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Thermal load on the beam screen in sector 12 after thermal cycle (replacement of A31L2) (Krzysztof Brodzinski)

Krzysztof summarized the observations after the thermal cycle during the EYETS. The thermal cycle was done with the correct sequence for cooling cold mass and beam screen (BS) circuits to avoid trapping of gas on BS surface. At the restart after the EYETS, it was observed that S12 generates the highest heat load (HL) among all sectors. In addition, it was observed that, during individual fills, the HL in S12 and S67 decrease faster than in the other sectors. It was pointed out (G. Iadarola) that the ratio of heat load attributed to quadrupoles and dipoles likely differs in each sector, which could give rise to different HL evolution during fills, since the HL in the two components scale differently with energy and intensity.

Cell 31L2 was instrumented by TE-CRG during the EYETS for detailed investigation of the BS heat load. The replaced dipole D4 was found to have lower HL compared to the other magnets in the cell. The HL distribution with 6.5 TeV beams allows concluding that the thermal cycle hardly had any effect on the cell-by-cell heat loads; the distributions in S12 in 2015/2016 and in 2017 are very similar.

The refrigeration capacity was measured in sectors 23, 34, 78 and 81. For the other sectors the default estimated value of guaranteed refrigeration capacity is 160 W per half-cell. Such mapping will be continued progressively during TS/EYETS to investigate the real limits of the cryogenic plants. The tests were done in between other activities as no dedicated time slot was allocated in the planning.

LHC beam screens: cryogenic observations in instrumented cells (Benjamin Bradu)

Benjamin presented an analysis of the heat loads in the BS per aperture in the instrumented cells, wherever this information is possible to extract. In general, there are two sensors on each BS, but some of the Q1's and D4's have only one sensor, making it impossible to distinguish the HL contribution from beam 1 (B1) and beam 2 (B2).

On July 23rd a test without beam using an electrical heater was done to check that all sensors behave similarly. The absolute errors were found to be less than 0.5 W, which corresponds to less than 2% error, when normalized to length and beam intensity.

The HL analysis was done for 3 fills in June-July 2017: a 25 ns scrubbing fill and two physics fills with 25 ns and 50 ns beams, respectively. For the 25 ns beam, both at 450 GeV and 6.5 TeV, a large dispersion of HL across magnets was observed, along with some asymmetries between B1 and B2, with the largest ones in Q1 in 12R4 and D3 in 34R4. In the case of the 50 ns beam at 6.5 TeV the HL in all magnets were similar and no asymmetries between B1 and B2 were observed. If

the differences in heat load were due to a restriction in the pipe or in the cooling flow, asymmetries in HL between B1 and B2 would be expected also for the 50 ns beam, but were not observed.

At injection, the Q1's in all the instrumented cells (12R4, 34R4, 13L5 and 31L2) have high HL, with an asymmetry in the contribution from B1 and B2 in the first two (in the latter two there is only one sensor, so the analysis cannot be done). Also the D3 in 34R4 shows a large contribution from B1. It was also observed that the HL in quadrupoles decreases with increasing energy, whereas in the dipole the HL increases with energy. This behavior with energy has been predicted in simulations (see presentation of G. Iadarola).

To conclude, it was observed that the sensors are good enough for BS heat load estimations per aperture. There is homogeneity across all magnets/apertures at 50 ns. Abnormal heat loads are observed in some magnets and apertures at 25 ns. The replaced dipole in S12 shows a much better behavior than the other dipoles in the same cell.

G. Arduini asked if there is any correlation between bad HL cells and bad/good HL cold mass, to which K. Brodzinski answered that there is not.

Analysis of LHC arc heat loads (Giovanni Iadarola)

During operation with 25 ns bunch spacing in Run2, large HLs are observed on the arc BS, with significant differences in the average HL per half-cell in each arc. Gianni presented the conclusions of the extensive analysis of the HL evolution that has been done to understand why the HL in some cells is much higher than in others.

The analysis shows that the HLs in the different arcs evolve in the same manner over time, but with an offset that scales linearly with intensity. A similar behavior is observed also at the cell-by-cell level: normalized heat loads differ only by a constant offset. The difference in heat load between sectors does not significantly change during the ramp, implying that the differences appear at injection and stay constant as a function of energy.

The cell-by-cell heat loads from the one-week test period with 25 ns beams in 2012 have been reconstructed and show that the spread between cells was not present at that time. Compared to the situation in 2012, the current HLs in some sectors are larger by up to a factor four.

Comparing the HLs at the beginning of the 2017 scrubbing to the end of the 2016 run, some decondition is observed in all sectors, with significant deconditioning observed in S12, which was warmed up and vented during the EYETS. The cell-by-cell heat loads in S12 are more similar than at the end of 2016, however, after conditioning the cell-by-cell pattern of 2016 is essentially recovered.

In the sectors that stayed cold during the EYETS the HL levels of 2016 at 450 GeV could be recovered after 24h of conditioning, while S12 recovered after 4 days of scrubbing. There are no signs of conditioning beyond the levels of 2016 in any sector, even with trains of 288 bunches.

Turning to the analysis of the instrumented sections, none of the magnets in S45 show a high HL. The newly instrumented cell in S12 is providing very interesting data; the magnet that was exchanged conditioned in two days, whereas the other magnets condition very slowly and show

much higher HLs, up to a factor ten compared to the newly installed one. The quadrupole in S12 also shows a large HL, and hardly any conditioning with dose. Magnets like these likely cause the differences between sectors and cells. Detailed analysis of the beam screens in such a magnet could provide valuable information on the origin of the difference.

Also the instrumented stand-alone magnets show rather high HLs and little conditioning. It was discussed that coating one of these magnets could be feasible and would provide useful information on mitigation strategies.

Finally, Gianni showed that the HLs in the fill with 50 ns beam is consistent with the expected amount from impedance and synchrotron radiation, which is not the case for the 25 ns beam. The HL reduction can be seen in all cells and no significant differences between cells or sectors are observed with the 50 ns beam.

Heat load from impedance of non-conformity in interconnects
(Benoit Salvant)

LHC PIMS are components where non-conformities can develop. The worst case scenario is if all HL from RF finger goes to the BS.

Non-conformity has been observed on the V1 line in the interconnection QQBI.18L1. A gap in the 1 mm range was found between a finger and the copper insert. This triggered a numerical case study for what happens impedance-wise in such a situation.

Three cases were compared for the study with a simplified geometry: perfect contact, 1 finger not touching without funneling and one finger not toughing with funneling. The conclusion of the study was that it is important to ensure the funneling in case of loss of contact. Analyzing the impact of the number of fingers that lost contact with funneling it was found that if half of the fingers lose contact the heat loss reaches at most 20mW with 25 dB attenuation, 2200 bunches and 1.1e11 p/b.

In the case of a real geometry and one finger with no contact the heat loss is 25 mW for 2500 bunches at 1.1e11 p/b, if hitting a major resonance line. If several fingers are not touching this can result in larger shunt impedances and heat loss. In the case that it stays in the background and does not hit a major resonance lines, the HL is low even for several fingers, implying that both a large number of PIMs with a large number of non-conforming finger would be required to explain the observed HLs. In both cases, however, the HL would be expected to be present also with 50 ns beam.

Can an impedance be the source of the observed differences?
(F. Giordano)

Assuming that the explanation of the observed heat load is heat loss due to impedance, two possibilities were considered: a broad-band and a narrow-band impedance, where the former scales linearly with the number of bunches and the latter has a square dependence on the number of bunches. The power-loss for 25 ns and 50 ns filling patterns for the two cases of impedance, the spectra are very similar and one could expect a 4 times higher power loss for the

25 ns beam from a narrow-band impedance and 2 times higher from a broad-band impedance. However, the cryogenic measurements for the two beam options (give a HL ratio of 8, or around 16 if scaled to the same number of bunches, which cannot be explained by a narrow-band, nor a broad-band impedance.

Looking for a resonator that could explain such a high power loss, a mode is chosen for which a scan of width and resonant frequency is done. In the expected range of impedances for a PIM non-conformity, no resonance was found that could match the ratio in power loss between the 25 ns and the 50 ns beam. Even considering a broader range of impedances, none can be found that matches the measured HL for all the different bunch patterns considered.

To conclude, the ratio between the 25ns and the 50ns heat load is too large to be explained by an impedance.

NOTES: At the end of the meeting V. Baglin presented a summary of activities in LS1. No evident correlation with the observed differences in heat load could be identified.

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GS & LM