Review on Functional Requirements for LHC Transverse Instability Diagnostics for the start-up 2015 - Summary of the discussion

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Indico reference: https://indico.cern.ch/conferenceDisplay.py?confId=234589

Scope and Aims of the Review:

- collect user requirements
- present capabilities of existing systems and options for upgrades
- ensure technology and infrastructure in place to optimally use available instruments (triggers, logging, software)
- identify missing technologies and systems that need further development
- prioritize requests (feasibility, resources, impact)
- identify requests that cannot be fulfilled for the start-up after LS1
- recommend allocation of resources to management

Motivations

Although the performance of the LHC has been excellent in 2012 high intensity operation with 50 ns proton beams has been limited by instabilities observed:

- at injection (with low octupoles or in the presence of electron cloud)
- at high energy during the squeeze, when going in collision and in collision

Operation with 50 and 25 ns may be affected by the same type of instabilities in 2015, and we expect that the tolerance to beam losses resulting from these instabilities will be smaller due to the higher energy. For the above reasons we need to characterize precisely these instabilities.

Functional Requirements[1]

A first line diagnostics should be available in PM and online with similar format / analysis. Simple information on mode (m=0 versus m≠0) could give precious indications on what could be done. 'Light' changes are limited to: Q, Q', octupoles, ADT gain, bunch length, filling schemes, intensity/brightness. Instantaneous bunch-by-bunch information can be crucial to take fast decisions for short-term 'cures'.

Specifically, through the whole cycle:

- instantaneous bunch-by-bunch tunes (10^{-4} resolution) at an update rate of 1 Hz
- Accurate knowledge of chromaticity with a precision of about 2 units at an update rate of about 0.05 Hz. Systematic measurement every week if not possible online and if the reproducibility of the machine is compatible with the above requirement.

To provide a snapshot of the machine when the instability occurs. This information should be stored permanently in the logging DB

1 given from an ideal beam observable point of view, i.e. without including physical limitations and/or technical feasibility

Specifically, in an interval of time of +/- 3 s around the moment of the instability:

- Continuous “turn by turn” “bunch by bunch” positions during the instability with a resolution of a few um.
- Intra-bunch time domain signal acquisition with an analog bandwidth of about 6 GHz, 20 GS/s sampling and transverse resolution of few μm.
- Continuous bunch-by-bunch intensity at the highest rate (10 Hz)
- Continuous bunch-by-bunch transverse emittance with fast scan (Is a 5 Hz sequential acquisition feasible?). **Action: BI to verify whether this is possible.**

The instability trigger, identified to be essential, should be automatically re-armed once the data have been transferred. It should be possible to inhibit the trigger in some periods (e.g. at every injection), also specifically on an instrument-by-instrument basis. It also shall be compatible and not compromise the existing PM functionality. A synchronisation on a per turn basis would be ideal, but – provided the large circular buffers are used – 50 ms delays would be acceptable and the data could be re-synchronised off-line using a precise internal time stamp. However, a latency / jitter of 50 ms would not guarantee that the new on board memory on the ADT hardware with some 2000 turns bunch-by-bunch storage capacity could be optimally exploited. Having only a latency of 50 ms, would certainly call for a deployment of a dedicated recording hardware in addition to the operational ADT VME boards, as already been suggested. Ideally the instability trigger would have a jitter, i.e. uncertainty of a few ms.

This stored information after the occurrence of an instability should be kept on a permanent basis, similar to the post-mortem data.

We need software to bring the data together, align bunches and turns etc. and to provide online ‘analysis' and display – similarly as for the PM part.

Proposed solutions

– A new “observation box” based on the damper data can provide bunch-by-bunch/turn-by-turn data continuously with a resolution of ~2 μm rms at least. Bunch-by-bunch tune data can be extracted at 1 Hz, but not the required high resolution in tune in the presence of strong damping. Tune resolutions with high damper gain (50 turns damping time) are expected to be in the 10^{-3} range. The resolution should be better for lower damper gain and in case of instability. Averaging over more turns or more bunches (group of bunches behaving similarly) can improve the resolution. The damper signal (amplitude of oscillation larger than a defined quantity, for example 25 μm) could be used as a source signal for the instability trigger and be used to freeze data of one or all bunches for +/-3 second buffer.

– It is possible to have a better tune resolution on a single bunch with the gated BBQ and reduced damper gain on one or a few bunches. This information could be used to reliably track the tune of the machine at 1 Hz, and in combination with a continuous dp/p modulation of the above witness bunches, it could be used to derive the chromaticity, possibly even during regular LHC fills. Dedicated excitation of the group of bunches with reduced damper gain has also been tested and could be used for an enhanced signal.

– High frequency (intra-bunch) diagnostics based on the present pick-up infrastructure (see Appendix for a possible alternative for implementation in LS2). A new analog-FE: new wide-band hybrid and low-level gain- and offset control is required to avoid accesses in the tunnel when significant changes of the bunch intensity are implemented in operation (e.g. during MDs).

  Two solutions are proposed for the Digital-Data-Acquisition:

  A) Classic time-domain: next generation digitizer upgrade, 6 GHz analog bandwidth, 20 GS/s sampling, 32 GB/channel sampling buffer (>1 s of beam data).

  B) Multiband-Instability-Monitor (MIM), three different acquisition options:

     I. Balanced Schottky Diode Detector. This could provide nm-level resolution and could be used as an early instability trigger, but would not allow to distinguish on which bunch the instability occurs. Already planned for implementation in LS1.

     II. Bunch-by-Bunch Balanced Schottky Diode Detector. This would provide bunch-by-bunch magnitude (no-phase information for bands > 400 MHz) data with sub-μm resolution. Needs ADC-DAQ and SW integration

     III. Direct-Down-Conversion Receiver providing full amplitude & phase information (identical info. to time-domain digitizer). Needs ADC-DAQ and SW integration

– The non-gated BBQ running in parallel to the gated BBQ could be used as an additional instability trigger. Compatibly with the existing resources, the high-sensitivity instability trigger will be provided by the MIM with the read-out given as described in B.I. This will provide similar, if not better sensitivities as the BBQ and in addition an indication on possible intra-bunch motion. Also, this option is explored in order to be compatible with and not perturbing the regular BBQ operation for Tune-FB and diagnostics operation.

– Without an upgrade of the underlying pick-up infrastructure, the time domain intra-bunch position measurement are expected to be limited to a resolution in the range of ~100 μm due to imperfections of the used broad-band RF hybrid. **Action: ABP to define what is the maximum acceptable resolution.** This would be the preferred solution if the resolution is considered sufficient.

– The MIM, an alternative to the direct time digitization, is designed to keep the compatibility with a later upgrade of either complementary option 'B.II' or 'B.III'. **Action ABP/BI to run simulations with some possible expected cases of instability and compare with the expected output from the MIM monitor in its versions B.II and B.III to verify whether the information provided by the MIM is sufficient.**

– At least two independent triggers have been identified and must be transmitted to the other observation channels. A solution similar to the post-mortem signal sent via the timing might be possible but according to CO experts that would not be flexible and could impair sequencing by an excessive load to the timing system. The preferred solution would be based on White Rabbit and it is going to be implemented for OASIS in the PS by Q3-2014. This would imply the availability of optical fibres among the instruments used for measurements/trigger. All the instruments/devices mentioned above are in point 4. **Action BI/CO/RF: Investigate the availability of optical fibres in point 4 and the**

feasibility of implementing the White Rabbit solution in time for the LHC start-up 2015.

– As an alternative back-up option: Provided the circular acquisition buffers of the involved devices are sufficiently long, one could provide a SW-level trigger using UDP multicast on the existing technical network with approximate 3 ms latencies (similar to what is already being used in the RT-FB infrastructure).

– Other tools have been mentioned as Diamond detector data. Can we consider that this has lower priority as compared to the above?

Other considerations

No discussion on the analysis/display tools has taken place. This should be addressed rather early at least for those observables for which it seems agreement exist. **Action: ABP/OP to provide examples of analysis and possible display outputs.**

Some possible points for discussion:

- Implementation of Sussix or similar data treatment for the display of the tune spectra
- Representation of the data from bunch-by-bunch position data. Which format? Bunch by bunch data, 2D FFT, SVD decomposition?
- Correlation plots tune, losses, intensity, beam-beam family?

Can we assume that the witness bunches as being used in 2012 are also being kept after LS1? Some of the presented Q/Q' diagnostics schemes rely on them? **ACTION OP/ABP: Can the witness bunches be kept and are these bunches representative enough for the other bunches?**

The requirements for the longitudinal beam parameters have not been addressed. Do we consider that it is sufficient what we have? **Action: ABP/OP/RF to define the requirements**.

Appendix

New electro-optical and synchrotron-light based pick-ups that can provide flat, high-bandwidth, and high-resolution beam signals. It is proposed to install an SPS prototype during LS1 and if the tests are successful this could be installed in the LHC in LS2. This aims to improve on the intrinsic short-coming of the electro-magnetic based strip-line monitors.