

# SESSION 7: LIMITATIONS

Gianluigi Arduini and Walter Venturini Delsolaro

## Abstract

Session 7 was devoted to the discussion of possible limitations to the LHC performance that might be inferred by observations and analyses of data from the 2011 run. The Session included five presentations:

- Impedance effects on beam stability (N. Mounet)
- Beam induced heating (B. Salvant)
- Electron cloud effects (G. Rumolo)
- Electron -cloud & vacuum instabilities (G. Bregliozzi)
- Luminosity lifetime - protons (G. Papotti)

addressing diverse topics such as impedance and electron cloud effects, vacuum and beam-beam effects.

## IMPEDANCE EFFECTS

Nicolas Mounet reviewed the possible beam instabilities in the LHC (single and multi-bunch) that can be studied by means of analytical formulas and computer simulations with the LHC impedance model. The talk focused on head-tail and coupled bunch instabilities based on the existing model of the machine impedance.

The present LHC impedance allows determining impedance driven tune shifts. Collimators and protection devices are one of the main drivers of the machine impedance and a comparison between the measured and expected tune shift as a function of the bunch intensity and of the collimator gaps showed agreement within a factor 2 (which is very good given the complexity of the elements and machine), with the exception of the TDI for which the discrepancy is larger and it has increased significantly from 2010 to 2011. A partial damaging of the Ti coating of the Boron Nitride jaws could be the responsible of the observed increase in tune shift. Similarly, rise times of the coupled bunch instability were shown to be close to the model at 450 GeV, whereas at 3.5 TeV showed discrepancies up to a factor 2~3. It was underlined that no measurements of the coupled bunch tune shifts were available yet. Nicolas offered a detailed analysis of the event of 29 August 2011, when the beams had been observed to become unstable in correspondence with the reduction of the parallel separation when going in collision at 3.5 TeV with tight collimator settings and a reduced crossing angle. Very likely the observed instability and losses were the result of the interplay of the increased impedance (because of the tight collimator settings), large chromaticity ( $>2$ ). As a result of that the  $m=1$  head tail mode become instable leading to emittance blow-up and to a reduction of the long range beam-beam separation exciting a long range beam-beam coherent mode. From the above observations it was inferred that the beam separation should be kept above 9 sigmas, the chromaticity should be kept close to zero ( $<1$  and possibly positive) and stronger Landau octupoles should be used to

prevent the instability build-up. Actually the currents in the Landau octupoles had been increased to 200 A at the end of 2011. Nicolas concluded that the most critical instability was the single bunch head tail mode  $m=1$ , for 50 ns (due to higher bunch intensity), with almost no difference between 3.5 TeV and 4 TeV. He reckoned that an increase of the Landau octupoles currents to 450 A should be sufficient to cope with the instability for a chromaticity of 2 units. Lower values of the Landau octupole currents would be sufficient to stabilize the beam for lower chromaticity.

S. Redaelli asked what the margin was on the Landau Octupoles. N. Mounet answered it depends on the value of the chromaticity, and that the margin would be zero for  $Q'=4$ . He reminded that it should be possible to run with slightly negative chromaticity. S. Fartoukh cautioned that in that case the dampers for transverse feedback would have to work harder.

B. Goddard observed that the geometry of the TDI (angles) had been changed, which might explain to some extent the larger difference between model and beam data. He further asked how much of the TDI coating should have to be removed in order to account for the observations. N. Mounet replied that one would need to assume a thickness reduction of 1.2  $\mu\text{m}$  along the whole TDI length. Reyes Alemany asked whether it was possible to control the chromaticity to subunit levels. G. Arduini recalled that this was required at high energy (were such control is easier as the persistent currents are more reproducible than at injection). S. Fartoukh warned against possible detrimental effects of high settings of the Landau octupoles. This included high  $Q''$  and resonances.

F. Zimmermann asked whether the discrepancies between data and simulations came from the impedances of the collimators, and how sensitive were the instability thresholds to the RF voltage (through bunch length and synchrotron frequency shifts). To the first question N. Mounet answered that some trapped modes might not be included in the model, or some broadband contribution could be missing and that 3D simulations would be needed. To the second question he just observed that the higher the bunch length the best it was for the stability.

G. Arduini asked to what current the Landau octupoles had been commissioned. Outside the meeting it was clarified that they have been commissioned up to 400 A, therefore they should be commissioned up to nominal current (550 A) before the 2012 run.

## BEAM INDUCED HEATING

B. Salvant presented an overview of the beam induced heating limitations in 2011 and a forecast of the possible limitations for the 2012 operation. In both cases, the bottlenecks seem to be at the injection kickers. Other sensitive spots are at some of the collimators and at the

double bellow module VMTSA. The subject had been reviewed at the mini-Chamonix workshop in July, where possible mitigations for the MKI had been considered, like increasing the temperature interlocks and, on a longer timescale, doubling the number of conducting strips to reduce the heat load. The increase of the MKI temperature interlocks should be done with the outmost care as close to the Curie temperature the kicker ferrites will lose their permeability and the kick provided by the kicker magnets will decrease. This could lead to damage. Quoting C. Bracco's presentation in Session 3, B. Salvant showed that in one case the Curie temperature had been already exceeded. A list of recommendations and actions for the winter stop was presented, including X-rays checks of the RF fingers at the MKI-8D.

For the collimators the temperature interlocks could be increased more easily in case of need, although there were some doubts on the accuracy of the measurement. Benoit went on by analysing the effect of bunch length on the heating. The losses scale linearly with the number of bunches and quadratically with the bunch intensity in case of broadband impedances, whereas the scaling is quadratic with both parameters in case of a narrow band impedance (cavity). A comparison of the beam spectrum measured before and during the energy ramp shows the effect of bunch length. A shift in the notch around 1.5 GHz can be observed. In stable beams the amplitude of the power spectrum is reduced. The MKI impedance was simulated in 3D (H. Day et al.). This allowed computing the heat load on the MKI as a function of bunch length. Increasing the bunch length will decrease the power deposited but the effect is expected to be marginal (~12 W, i.e. 15 % reduction for an increase in bunch length from 1.2 to 1.4 ns). A strong effect of increasing the number of conducting strips is highlighted. From a semi empirical model by B. Goddard, the problem of MKI heating is anticipated to have a strong impact on turnaround in 2012, if not mitigated.

Benoit showed evidence of broadband impedance as the mechanism responsible for collimator heating.

Concerning the TDI, the problem seems to have been solved by increasing the gap opening. Also in this case impedance simulations had been carried out, confirming the observations.

A consolidation of the VMTSA double bellow was foreseen for the winter stop to minimize the risk of bad RF finger contact that were individuated to be the main cause of the damage to the RF fingers observed during X-rays and visual inspection.

The beam screen temperatures had been under control in 2011, the beneficial effect of scrubbing and increasing bunch length was underlined. The main worry here was the temperature of the beam screen at Q6R5, where very little cooling margin was left. A temperature increase of 17 K had already been observed, which raises concerns for the vacuum.

A need for monitoring the heat load at triplets was also pointed out.

G. Arduini asked to the vacuum colleagues if going above 17 K at Q6.R5 was an issue. V. Baglin answered in the negative because that the next desorption level is at 28 K (carbon oxide).

R. Schmidt wondered about the different temperatures in the two MKI. B. Goddard replied that there might be a different thermal contact in the two cases, but we are sure that at least in one case the Curie temperature was reached. He further elaborated on the problematic MKI, recalling that this element is bad in several respects and they are considering taking it out. The change could be done in a 5 days long technical stop.

E. Shaposhnikova remarked that the increase of bunch length was an easy way out, but it was bad in the long term as the bunch length already increases in stable beams and could lead to a reduction of the luminosity lifetime. G. Arduini asked whether ALFA in parking position was giving any concern. Benoit replied that the situation was similar to that of TOTEM: possibly the detector will have to be taken out if it gets too hot. S. Redaelli pointed out that their temperatures are not interlocking the beam.

## E-CLOUD EFFECTS

G. Rumolo reviewed the observables that are used in the study of the electron cloud effects and explained the method used to estimate the secondary emission yield of the beam screen surfaces. He summarized the results of the scrubbing run that was carried out in April 2011, when up to 1020 bunches in a 50 ns time structure were stored in the LHC at injection energy. Machine cleaning was apparent from all the monitored observables (heat loads, vacuum, stable phase, and beam instabilities). This scrubbing run provided good conditions for the subsequent intensity ramp up. After the scrubbing run, the maximum secondary emission yields asymptotically approached their thresholds until 29 June, when the first 25 ns beams were injected in the LHC. The experience with 25 ns culminated on 24-25 October when 2100 bunches were stored in B1 and 1020 in B2, in a 25 ns time structure with 1  $\mu$ s batch spacing. In spite of some evidence of cleaning, the beams were still unstable after that because the achieved Secondary Electron Yield (SEY) was larger than the build-up threshold resulting in electron densities larger than the instability thresholds. In conclusion, operation with 50 ns beams should be possible in 2012 without electron cloud, up to very high bunch intensities, thanks to the scrubbing performed in 2011, while further scrubbing would be needed to suppress the e-cloud with 25 ns.

B. Goddard asked whether a scrubbing run would be needed at all if we were to choose to stay with 50 ns in 2012. G. Rumolo replied that if the arcs were not opened, no further scrubbing would be needed. G. Arduini observed that some locations in the ring will be opened and that the arcs will be warmed up. He proposed a short scrubbing run, also to estimate the time needed to fully scrub at 25 ns, and to move up the thresholds of the instabilities. G. Rumolo reminded that the beam parameters could be optimized during the scrubbing to

speed it up. R. Schmidt asked if we had observed performance changes in other respects (i.e. UFO occurrence, vacuum, etc) after the scrubbing. G. Rumolo replied that he had not looked into that. D. Valuch reminded that the RF phase loop was not designed to have sub-degree resolution. In reply to Daniel, E. Chapochnikova observed that the data were consistent from the physics standpoint.

## E-CLOUD AND VACUUM INSTABILITIES

G. Bregliozzi illustrated the layout of the LHC vacuum system and reviewed the observations of the electron cloud effects from the point of view of vacuum. The LHC beam vacuum system features surfaces at several temperatures: the cold bores in the arcs are at 1.9 K, the beam screen temperatures vary between 5 K and 20 K, and the standalone magnets are at 4.5 K. The cold surfaces provide a huge diffused cryo-pumping. The room temperature parts rely on the NEG coating pumping. But the cold-warm transitions are not baked over a short length. Apart from the NEG areas, all the remaining surfaces require scrubbing to suppress the electron cloud.

When looking at the dynamic pressure, a clear difference can be seen between baked (NEG-NEG transitions) and unbaked (cold-warm transitions) areas, whereby it is apparent that unbaked surfaces have higher desorption rates, as one should expect. During the scrubbing with 50 ns beams, operation was limited by pressure increases in the baked and unbaked transitions. On the contrary, with 25 ns beams the limitations came from the electron cloud in the arcs. This confirmed the incompleteness of the scrubbing with 25 ns. From a plot of the dynamic pressure versus electron dose one can clearly see however the effect of the little 25 ns operation that was done, which shows up as a change of slope in the curve.

Giuseppe went on by analysing a few cases of localized pressure spikes (injection regions, TDI, ALICE, and CMS). Non-conform RF fingers not providing a good electrical continuity were suspected. In the last part of his talk Giuseppe presented a strategy to mitigate the effects of electron cloud and heating in 2012. For the electron cloud, additional scrubbing with 25 ns beam should be performed for operation at high intensity with 50 ns (either in one block of 7 to 10 days or distributed in blocks of 24 to 48 hours after each technical stop) Solenoids will be installed in uncoated zones and in particular at the MKIs to avoid pressure rise that have limited the intensity ramp-up during the scrubbing in particular for beam 2. For the pressure spikes and the heating effects, additional pumping speed will be installed where needed. The Vacuum Modules VMTSA will be consolidated. The new settings of the TDI gaps, fully opened after injection, will reduce heat load and pressure increase. The CMS pumping system will be also upgraded and X-rays will be used to investigate the RF fingers.

M. Lamont asked if 7-10 days of scrubbing were really needed. Giuseppe replied that the estimation took into account the machine availability. G. Arduini added that if

the choice was made to stay with 50 ns, the scrubbing run could be faster, he reminded that scrubbing at 25 ns brought additional benefits (to be studied in detail). G. Arduini further asked about the situation in CMS. Giuseppe said that a partial bake-out was foreseen along with a local increase of the pumping speed. V. Baglin added that a common effort was ongoing between the vacuum group and CMS and that it was agreed that we could not afford opening the vacuum pipe.

G. Arduini finally asked what could be the evolution of the temperature at the primary collimators. The interlock level being at 70°C he wondered what was expected for the vacuum. Giuseppe answered that the NEG coating was probably pumping all the released gas, so it was possible that the actual temperature of the inner surfaces was very high. V. Baglin said that it would be important to minimize the NEG saturation as the area is bound to reach high dose levels.

## LUMINOSITY LIFETIME-PROTONS

G. Papotti discussed the observations performed in 2011 on luminosity related issues. After reaching the maximum allowed number of bunches for 50 ns spacing, peak luminosity has been increased by reducing and finally suppressing the transverse emittance blow-up in the SPS, and by increasing the bunch intensity. The beam-beam parameter saturated above  $6 \cdot 10^{-3}$  per interaction point which is about twice the design value. Some optimization of the working point had been done, with beneficial effects on the initial intensity lifetime in collision, although the effect on luminosity lifetime was much harder to assess.

A dynamic model for luminosity evolution, developed by V. Lebedev for the Tevatron, was being adapted to the LHC with some first good results.

Empirical fits with double exponentials were also presented, and comparison with 2010 data evidences smaller scatter of the fit parameters.

The limitations coming from beam-beam effects had been investigated in dedicated MDs. It would seem that head-on beam-beam is much less of a problem than anticipated, and no hard limit has been found up to very high brightness. On the contrary, long range interactions appear to cause losses through reduction of the dynamic aperture. A list of studies to be performed in 2012 was presented including tune scans during standard operation and experiments to be scheduled as MD sessions.

E. Shaposhnikova asked if the transverse dampers were included in the model only as a source of noise or also as a damping term. Giulia replied that they only appear as a noise term. W. Höfle said that an external source of noise is always superimposed to the noise generated by the damper. Giulia agreed and said that the two terms could be disentangled by a dedicated experiment. G. Arduini suggested that the effect of ADT noise should be visible on the non-colliding bunches. K. Cornelis disagreed, explaining that the sensitivity to noise depends on the potential that the bunches see, which is very different for non-colliding bunches.

R. Assmann asked if we understood the effect of the positive tune trim. O. Bruning said that it was expected as this moves away the tune footprint from harmful resonances. R. Assmann suggested trimming the collision tunes further up. G. Arduini agreed but reminded that the effect on luminosity lifetime seemed to be small. Y. Papaphilippou asked if we were sure that the long range experiment had evidenced a reduction of the dynamic aperture. Giulia answered that it was believed to be a dynamic aperture effect because the emittance had remained constant and because the loss rates had gone back to normal when the crossing angle was brought back to the nominal value.

- Additional solenoids to be installed at the MKI in point 8 to minimize the impact on the intensity ramp-up during the 25 ns scrubbing run;
- The TDI should be moved to parking position at  $\pm 55$  mm just after injection to minimize TDI heating and outgassing;
- Beneficial effect of working point tuning on losses has been but the tune scans should be continued for luminosity lifetime optimization (ABP,OP);
- Effort to be continued (increased) to understand the contribution of the various sources to luminosity lifetime (ABP, OP).

## IDENTIFIED ACTIONS

The following actions have been identified:

- Need control of chromaticity down to  $<1$  unit at top energy. The possibility to operate with slightly negative chromaticity with the transverse feedback on should be identified (ABP, OP);
- Landau octupoles should be tested up to nominal current (550 A) before the start-up 2012 (OP, HWC);
- The impact for the operation at 7 TeV should be assessed (ABP);
- The status of the Ti coating of the TDI jaws should be assessed (ABP/STI/VAC);
- X-rays of RF fingers for MKI8-D (ABP, ABT, VAC);
- More measurements in 2012 to determine how far from the Curie temperature the MKI magnets are getting during stable beams (ABT);
- An increase of the bunch length should be tested in 2012 and its impact on heating and luminosity lifetime should be evaluated (ABP, OP, RF);
- X-rays of the RF contacts at the TCP.B6L7. (ABP, STI, VAC);
- X-rays of the RF fingers of Q6.R5 (ABP, VAC) should be performed;
- ALFA temperature increase. The impact on the detector should be evaluated and its compatibility with high intensity operation should be assessed (ABP, ALFA);
- Duration of the scrubbing run for operation at 50 and 25 ns should be assessed more precisely ABP, ABT, OP, VAC;
- The scrubbing should take place as early as possible in the run and in any case before any serious intensity ramp-up (ABP, OP, VAC);
- The effect (if any) of the scrubbing at 25 ns on vacuum pressure during 50 ns operation should be analyzed further (VAC);
- The need for a mini scrubbing run after each technical stop should be evaluated (VAC);
- A solution for the RF fingers in the VMTSA should be identified and implemented (ABP, VSC)
- X-rays on RF fingers 18 m (R5) should be performed;