Minutes PSB Upgrade WG Meeting 19th July 2016

Participants: S. Albright, L. De Mallac, J. Devine, G.P. Di Giovanni, V. Forte, G. M. Georgiev, G. Guidoboni, M. Haase, B. Mikulec, M. Morgenstern, L. Sermeus, J. Speed, W. Weterings.

Agenda (https://indico.cern.ch/event/555595/):

1. Approval of Minutes

- The minutes of the LIU-PSB WG meeting #176 have been approved.

2. Communications

- Nothing to report.

3. Follow-up of Open Actions

- L. Soby/J.Belleman/J. Tan on "Demonstrate 200 μm resolution for low intensity beam for the turn-by-turn measurement system. Demonstrate reliable operation with new firmware/software. Electronics to be ready for deployment in EYETS 16-17." → B. Mikulec reported that many MDs have been carried out to investigate the performance of the system. Several remaining issues are being tackled, but finally the decision to replace the electronics of the BPMs in the rings during the EYETS 2016/2017 has been taken. → **Action Closed**

- J.Coupard, D.Hay, S.Pittet on "Report which is the work that the TE-EPC Group can carry during the EYETS." → S. Pittet communicated that the activities to be carried during the EYETS 2016/2017 by TE-EPC will only concern civil engineering work for the BRF2 transformer alcove and some preparation work in BRF2. Any other work in the PS Booster would conflict with the decabling campaign. → **Action Closed**

- L. Sermeus on "Provide the functional specifications of the new recombination kickers including the results of the measurements campaign performed during YETS 2015/2016" → Measurements and simulation reported today, see below. Some work is still missing to reach a conclusion. The aim is to decide before the end of the year. **Action postponed and V. Forte added to it.**

4. Summary of Recombination Kicker Rise Time Measurements and Simulation

- **The LIU specification for the recombination kicker rise time is to have a maximum rise time of 105 ns**, see here.

- **Measurements on the recombination kicker rise time performed during YETS 2015/2017 by L. Sermeus with seach coils showed:**
    - **BT1,4.KFA10 have a rise time of 134-135 ns, outside the LIU specifications.**
    - **BT2.KFA20 has a rise time of 92 ns, within the LIU specifications**, **but it would be required to run almost at its limit, i.e. 36.5 kV with the breakdown voltage being at 37 kV.**
- The difference is probably **due to the different ferrite type used in the kickers.**
    - **A spare BT2.KFA20 has been recabled to match the KFA10 configuration:**
    - Simplified models showed an **improvement in the rise-time performance, but the simulation is not perfectly reproducing the measurements.**

- **New automated measurements of the rise time were presented by V. Forte:**
    - **BT1.KFA10 rise time was measured to be 99 +/- 10 ns with an intensity of 30E10 ppp.**
    - **BT4.KFA10 rise time was measured to be 101 +/- 10 ns with an intensity of 30E10 ppp.**
    - **BT2.KFA30 rise time was measured to be 109 +/- 10 ns with an intensity of 200E10 ppp.**
        - A dependence of the **ripple as a function of the intensity** has been observed along the waveform.
    - By analysing the beam profiles measured at the **SEM grid in the BTM line** it was estimated that **an LHC-type beam up to 255 ns could be transported to the PS.** The estimation does not include limits in PI.KFA45 at PS injection.

- **The difference between the measurement with search coils and with the beam seems to come from the low quality of the probe used in the measurements during the YETS 2015/2016.**

- **Next measurements include:**
    - Continue the work to **recable the spare BT2.KFA20 to completely match the KFA10 configuration** and measure the rise time to be compared with simulation.
    - **Perform measurement with the beam using a nominal LHC-type beam with a bunch length of 220 ns.**
    - **Further analysis have to be performed to evaluate the resolution of the measurements and the frequency response of the system, as this is important for the assessment of the performance of the TFB in the PS.**
    - **B. Mikulec recommended to repeat the measurements for low intensity beams with an adjusted gain for the BPMs to confirm the ripple dependence as a function of the intensity.**

- **Roadmap:**
    - **Present the results before the end of the year in order to reach a clear conclusion.**
    - If the present BT1,4.KFA10 kicker rise-time is confirmed to be within the LIU-PSB specification, the proposal would be to re-cable BT2.KFA20 as BT1,4.KFA10 to reduce the risk of magnet breakdown. **This was not in the LIU PSB kickers initial plan (only an option).**
        - **B. Mikulec asked if this option would require additional money to be requested. L. Sermeus replied that the issue is not the lack of budget but in the lack of manpower within the TE-ABT group to dedicate to this task.**
    - The production of a **spare BT1,4.KFA10 with CMD5005 ferrite blocks is expected to be ready by the end 2017**. The installation in the tunnel during LS2 is to be discussed

    because it might not be necessary, if the present rise-time meets the LIU-PSB specifications.
  - Production of a spare BE.KFA14L1 (not discussed today) is expected to be ready by the end of 2017.

5. Recombination Kicker Rise Time

- L. Sermeus reported the latest measurements in laboratory and simulation of the recombination kicker rise time, see here.

- **BTx.KFA10, x=1,4:**
  - **Current operational setting:**
    - The system is composed by 4 magnets, 2 per ring (2 different types). One pulse generator per ring supplying 2 magnets in parallel.
    - The modules were originally designed for 800 MeV beam operation. The vacuum tank was installed 1970.
    - **The kickers in the tunnel are equipped with glued ferrite C cores of 4L1 type. This ferrite type is not the optimal choice for fast kickers and vacuum performance.**
    - **No spare available**
  - **Measurements during YETS 2016/2017:**
    - Measurements performed on the recombination kickers installed in the tunnel during last YETS 2015/2016.
    - Measurements performed at 50 kV.
    - Measurements performed with a small inductive loop hidden in magnet ground conductor: **unknown frequency response, and so the probe is not optimal.**
    - **The measured 2-98% rise time is 134 ns. The expected rise time specified for LIU-PSB is 105 ns.**
    - A step slightly below 100% was observed and it seemed to be come from the Tx cables mismatch.
    - **The 100% was taken after 1 µs, where the pulse was observed to be stable**. Even normalizing differently the measurement, and taking the 100% earlier in time when one expects the LHC beam to arrive, the 2-98% rise time is 125 (122) ns for BT1.KFA10 (BT4.KFA10), i.e. **out of the LIU required specifications.**
  - **The measurements done on BT2.KFA20 during the YETS 2016/2017 showed that the kicker rise time met the expected LIU specifications**, see here:
    - **It was proposed to recable the spare module of the KFA20 to replicate the KFA10 circuit and measure the kicker rise time.**
    - **The spare module of KFA20 is equipped with CMD5005 ferrite, which is proven to be better performing that the glued ferrite C cores of 4L1 type.**
  - **First tests on KFA20 spare configured as KFA10:**
    - **Simplified version of the circuit with only one magnet recabled and filters disconnected.**
    - The simplified version of the kicker is useful to refine the Pspice simulation model, by removing many complexities of the full circuit.
    - Measurements performed with a strip-line probe.
    - **The measured and simulated 2-97% rise time is 95 ns.** The agreement is generally good. On the other hand, few discrepancies were found in the waveform description:

        - First measured peak is at 97%, while in simulation it is at 98.5% → the difference is probably due to the magnet conductor skin effect which is not properly modeled in Pspice simulation due to convergence problems.
    - A prepulse ripple due to thyratron switching was also measured.
  - **Second series of tests done with the filters still disconnected, but adding a saturating inductor at the magnet input:**
    - **The prepulse ripple was removed.**
    - **The measured 2-97.5% rise time is 90 ns and the simulated one is 95 ns.**
    - **Visible differences in the waveform:** First peak measured at 97.5% followed by an undershoot at 93%. Simulation shows the first peak at 98.5%. The difference could be still due to the incorrect model of the skin effect and, additionally, to the saturating inductor behaviour.
        - **B. Mikulec explicitly asked about the undershoot in the measurement. L. Sermeus replied this may be due to the skin effect as the resistance of the magnet conductor varies during the rise.**
  - **Tests to be done:**
    - **Connect the filters and optimise them in order to meet the 105ns rise and +/- 2% ripple with one magnet.**
    - **Connect the second magnet and re-optimise the filters**, if necessary.
    - **Every new arrangement takes approximately two weeks to be properly performed.**

- **BT2.KFA20:**
  - **Measurements done during YETS 2015/2016 found a 2-98% rise time of 94 ns, within the LIU specification of 105 ns. On the other hand, V. Forte measured a kicker rise time of about 109 ns, which is out of the LIU-PSB specifications.**
  - **The magnets are charged with PFLs up to 36.5 kV (breakdown limit is 37 kV)%ENDCOLO%**. For LIU, **one could use the KFA10 configuration to remove this limitation, if it is proven that the LIU specifications can be met.** That seems the observation from V. Forte's work presented today.
    - **B. Mikulec asked which could be the cause of the discrepancy between the measurement done by L. Sermeus and the ones performed by V. Forte. L. Sermeus replied that his measurements were limited by the low quality of the probe used.**
    - **G.P. Di Giovanni recollected that there was an ongoing effort from TE-ABT to review the optics model trying to reduce the load on the KFA20 kicker. L. Sermeus reported that no progress was done in this direction. That is the reason why it would be preferable to opt for the KFA10 configuration for KFA20 as well.**

- **Roadmap:**
  - Measurements in laboratory to be continued.
  - Production of a **spare BT1,4.KFA10 with CMD5005 ferrite blocks. Expected to be ready end 2017. The installation in the tunnel during LS2 is to be discussed because it might not be necessary, and will avoid several risks, if the present kicker rise-time is confirmed to be within the LIU-PSB specification.**
  - **Re-cabling of BT2.KFA20 in BT1,4.KFA10 configuration to reduce the risk of magnet breakdown**. **This was not in the LIU PSB kickers initial plan (only an option).**

        - **B. Mikulec asked if this option would require additional money to be requested. L. Sermeus replied that the issue is not the lack of budget, but the lack of manpower within the TE-ABT group to dedicate to this task.**
    - The production of a spare BE.KFA14L1 (not discussed today) is expected to be ready by the end of 2017.

6. Recombination Kicker Waveform Measurements

- V. Forte presented measurements of the recombination kicker waveform using the beam as a probe, see here.

- **The aim of the talk is to present a new and automatic method for beam-based kicker waveform measurements.**
    - The measurements will allow to **evaluate the kicker rise time in the PSB-PS transfer line.**
    - The measurement should **complement and validate measurements with search coils.**
    - Additionally, analyzing the transverse profiles at the BTM line SEM grids, it would be possible to **evaluate the bunch length limits of a given kicker.**
    - **The work is still in progress.**

- Previous beam-based kicker waveform measurements were performed for the LHC injection kickers:
    - In this analysis the bunch length was shorter than the kicker rise time, therefore the beam could be used to sample the waveform in different points.
    - **The complexity of a kicker rise time measurement in the PSB-PS transfer line is that the typical bunch length is comparable or higher than the rise time to estimate.**

- **Requirements of the method:**
    - Use the best possible time resolution, which is defined by **maximum sampling frequency of the OASIS scopes: 1/2 ns.**
    - High granularity for reliable statistics.
    - **Low losses.**
    - Suitable for automated measurements, requiring **several hours of beam time.**

- **BPMs are the main devices to measure displacement, statically and dynamically caused by the kicker to the beam:**
    - BPMs will be used to measure the (horizontal or vertical) displacement of the beam.
    - In principle BTVs are available, but they have lower resolution performances.
    - **BPMs need a minimum current (line density) to work properly. In the presented analysis the intensity ranged from 30E10 to 200E10 protons-per-bunch (ppb).**

- **Kicker Parameters:**
    - The kickers in the PSB-PS line can be pulsed with **fine time delays in minimum steps of 1 ns.**
    - Kicker time-of-flight (TOF) is around 5.6 ns (kicker lengths ~1.5 m, β_{rel}=0.916) and could limit the resolution.
    - **The stability of the trigger of about 10 ns between the minimum and maximum jitter can be a limit to the dynamics resolutions.**

- **Limits on the amount of losses can be guaranteed though the BLMs in the BT-BTM-BTP lines and their counter interlock.**

- **The method:**
  - The kicker magnetic field rises in time between two consecutive bunches, so **two adjacent bunches in the machine are needed to perform the measurement.**
  - **The kicker is started with different delays touching eventually the two adjacent bunches.**
  - **The BPM signals are analysed for different time delays of the kicker.** The sampling of the BPM is of the order of 2 ns.
  - **The BPM gating, time window kept for the signal reconstruction, is fixed throughout the measurement.**
  - **It is very important to make sure the BPMs are well calibrated** (w.r.t. the kicker voltage) in order to properly combine the measurements for the two adjacent bunches. The calibration is performed every time before starting the measurement, as the beam conditions may have changed in time.

- **Results on BTx.KFA10, x=1,4:**
  - **BT4.KFA10:**
    - **The 2-98% rise time was measured to be 101 +/- 10 ns.**
    - The strength of the kicker at the nominal strength of 43 kV.
    - BT3.BPM20 was the monitor used.
    - **Intensity at about 30e10 ppb.**
    - The waveform with the search coil seems to agree generally well, while the OASIS signal is limited in resolution and not reliable for estimating the rise time. L. Sermeus added that OASIS shows the magnetic input current, so it is affected by reflection.
  - **BT1.KFA10:**
    - **The 2-98% rise time was measured to be 99 +/- 10 ns.**
    - The strength of the kicker at the nominal strength of 42 kV.
    - BT2.BPM20 was the monitor used.
    - **Intensity at about 30e10 ppb.**
  - *The two kickers should be identical by design, nevertheless different calibrations were found, about a factor 2 in the DC-gain due to different hardware amplification settings.
    - This was an issue coming from the observed BPM, which had to be fixed by the BI Group.
  - Additionally the measurement on BT4.KFA10 is less noisy than the one in BT1.KFA10.

- **Results on BT2.KFA20:**
  - The strength of the kicker at 43 kV.
  - BT3.BPM20 was the monitor used.
  - **Measurement performed with R3 and R1 (respectively first and last in batch) to have a large inspection window.**
  - **Observed a dependence on the size of the ripple based on the bunch intensity.**
  - **A large flat-top ripple is present for an intensity of about 30E10 ppb and almost disappears at intensities as high as ~200e10 ppb.**
  - The measurement looks cleaner and smoother at higher intensity (better BPM response).
  - The agreement with the waveform measurements in laboratory is generally good.
  - The measurements also depends on the length in time of the gating window.

    - **The 2-98% rise time is estimated to be 109 +/- 10 ns at ~200E10 ppb and averaging over the results from different gate windows.**
    - **B. Mikulec asked if the BPM gain was adjusted for the different intensities or kept always the same. V. Forte replied that he did not adjust the gain and the default one was set for LHC-type intensities. B. Mikulec suggested to repeat the measurement with a proper gain for the lower intensities.**

- The sources of errors for the rise time estimation are being investigated. Common error sources are:
    - The beam reproducibility: Measurements last typically 3-9 hrs.
    - The calibration technique and the length in time of the gating window.
    - The jitter in time of the kicker waveforms (~10 ns peak-to-peak).

- **Emittance blow-up due to non-synchronized kicks could be evaluated with the SEM grids in the BTM line.**
    - The SEM grids provide shot-by-shot the information about the beam size, and thus the emittance, in both planes at 3 consecutive locations.
    - For a given vertical emittance the length in time of the intersections where the emittance is not altered gives a measure of the possible bunch lengthening.
    - **For an LHC-type beam with intensity of about 150E10 ppb and bunch length of about 180 ns, the measured margin in increase in bunch length is estimated to be 75 ns.**
        - **The result is obtained under the assumption to keep the vertical transverse emittance to 1.7 μm.**
        - **The results exclude issues with PI.KFA45 at the PS injection.**
        - **The claim is that a bunch length up to 255 ns could be transported from the PSB to the PS.**
        - The maximum bunch length found depends on the beam brightness. For instance for an intensity at ~40E10 ppb and a vertical transverse emittance of 1 μm the maximum bunch length increase margin is estimated to be 90 ns. * First tests with the wire-scanner in the PS demonstrated that the vertical halo induced by the un-synchronization of the recombination kickers gets lost at the entrance in the PS and no blow-up has been seen in the PS ring.

- Next Steps:
    - **Perform measurements with a nominal LHC-type beam with a bunch length of 220 ns.** The beam is getting prepared by S. Albright. This is to check the emittance blow-up at the SEM grids with future LHC bunch lengths.
        - S. Albright mentioned that currently the beam he is preparing has also a larger Δp/p and if this may be an issue to look at.
    - **Further analysis has to be performed to evaluate the resolution of the measurements and the frequency response of the system.** In particular to check the high frequency component of the rise time as PS experts are concerned about the possibility to excite higher modes. This is **important for the assessment of the performance of the TFB in the PS.**
    - **B. Mikulec recommended to repeat the measurements for low intensity beams with an adjusted gain for the BPM.**
    - **V. Forte mentioned that also the steady state he assumed is a bit lower than what L. Sermeus took. So it would be good to extend the measurement on the steady state as far as possible.**

- **B. Mikulec remarked that the rise time is important, but also the ripple along the steady state should be checked and clarified if it could have an influence on the beam.**
    - **V. Forte replied that this can be evaluated.**
    - B. Mikulec suggested to check the value from measurements and feed it back to simulation to check the expected blow up. W. Bartmann already assessed the blow-up due to ripple in the kickers, so it may be as simple as providing him with the value or compare the current observed ripple with his assumptions.
    - V. Forte mentioned that in the end the SEM grid will help to evaluate the blow-up due to the ripple.

7. AOB

- Next meeting is scheduled for the 2nd August 2016.
- J. Devine reported that the current budget for EN-EL has been fully committed and probably additional money will be committed in the next weeks for payment to be done in 2017. This should impact the new baseline.
- **B. Mikulec and W. Weterings reported that the HST installation is progressing nicely.**
    - **G. M. Georgiev asked when he could prepare the connection of the DC cables.**
    - G. Guidoboni mentioned that the girder should go into the tunnel on Monday 25th July and there will be work to be done for the alignment measurements. Afterwards the vacuum pump-down will start. **So after next week, the work on the DC cabling could be performed in the tunnel.**