# WP2 Meeting #163

## Tue 26 Nov 2019, 09:00 – 12:00

*Chair:* G. Arduini

*Speakers:* R. De Maria, S. Furuseth, S. Kostoglou, G. Sterbini

*Participants:* S. Antipov, C. Bracco, X. Buffat, H. Garcia Morales, M. Giovannozzi, M. Martino, E. Métral, N. Mounet, Y. Papaphilippou, F. Plassard, A. Poyet, K. Skoufaris, R. Tomás, F. Van der Veken

## AGENDA



## MEETING ACTIONS

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| **Riccardo** | Review the β-function limit in IR-6 |
| **Riccardo** | Find out what constraint ultimately limits the beam size at the dump |
| **Xavier** | Determine noise limits from stability considerations |
| **Sondre** | Study the dependence of latency and diffusion rates on impedance |
| **Yannis** | Possible MD studies aiming at clarifying the origin of the observed lines and possibly the interplay between noise and impedance should be defined. |

**Elias** study with simulations or theory whether the interplay between impedance and noise can lead to an enhancement of the noise amplitude

# General information (G. Arduini)

Minutes of the last meeting with be circulated shortly.

# 1 IR6 optics and limitations (R. De Maria)

Multiple optics constraints exist in IR6: matching the optics functions to the arcs and squeeze of IP5; strengths of Q4.L/R6 are fixed by transfer line; MKD-TCT phase advance, which depends on the available horizontal aperture; beam size at TCDQ; peak β-function in the insertion during Squeeze; injection aperture; low strength of the MQTL.11 quadrupole etc. Overall, there are 16 individually powered quadrupoles to match the optics.

In the presented analysis no significant issues were found in Flat or in Round optics. The aperture provides margin for Flat and Round optics with and without crab cavities. The additional margin can be used to further push performance ($\beta^*$), offset the orbit at the IP to reduce irradiation of the triplet (being studies by F. Cerutti), or relax collimator setting in order to reduce impedance.

An optimization of beam size at the dump has been undertaken in order for it to able to sustain HL-LHC beams. Ultimately, one can reach Horizontal β-functions of 9 and 5 km and Vertical β-functions of 5.5/10 km for Beam 1 and Beam 2 respectively. This corresponds to a 25% increase of beam size.

- **Gianluigi** questioned the β-function limit of 1.5 km, since in Flat optics it goes up to as much as 1.2 km in many quadrupoles of the ATS arcs, according to **Rogelio**, and proposed reviewing the number (Action: **Riccardo**).
- **Gianluigi** asked if the MQTL.11 quadrupole can be trained. **Riccardo** replied it could be done but experts advise not training the magnet without reason.
- **Chiara** pointed out that the present windows will not survive HL beams, therefore new ones must be installed, a process which started in LS2. **Chiara** proposed not discussing increasing the beam size before the new windows are installed as even the 10 km β–function might not be sufficient with the present windows. **Gianluigi** emphasized the significant improvement obtained by optimization and should be further pursued to see whether this can reduce the required HW changes. **Chiara** proposed discussing the limits with the FLUKA team. **Gianluigi** noted no constraints have been relaxed during this study and raised a question what constraints ultimately limit the beam size at the dump (Action: **Riccardo**).

# 2 STATUS OF STUDIES OF THE IMPACT OF NOISE ON BEAM STABILITY (S. FURUSETH)

Instabilities with large latency times have been observed in LHC. They are believed to be caused by noise, which has been reproduced in dedicated studies and numerical simulations. In simulation the latency time turned out to be inversely proportional to the magnitude of applied white noise. The noise leads to diffusion in phase space and thus modifies the distribution and leads to a loss of Landau damping.

An analytical model developed to study the phase space diffusion. The model uses extrapolation from unstable region to find the frequency of a mode when it is inside a stability diagram. In the model the diffusion coefficient is peaked at the mode frequency, leading to spread of particles close to that frequency. As a result, both in a 1D and a 2D case one sees a flattening of the bunch distribution at the mode frequency.

From stability point of view, the most critical is the situation when the noise affects the azimuthal mode 0, which happens at negative chromaticity. Also, crab cavity (CC) amplitude noise can affect mode 1 severely leading to short latency times. In principle, noise acting at particular frequencies can drive similar instabilities, even in the absence of wakefields. For this, the frequency of the noise must be close to a beam mode.

In order to mitigate noise-driven instabilities one can try reducing the noise amplitude, avoid unstable mode 0 (i.e. negative chromaticities), lower the impedance to increase the margin to stability threshold, reduce the waiting time by colliding the beams as early as possible and turning CC's on in collision. One more possibility is to modify the nonlinear detuning to have a 0 direct term in order to avoid the dependence of the stability diagram in the derivative of the distribution.

Experimental verification of the noise hypothesis was tried in 2018 when an instability was observed with white noise during a beam transfer function (BTF) measurement. Future measurements can focus on latency and its dependence on parameters such as Q', damper gain, octupole current, beam intensity. Similar studies can also be performed in SPS and at IOTA.

- **Elias** asked what defines the time it takes for the particles to diffuse out and the beam to become unstable. **Sondre** replied the answer is not obvious: the frequency of the noise plays a role, just as the distance to the edge of stability diagram.
- **Xavier** noted that the CC amplitude noise might pose a challenge for turning CC's on before collision. **Gianluigi** requested informing the CC team about the potential issue. For that, it would be important to determine noise limits from stability considerations (Action: **Xavier**). **Sergey** asked what experiment could be performed to demonstrate the impact of CC noise. **Xavier** proposed a study at negative Q' in LHC, where the situation should be similar to that with CC noise at high positive Q'. **Yannis** suggested trying to make an observation at the SPS test.
- **Yannis** noted that modifying the octupole detuning cross term can be done with wires in Run 3.
- **Gianluigi** suggested to clarify the scaling of the effect on parameters. **Xavier** pointed out it is not trivial, one may have a small stability margin with a large latency time, for example. **Gianluigi** proposed to start with studying, in theory or in simulation, the dependence of latency and diffusion rates on impedance (Action: **Sondre**).

- **Gianluigi** reminded that **Guido** is collecting a table of all the possible known sources of noise and their characteristics.

# 3 STATUS OF NOISE SOURCE STUDIES IN THE LHC, EXPECTED IMPACT FOR HL-LHC (S. KOSTOGLOU)

Sofia considered the impact of noise from dipole and noise from quadrupole magnets. The two types of magnets have different sources of noise, affecting the beam in different ways. Noise in the main dipoles is generated by their SCR power converters and leads to a comb of 50 Hz harmonics in the beam spectrum, which may excite tune resonances. As the power converters of the quadrupoles of the Inner triplet are Switch Mode type with high switching frequency a comb of 50 Hz harmonics is not expected in this case. Depending on the amplitude and the frequency of the switching frequency, a tune modulation may be observed, which excites sideband resonances in the tune footprint.

There are two distinct regimes of interest in the beam spectrum: a low-frequency comb of 50 Hz harmonics below 3.6 kHz and a high-frequency cluster around 7-8 kHz. It is important that to resolve these spectral lines in the beam one must perform averaging of the spectra of all bunches, properly taking into account phases of each spectral line, as the signal is below the noise floor for a single bunch. This procedure should be done automatically in Run 3, with beam spectra saved and an online monitoring tool available.

The 50 Hz harmonics have a very specific signature allowing identifying them in the spectrum. On top of that, one can follow the phase advance of the induced oscillation between two closely spaced pickups and, after comparing with the betatron phase advance, confirm that the beam excitation is real. This is true for all identified spectral lines. The high-frequency spectrum seems to be centered at a frequency equal to a difference of revolution and tune frequencies.

Low frequency 50 Hz harmonics can be suppressed by an active filter, confirming it is the power converter (PC) what is causing them. This is not the case for the high frequency cluster and consistent with the expected bandwidth of the active filter (up to 1 kHz).

In terms of amplitude, the largest noise line is around 0.1 $\mu$m, or 1e-3 beam $\sigma$. Beam 1 is more affected than Beam 2 and no dependence on $\beta^*$ is observed. The feedback seems to be efficiently suppressing the noise lines, which can be seen from one fill where the bandwidth was not changed from Extended to Standard and the noise lines were greater than in other fills.

It is not completely clear why noise amplitudes at high frequencies are higher at low ones. A direct excitation is excluded as the source of noise since it must be attenuated towards higher frequencies. The working hypothesis is an interplay between a mechanism acting on beam, noise in dipoles and damper. The central frequency, being the lowest coupled–bunch mode frequency hints a relation to impedance. Several tests are proposed for Run 3: to remove damping around a single 50 Hz harmonic with a notch filter and to increase the ADT gain only around 50 Hz with a comb filter.

In simulation the high-frequency noise affects beam lifetime in LHC already on the timescale of 90 sec. For HL-LHC inner triplet, the switching frequency will be at 50-200 kHz and it is not expected to have an impact on the beam. A scan up to 10 kHz shows that the threshold for DA reduction is orders of magnitude above the gabarit line.

- **Guido** made a comment that when a damper bandwidth is changed, its gain could also change by a factor two, according to Daniel Valuch.
- **Yannis** pointed out the noise could potentially be the effect behind the B1/B2 difference. **Xavier and Gianluigi** proposed investigating experimentally the interplay between of high-frequency noise lines and impedance.
- **Yannis** raised a question what happens to emittance evolution with larger noise. **Sofia** emphasized the lack of measurement data on longer time scales. **Yannis** mentioned that in Fill 7035, where the noise lines in Stable Beams were higher by a factor of 2, an impact on emittance evolution was not observed, possibly because of the limited duration of the fill.
- **Michele** noted it is surprising to see a low frequency cutoff around 3.6 kHz in the spectral data, as the physical properties of hardware, such as beam screen, suggest a cutoff ~ 100 Hz.
- **Gianluigi** suggested studying the dependence of the 7-8 kHz lines on collimator opening. Possible MD studies aiming at clarifying the origin of the observed lines and possibly the interplay between noise and impedance should be defined (Action: **Yannis**).

  **Gianluigi** also noted that we should study with simulations or theory whether the interplay between impedance and noise can lead to an enhancement of the noise amplitude (Action: **Elias**).

# 4 Summary of the HL-LHC Wire Compensation Meeting (G. Sterbini)

At the moment, wire compensation is not in the HL-LHC baseline. Only if additional resources are allocated the HL-LHC compensator can be installed.

LHC has 4 technology demonstrators in Beam 2 mounted in the jaws of tertiaries collimators. This limits the minimum distance between the wire and the beam to avoid loss of collimation hierarchy. A rich experimental campaign was undertaken in 2017-18 and its results demonstrated a clear effect of wire compensators, observed as reduction of losses in operational conditions.

Numerical tracking simulations suggest that two wires powered at maximum current improve the dynamic aperture by 0.5 $\sigma$. In Run3 the wires will be powered at the end of leveling. Next steps include equipping Beam 1 with wires by moving two wires from Beam 2 to Beam 1 (both beams will have 1 wire per IP) and utilizing the wires routinely in operation.

For HL-LHC, numerical simulations allow optimizing the octupole current and wire to maximize the DA. Recent progress in theory with Hamiltonian approach proved that by correcting the low order resonance driving terms one can at the same time correct the higher order ones (so far shown only in 1D). This opens the door for a large distance high current configuration. In the ultimate HL-LHC scenario 1.5 $\sigma$ of DA can be gained with wire compensation, with a large area of tune space available to accommodate the tune footprint. Alternatively, half-crossing angle can be reduced to 190 $\mu$rad while retaining a nearly 6 $\sigma$ DA, therefore allowing a half-crossing angle of 190 $\mu$rad (corresponding to the crabbing angle) at the end of levelling. Finally, for the Flat optics having a wire is fundamental to compensate the long-range interactions. In terms of luminosity, wires add 3% for the baseline round optics with CCs and reduce the integrated luminosity drop without CC's from -13% to -6% (round) or -5% (flat).

Currently, space is reserved for wire compensation in left and right of IPs 1/5 for 3 1-m-long modules in both beams. A proof-of-concept has been proposed and wire specimen ordered. The first prototype will come in 2020 and a technical review for using wire compensation in HL-LHC is scheduled in 2020.

TRIUMF is willing to take part in the project and to participate in future beam tests and tests of short models.

- During the review **Oliver Brüning** emphasized the interest to study interplay between the electron lens and the wire. **Yannis** mentioned there is clear diffusion from the core at 190 μrad crossing angle, leading a loss of lifetime and DA below 3 σ. **Gianluigi** recalled Alexander Valishev performed the simulations. **Yannis** mentioned these results have been brought up during the meeting, the requested simulations have to be performed for the review.
- **Yannis** proposed reviewing what resources can be allocated to the wire compensation effort in the years to come.

# 5 ROUND TABLE

Next meeting will be held the 3rd of December at start at 9 am due to a large number of reports.

*Reported by S. Antipov*