WP2 Meeting #157

Tue 3 Sep 2019, 9:00 – 12:00

Chair:	Gianluigi Arduini
Speakers:	Michal Krupa, Hélène Mainaud Durand, Lukáš Malina, Riccardo De Maria, Manfred Wendt.
Participants:	Androula Alekou, Joel Andersson, Manoel Barros Marin, Douglas Bett, Irene Degl'Innocenti, Ilias Efthymiopoulos, Paolo Fessia, Massimo Giovannozzi, Giovanni Iadarola, Elias Métral, Nicolas Mounet, Yannis Papaphilippou, Fabien Plassard, Benoît Salvant, Rogelio Tomas, Frederik Van der Veken.

AGENDA

The meeting was devoted to BPMs: general requirements from optics, upgrade plans, and discussion around the option of a BPM downstream of D1 (including alignment issues).

MEETING ACTIONS

Manfred	Report to the impedance team any issue potentially harmful for impedance, that would be found on the BPMs during LS2

Benoît Simulation of the possible modes for shorted stripline monitors.

Paolo Check with vacuum and magnet whether the tilted D1 solution is feasible (in particular for the bellows).

Hélène Check with S. Redaelli and A. Masi if the position of the TCT jaws (next to D2) can be linked to the rest and with which accuracy.

Paolo Write an HL-ECR related to the suppression of the D1-BPM from the baseline.

GENERAL INFORMATION (G. ARDUINI)

Gianluigi reviewed the minutes of the 156th meeting, in particular the action related to the BPM specifications to be passed to **Manfred**, and that related to the levelling procedure (a realistic proposal has to be made by optics and orbit teams, to operation and experiments).

Gianluigi also summarized the actions related to the talk of **Nikos Karastathis** during the 156th meeting about the dynamic aperture (DA) at injection: the investigation of the possibility to operate below the diagonal in the tune diagram during the full cycle, the determination of the most critical scenarios at injection in terms of DA, and the understanding of why the DA is more critical in HL-LHC vs. LHC.

BPMS IN TURN-BY-TURN MODE: LHC EXPERIENCE AND HL-LHC REQUIREMENTS (L. MALINA)

Lukáš reviewed the current BPMs and the HiLumi requirements, in the context of optics measurements.

In the LHC, measurements with beam excitation are done on a single pilot bunch (up to 10^{10} protons/bunch), possibly 3 bunches in Run III. BPMs are then used in turn-by-turn/bunch-by-bunch mode, currently limited to 40’000 turns $\times$ bunches per BPM. The main sources of uncertainties are the calibration errors, the positional noise and the faulty BPMs.

The calibration errors (initially specified to be less than 4%) can be improved by a factor of 2 between Q1 and Q4 thanks to a fit from ballistic optics measurements [A. García Tabarés, PhD thesis]. While the gain errors from the button BPMs in the arcs exhibit a spread of 1.7%, the stripline BPMs in the interaction regions (IR) are more problematic, with a decentered spread of errors of (-3 ± 5).

The positional noise in the LHC is estimated (from turn-by-turn data) to be 100μm in the arcs, 200μm in the IRs, and 15μm with DOROS, which all respect the LHC specifications (<200μm). The faulty BPMs represent around 4% of all BPMs and can be identified thanks to the accumulated statistics; nevertheless, one critical BPM (BPMSW.1R5.B2, vertical) was missing during the full Run II, which is an issue.

With the current BPMs, the β-beating in the LHC could be corrected within 2% r.m.s. (for β^*=30 cm).

For HL-LHC, stronger requirements on BPMs are made necessary by the need for a IP1/5 luminosity imbalance smaller than 5% (which means an error on β^* smaller than 2.3%). The BPMs are crucial to get β^* and β_{waist} at the required precision, as measurements using K-modulation or luminosity scans are slower. Then, the larger β-functions in the triplets (up to 22km, hence a 10mm amplitude oscillation for the beams during optics measurements), and the very small phase advances between BPMs in the IRs (as low as 0.4mrad), require the calibration error of the IR BPMs to be as low as 1.6%, the noise as low as 15μm, and the BPMs to be able to measure from -20mm to +20mm from the center.

Current LHC arc BPM performance is sufficient for HL-LHC as well, but improvements are welcome. Finally, one should be able to record at least 20'000 turns for all 3 bunches, for all BPMs.

- **Gianluigi** asked how can one improve the error on β^* when measuring it using K-modulation (slide 9). **Lukáš** answered that the noise and jitter of the main power supply should be decreased by upgrading the controls of the dipole power converters in the ATS arcs.
- **Manfred** said that we can improve the positional noise with an increased intensity & number of bunches (it goes with the square root of the latter). **Rogelio** & **Lukáš** replied that up to now machine protection prevents this. **Gianluigi** added that indeed some interlocks can be relaxed because we are at low intensity for these measurements.
- **Gianluigi** asked if the arc BPMs are ok regarding the optics measurements, and **Lukáš** answered in the positive.
- **Manfred** wondered why the positional noise and gain error are different in the IRs with respect to the arcs, while the polynomial fit is done in the same way in both. Possible explanations are: pickups are different (striplines in the IRs, buttons in the arcs), and some BPMs are rotated by 45 degrees (which is not a good thing, according to **Manfred**).
- **Benoît** asked if there are BPMs not giving any signal, which would indicate the presence of a short, and possibly a very large impedance. **Lukáš** answered in the negative, but **Manfred** said this might be the case when a "flat signal" is observed (below 20μm, when one expects mm).
- **Manfred** mentioned that at each shut down, BI tries to get some of the faulty BPMs back to life, but they cannot check all of them. It is not always clear what happens to them (it can be electronics, or something else). During LS2, they were focused on the BPMs in the IP (e.g. BPMSW.1R5.B2 mentioned in the talk), and also those outside of the cryostat. **Gianluigi** asked how the BPM is terminated in case the damage is outside and one cannot fix it (in relation to the previous question of Benoît). **Manfred** said the BPM is then left as is, but this eventuality is very rare, as problems are usually in the electronics. **Benoît** said that one stripline badly terminated can be an impedance issue. **Gianluigi** said to **Manfred** that any such finding should be reported to the impedance team (Action: **Manfred**).

Plans / Ideas for the LHC BPM Upgrade (M. Wendt)

Manfred gave an overview of the on-going and future work on the LHC BPMs.

Current activities are focused on the 8 stripline interlock BPMs in point 6, for which one can use commercial electronics. A first prototype was tested with beam during Run II; a final one will be installed by the end of LS2 and fully deployed in an upcoming YETS. The interlock BPMs also serve as a test for the other BPMs' consolidation and upgrade, in particular regarding the time-multiplexed single channel read-out technique, which improves symmetry and long-term stability. The interlock BPMs meet the requirements (<500μm r.m.s. resolution, $\pm$7.5mm beam displacement range), without the need for gain switching from 5.10^9 to 2.10^{11} p+/bunch.

In the LHC ring, the current ~1000 wide-band BPMs meet all requirements, but their analog components age, degrading the BPM performance. Despite the upgrade to temperature controlled racks, the analog integration technique to generate the BPM signal still suffers from residual effects to the ambient temperature, giving additional uncertainty on the LHC orbit data. Moreover, long-term maintainability is becoming an issue as the technology itself gets obsolete. Consolidation plans include a new read-out system (time-multiplexed, single-channel) to improve resolution, long-term reproducibility and flexibility, while keeping the existing infrastructure (pickups and optical fibers). The new read-out system might enable the measurement of beam emittances, depending on the number of time-multiplexed BPM electrodes (among others). New Analog-to-Digital Converters (ADC) need to be tested at CERN for radiation compatibility. Signal processing will be performed out of the tunnel. Prototypes are foreseen for Run III, but installation is not foreseen during LS3, due to manpower limitations (among others).

In the IRs, the 28 new stripline BPMs (in the cryostat) need a new read-out system by the beginning of LS3. There, one needs to compensate for errors due to the counter-rotating beam (the B1-B2 bunch spacing can be as low as 4 ns). To avoid the need for radiation-hard electronics, the plan is to avoid putting electronics in the tunnel, and use commercial electronics. The final prototyping with beam should come before LS3, and the deployment of the entire system by the end of LS3.

- **Riccardo** asked if there are figures for the noise in orbit mode. **Manfred** answered that everything scales with the band width. **Riccardo** insisted that we need to stay at the level we have today (~20μm). **Manfred** replied that things will rather improve because there will be more statistics (now there is one sample per bunch, everything is treated with analog electronics on site – later one can use filtering).
- **Gianluigi** asked if what is foreseen in the IRs really meets the requirements seen in **Lukáš**' talk. **Manfred** answered that what is asked is indeed a challenge, but the prototype in point 5 was already tested with beam during Run II, and the resolution was below 20μm. This was done with a high sampling rate ADC. **Rogelio** also mentioned that for a pilot bunch, it seems the resolution is not better than 200μm (see slide 11), hence not better than for the LHC, but **Manfred** explained that gain switching is possible (not for the interlocked BPMs) and should help to improve resolution. For single bunch the ultimate goal is 10μm, which is very challenging, but the chips used for IR BPMs perform well in terms of linearity (better than the radiation tolerant ones used in the arcs). **Lukáš** insisted that the requirement on resolution is per bunch (not for 3 bunches).
- **Riccardo** mentioned that in the IRs we often measure a small variation on top of a large offset – this is particularly the case with a crossing angle. **Manfred** said that in that case the main issue is the error term due to the other beam. One can read each electrode separately and use time-multiplexing with the other beam to compensate this error.
- **Gianluigi** asked if we can localize the bad BPMs (e.g. with a short, creating a large impedance) using beam-based measurements. **Elias** answered that it would not be easy – one needs to perform instability measurements, and, as for crab cavities, look for a particular mode, but the frequency will shift depending on the length of the cable between the short and the BPM. Simulations of the expected modes can be done (Action**: Benoît). Manfred** said that there are cases of bad connection directly at the BPM, and that anyway when the issue is outside the cryostat it's easy to spot, while it's more problematic when it's inside it.

D1 BPM AND APERTURE (R. DE MARIA)

Riccardo reviewed the pros and cons of installing a BPM downstream (right after) D1, which could indeed spot an otherwise unobservable close bump between D1 and D2. Still, such a bump could be at worst 320μm at injection and 32μm at flat top, hence very small, provided that the errors in the transfer functions for D1 and D2 are within specifications. Moreover, the statistically distributed error at flat top can be corrected without it, by updating the weights on the BPMs close to D1. Therefore, this BPM would be useful essentially only for redundancy, or if errors are larger than expected, but even this aspect is minimized by the possibility to use the button BPMs on the TCTs right before D2 (this latter option has to be confirmed: the jaws have their own local control, independent on the orbit). The D1 BPM has also no impact at the IP.

The D1 BPM was first thought to be critical because the horizontal aperture at the edge of D1 cold mass is at the limit, especially with the extended D1 beam screen. The new beam screen design helps [C. Garion, 13/2/2019], restoring the aperture hierarchy for round optics by ~0.5σ, but the problem is not fully solved for flat optics. Since the beam envelope is not symmetric, misaligning D1 by 1.5mm towards the outside of the machine would help further, or, similarly, by tilting the magnet by ~0.2mrad.

Finally, in the eventuality that no BPM is placed in D1, **Michal** investigated the possibility to put instead one headtail monitor for the crab cavities damper (see next talk), instead of one in point 4, as the β-functions are appropriately large downstream D1. However, the phase advances from IP1 and 5 are not yet frozen (**Fabien** is currently optimizing them) and the specifications for the crab cavities are not known yet.

- **Gianluigi** wondered if one can get absolute orbit measurements from the BPM in the TCT jaws. **Riccardo** answered that he does not know how it is related to the orbit stability, and how one can control the jaws within microns. **Gianluigi** argued that there must be a way to know the calibration of TCLX w.r.t. the center of D2 (otherwise there would be an issue for machine protection). **Michal** said that they know the absolute position but not with a high accuracy, and **Riccardo** added that indeed, for machine protection the error on the position center matters only if it's larger than 0.5mm.
- **Gianluigi** asked if the misalignment is an alternative to the change of design of the beam screen. **Riccardo** answered that yes, but it can also complement it.
- **Paolo** asked if the proposal of **Cedric Garion** is to keep the tungsten shielding on the top, and take away that in the middle, **Riccardo** answered in the positive.
- **Paolo** also asked if the aperture problem is now solved at the exit of D1, **Riccardo** answered in the positive.
- **Massimo** asked if one can introduce an angle in D1, rather than a shift. **Riccardo** answered yes, with a tilt angle of 0.2 mrad (*note: the latest version of the slides does actually show this option*). **Paolo** said that the shift requires modifying all interconnects. **Paolo** said that we need to check with vacuum people, and discuss with **Cedric Garion** for the bellows (Action: **Paolo**).
- **Gianluigi** asked about the weld possibly added by the beam screen extension. According to **Riccardo** and **Paolo**, the weld was already there, so the additional part does not add any weld.

BPM DOWNSTREAM OF D1 – WP13 INPUT (M. KRUPA)

Following-up on the previous talk, **Michal** presented the design constraints of a warm BPM after D1. Since both beams are in a common chamber, a directional coupler is needed. The location is optimal in terms of beam separation (~10ns); on the other hand, the design is made relatively complex because of the large aperture (150mm – this would be the largest BPM of the ring) and the length of the cables (~150m – this is a source of signal degradation). The design would be unique to this BPM, hence requiring significant manpower, as well as prototypes, qualifications and spares for almost all of its components.

Michal also evoked the alignment issues, in particular with respect to the other machine components (see next talk). Finally, he mentioned the option to install a headtail monitor instead of the BPM to measure the residual crabbing, which would be indeed relatively large there. Still, measurements would be made difficult because of the presence of the two beams, and the aperture would be even larger since this headtail monitor would have to be moved closer to D2.

- Concerning the use of the BPM has a headtail monitor for crab cavity diagnostics, **Gianluigi** concluded that it's not that appealing, adding the fact that it would rely on phase advance constraints that are not guaranteed.
- **Riccardo** wondered if we could really work with such a BPM, as it would be the only warm BPM in the whole region.

ALIGNMENT SCENARIOS: D1 DOWNSTREAM BPM (H. MAINAUD DURAND)

Hélène reviewed the context and possible scenarios for the alignment of the D1 BPM evoked in the two previous talks. With HL-LHC beams the area around IP1 and 5 will exhibit a high ambient dose equivalent rate (especially close to the D1 BPM location), even weeks after switching off the beams in LS4. Therefore, a Full Remote Alignment System (FRAS) is foreseen between Q1 and Q5 for the cryostats. But since the D1 BPM will sit outside of the cryostat, a specific solution has to be found for him, given the ground motion of few tenths of mm or higher, especially around IP5 (up to ±0.3mm/year radially and +0.5mm/year vertically, close to the D1-BPM location).

There are essentially two possible scenarios for the D1 BPM alignment:

1) The BPM support is equipped with Wire Positioning System (WPS) sensors and an inclinometer, which allows to determine continuously its position with respect to the remotely aligned equipment (within ±0.1mm). The cost is estimated to be 40kCHF per BPM support.
2) The BPM support is not equipped with WPS. This solution is much less costly but the exact BPM position can be known only from measurements at the end of YETS or LS (within tenths of mm).

In both cases the misalignment with respect to D1 will be up to ±2.5mm, and will be corrected only at the end of a YETS or during a long shutdown, using a semi-manual alignment procedure (made faster by the use of temporary motors).

- **Rogelio** asked if there exist longitudinal plots for the alignment uncertainty, similar to the radial and vertical ones visible in slides 10 and 11. **Hélène** answered no, but she said that the longitudinal alignment uncertainty is of a few tens of microns from one side to the other.

- **Gianluigi** asked if one can get the relative offset of the BPM, in particular w.r.t. D1. **Hélène** answered that yes, and continuously with scenario 1.
- **Gianluigi** asked what prevents to put the BPMs in the cryostat, **Paolo** answered that in that case the BPM will be connected to a bellow on each side and therefore the positioning would not be guaranteed.

ADDITIONAL DISCUSSION ABOUT THE D1 BPM

- **Gianluigi** asked if the main use of this BPM is for horizontal measurements, and **Riccardo** answered yes.
- **Gianluigi** said there can be a drift over the year vs. the rest of a few 0.1mms, so overall a relative uncertainty of 0.1-0.2 mm of D1 w.r.t. the BPM. **Hélène** confirmed. Then, **Gianluigi** wondered if the BPM is still good to close a bump, i.e. if it can be more than a redundancy. **Riccardo** confirms that indeed the part we do not see is only of ~30μm at flat top. **Gianluigi** concluded that we do not need a remote alignment of the BPM. Main issue is the radiation people will take if we have to realign it during YETS
- **Riccardo** explained that there is not too much justification for this BPM, especially if there is a control of the TCT jaws position w.r.t. external fiducials. **Gianluigi** agreed and said we need to check with collimation whether this can be guaranteed and with which precision. **Hélène** mentioned the WPS on top of the collimator, that can be linked to the others – this has to be checked (Action: **Hélène, Stefano**).
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- **Gianluigi** asked if the feed-down related to the 1.5mm misalignment of D1 could possibly be an issue. **Massimo** and **Riccardo** answered that no, and anyway centering the beam w.r.t. the aperture can only help.
- **Gianluigi** asked if the consolidation of the ring is funded. **Manfred** said yes, up to the end of LS3, but for the D1 BPM, the cost vs. added value is large.

In conclusion, in the absence of strong motivation for the D1 BPM, and after checking with **Jorg Wenninger** (as a follow-up to the meeting) it was decided to prepare an HL-ECR (Action: **Paolo**) to take away the BPM.

AGENDA OF NEXT MEETING (G. ARDUINI)

The next meeting will be on 10th Sept at 2pm and will be devoted to cryogenics (hence the unusual time, to allow people from cryogenics to attend). The preliminary agenda is:

- Request for slow luminosity increase *(S. Claudet)*
- Maximum cooling capacity for cryogenics in Run 4 *(K. Brodzinski)*
- Beam lifetime in collision - LHC experience *(G. Iadarola)*
- Luminosity model update: coupling, noise, and burnoff *(S. Papadopoulou)*
- No MS10 studies *(F. Plassard)*

Reported by N. Mounet