we are dealing with CuBe fingers coated with Gold. **Sergio C** adds that he sent a note with all the information on RRR of gold plated CuBe fingers to Benoit. RRR of CuBe fingers is 2.26, and increases to a range of 6 to 32 with gold coating, depending on the Gold deposition thickness and process. He adds that it would be good to check with the exact value expected for the temperature in the PIMS.

Carlo states that a higher conductivity means a narrow mode with also higher peak value and, in the unlucky case that you heat one of the beam lines, this could lead to even higher power loss.

Elias says that as we are considering the worst-case scenario, the worst is really when the shunt impedance is the highest and increasing the conductivity is even worse.
He and Sergio congratulate Carlo and Benoit for the work in such a short time.

Sergio C: what is the probability of hitting a beam spectrum line? **Carlo** replies that it depends also on material properties, if you have higher conductivity, you have higher probability to hit a major beam line at a multiple of the inverse of the bunch spacing (~40 MHz for 25 ns). Anyhow, since we do not know the exact frequency of the mode - that is related to the shape of the finger - and since it could also change during Run3, the situation will evolve and is difficult to estimate a value, but he thinks the probability is not negligible.

Elias underlines that a question will arise concerning how we can go about such considerations in the future. He asks if in future another study like the one just performed will be carried out or if it will be taken another decision, as for example, to consider another design.

Benoit replies that the design should be made to be robust for this kind of failure, and he does not see a general solution.

Elias adds that the design was very good at the beginning but when it came to CERN there was an angle that has been modified and it has not been checked and validated.

Fritz said that a non-conformity on the roughness required modifying the design (increasing the kink angle) to increase the contact pressure between the fingers and the tube, and reduce the contact resistance. Unfortunately, this leads to a larger probability of buckling of the fingers.

Christine would like to know where the part covered by the coating is and the surface roughness of PIMs.
Benoit says that concerning the robustness of the PIMs we should ask tomorrow.

Christine suggests to Carlo to put the spare slides 19 and 26 in the presentation and suppress the 21. Sergio and Elias agree.

Elias asks what we will do if this happens again in the future. Just redo all the simulations study or the conclusion will be to warm up the finger? Do we have a general statement?
Carlo replies that it is also dependent on how the finger is deformed.

Benoit agrees with Carlo and adds that is important to perform again the simulation study, and if the finger is not touching at all on the other side and protruding inside the aperture, then the difference should be quite small with the case simulated today, but we should still simulate (and it is quite fast). If there is a connection within the fingers and the tube, as in figure, the conclusion could be different from the one of today. However, he recommends that this is simulated every time.

Christine asks if we have radiation studies. **Sergio C**. replies that he doesn`t know for the PIMs but it may have been done for collimators where RF fingers are the same.

Benoit comments that when they recommend warming up the fingers and then taking the risk to have another issue like this, he assumes that the risk is much smaller than running with the fingers buckled.

Sergio asks if without one finger the situation is still the same and Carlo comments that it is, since only one mode appears around 2 GHz, but we are around 6 Ohm then the shielding still works.

Elias adds that from discussion in the past with vacuum people, there could be constrains on the number of fingers.

Benoit: Is 20KOhm shunt impedance quite significant for longitudinal impedance? **H. Damerau** replies that is very hard to answer. **Alexandre** adds that to do considerations about stability, it is important to know also the quality factor.

Fritz suggests taking the module out and make detailed analysis of the material properties of the fingers (fatigue test etc…)

Elias recommends asking to repair or properly identify all these issues before HL-LHC.

Fritz suggests planning an exchange of the model, since sooner or later we will be forced to do this if we exploit these issues every time.
Benoit and **Sergio** say that it is not up to us to decide this.

Josef S. says that we are afraid of the fact that the finger could touch the bellows and it could be a huge problem. For the future we could implement an extra bellows shielding protection inside, just to make sure to not touch the bellows.

Benoit would like to suggest doing an extra x-ray at warm to try to understand what happened but **Josef** thinks is the warm up that gradually destroyed this.

Christine thinks there is a big interest to do a follow up of this PIMs and to document how many PIMs have already been replaced. This question will be asked tomorrow if not already covered by TE-VSC.

Elias wonders how long it takes and how much it costs to do all the x-rays and suggests talking about this with the Vacuum group.

Fritz recommends doing an easy measurement consisting in mimicking the image currents over these fingers and to provoke these welding between rhodium and gold and check where it starts getting stuck.

Sergio C. replies that the non-conformity is not at the contact with the rhodium, but inside where there is the Stainless Steel.

All the IWG agree to present this tomorrow by Carlo Z.
Benoit asks if IWG agree to the strategy of simulating every time when issues like these will happen again and everyone agree with this strategy.

Benoit suggests doing some RF measurements with the current PIMs if it won`t be radioactive, like wire or bead pull measurements.

Fritz C. comments that you won`t be below cut-off and probably is better to do numeric wire measurements.

Benoit said that simulated wire measurements are also planned and adds that the management asks if we can make this kind of measurement and they reply that it is possible, but it would take time to setup everything.