OPERATIONAL TOOLS FROM 2017 TO 2018

A. Calia, K. Fuchsberger, M. Hostettler, D. Jacquet, G.H. Hemelsoet, M. Gabriel, M. Hruska
CERN, Geneva, Switzerland

Abstract

During the 2017 run of the LHC, several applications and tools underwent improvements and new features were added. Next to others, the main focus was on a new system for coupling measurement, based on the ADT AC-Dipole and the luminosity control system, to which e.g. separation and crossing-angle levelling functionality were added. For 2018, it is foreseen to push these systems even further: β^* levelling functionality is on its way to be available in the luminosity control system and new approach for precise tune measurements through ADT excitation and pickups is in the planning stage. This paper gives an overview of the relevant improvements done in 2017 and an outlook of what is foreseen to be improved for the 2018 run.

INTRODUCTION

2017 brought significant improvements to the CERN operational software suite. On the one hand, a new application for precision measurement of the LHC coupling was developed and tested at injection. On the other hand, the luminosity control application (LumiServer) has been improved allowing the automatic separation luminosity levelling and the crossing angle steering at the Interaction Points (IP).

COUPLING MEASUREMENT AND CORRECTION

During 2017, an effort has been made in the development of a new software to precisely measure the linear coupling in the LHC.

This new approach is based on the usage of the ADT for excitation in "AC Dipole" mode. First, the ADT produces a very local excitation (at a pre-set offset to the natural tune) on a single selected bunch per beam. During this excitation, the orbit is recorded by the Beam Position Monitors (BPM). Thereafter, the acquired BPM data is analyzed to precisely calculate the coupling of each beam of the LHC [3].

The ADT and BPM communication is managed by a Java server that propagates to the GUI the proposed coupling correction to apply (Fig. 1).

For the analysis of the BPM data, it was possible to reuse the code developed for LHC optics measurement and correction [5], written in Python. In order to integrate the Java server with the Python analysis code, a new approach has been taken. In contrast to the traditional technique of creating a subprocess for running the Python analysis code, it has been decided to treat the analysis as a state-less web service. The Python code was encapsulated into a Docker container and a web end-point was made available using gRPC [7] as a communication layer. This approach presents significant advantages including robust deployment and versioning of the code, reusability, decoupling of projects, and performance scaling.

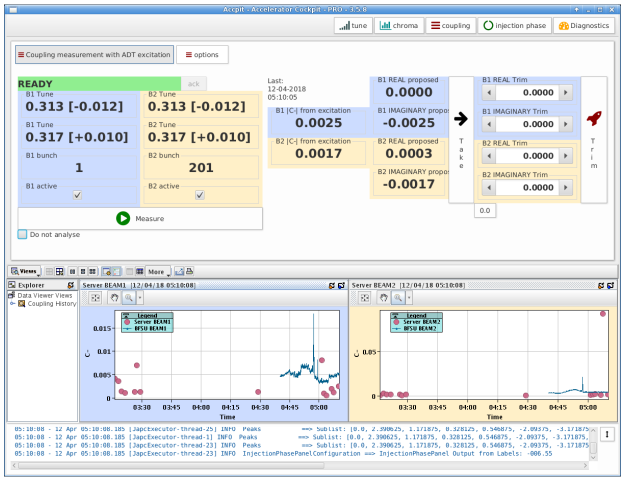

Figure 1: The coupling measurement GUI is embedded into the Accpit application in the CCC. The screenshot shows the measurement of the coupling at injection using the ADT-AC Dipole to excite one bunch per beam

Future Improvements

Algorithm performance: The way the algorithm detects the coupling value and proposes a correction can be improved. More BPM data could be used for compensating the driven motion [4] and the LHC model used for the analysis can be adapted to the current LHC optics queried from LSA. A significant performance improvement could come from the integration of a more efficient FFT implementation [6] and from the code parallelization.

Horizontal scaling: The coupling correction analysis is a resource-intensive computation. At the moment, the process is performed on a standard server and the process take approximately 3 to 4 minutes. This time can be reduced by deploying the analysis code on a cluster that can be scaled and optimized for performance. The cluster can distribute the available resources on-demand allowing to analyze e.g. Beam 1 and Beam 2 in parallel without saturating the CPU capacity of the server.

Measurement queue: With the current implementation, the measurement, analysis and correction of the coupling takes about 5 minutes. This delay makes the coupling measurement difficult when machine conditions are changing over time (e.g. during the ramp or the squeeze). In combination with the other proposed improvements, a new feature in the software will be added to allow for series of measurements. In this mode, a new execution of the ADT excitation would be scheduled as soon as the previous excitation finished, without waiting for the analysis of the BPM data to be done. This would allow measurements to be performed at a much higher rate, since the beam excitation takes significantly less time than the analysis.

In addition to finer grained measurements when beam conditions are changing, this method would also allow to collect statistics from multiple coupling measurements before applying a correction when beam conditions are stable (e.g. at injection).

Coupling corrections in operations

For the 2017 LHC run, the coupling at injection was successfully reduced down to $|C-| < 2 \times 10^{-3}$.

During August and September, a coupling measurement and correction campaign was undertaken. The outcome showed a sensitivity of $|C-|$ at the level of ~ 0.002 with respect to the filling scheme. This effect was further studied in MD2877 [2], which confirmed the impact of different long-range beam-beam configurations on the transverse coupling. A possible explanation for this effect is a roll of crossing angles in the order of 10 µrad.

Bunch-by-bunch tune measurement

An operational bunch-by-bunch tune measurements using the ADT is in the development pipeline of the ADT team; this has been used by the experts in the past during MDs. This would further improve the coupling correction, as a precise measurement of the natural tune is crucial for the analysis. Also, it could be used to measure (and potentially correct) the tune of selected bunches immediately before going to collisions.

LUMINOSITY LEVELLING

During operations, the luminosity of the LHC has to be controlled. The most commons scenarios are luminosity optimization (finding head-on collisions) and luminosity levelling (keeping the luminosity at a desired level).

The LHC luminosity can be managed by a server called the LHC Luminosity Server (LumiServer). The server is controlled via a GUI client in the CCC (Fig. 2). The LumiServer is used during LHC operations since its commissioning in 2015. Its operational functionality includes luminosity optimizations, emittance scans and luminosity levelling. Each feature is coded in a so-called task; an internal scheduling system ensures that tasks do not act on the same IP at the same time.

This paper is focused on the levelling abilities of the LumiServer. LHC luminosity has been levelled in 2017 for coping with pile-up constraints and to increase the integrated luminosity per fill. At the moment, three forms of levelling are supported by the LumiServer: separation; crossing angle; and β^* levelling. Each levelling technique acts on the corresponding geometric factor that affects the luminosity: the beam separation at the IPs; the beams angle in the crossing plane; and the value of the Betatron function at the IPs.

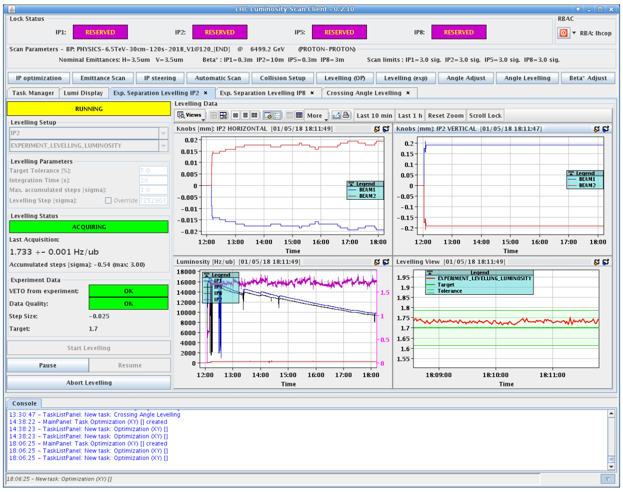

Figure 2: The application in the CCC that controls the LumiServer. In this example, the automatic separation levelling of IP2 is ongoing.

Orchestration: With the latest features of the LumiServer, it has been necessary to keep in sync more and more LHC systems. For example, changes in crossing angles or β^* significantly change LHC orbit, requiring to update the reference orbit of the orbit feedback system and the position of the tertiary collimators around the IPs (TCTs) accordingly.

In the LumiServer, this synchronization process in done using a newly created library called *lhc-orchestration-trim*. The library "orchestrates" a trim by calculating the orbit response that it will produce. With this information, it calculates the new position of the collimators and the new reference orbit for the LHC Orbit Feedback system (OFB). It then creates and uploads a timing table to the LHC timing system to start the change of the power converter currents, the collimators position and the OFB reference orbit synchronously [1].

Automatic separation levelling

During a typical physics production fill with "8b4e BCS" type beams in 2017, the initial head-on luminosity in ATLAS and CMS was about 2.1×10^{34} cm^{-2} s^{-1}, leading to an average pile-up of up to 85. At the request of ATLAS and CMS, this peak luminosity was reduced to 1.5×10^{34} cm^{-2} s^{-1} for peak pile-up of about 60. This was achieved by merging the automatic separation levelling, which was used in the past for ALICE and LHCb, into the LumiServer and to extend it for the needs of ATLAS and CMS. The target luminosity that the LumiServer has to keep can be specified either via the GUI by the user or by the LHC experiments via DIP communication protocol.

Crossing angle levelling

Reducing the crossing angle at the IPs can be an effective anti-levelling technique. As the intensity decays during the fill, the Dynamic Aperture allows for margin to reduce the crossing angle compared to the beginning of the fill. The functionality to change the crossing angle has been added to the LumiServer in 2017. It has been commissioned and effectively used for maximizing the LHC luminosity gaining an estimated 5% more for a 16 hours fill.

Unlike a typical separation bump at an IP, a crossing angle bump has a significant effect on the orbit. Therefore, the OFB has to control the orbit considering the newly added bump. Also, the collimators positions need to be adjusted so that they follow the new orbit of the beam. The affected collimators are the TCTs in the crossing plane around the IPs where the crossing angle is changed, and the (horizontal) TCLs if the crossing plane is horizontal (IP5).

Continuous crossing angle levelling In the 2017 LHC run, the crossing angle was reduced manually using steps of 10 µrad. During a test in 2017, it was observed that smaller (1 µrad) and more frequent steps in crossing angle could lead to better performances, increasing integrated luminosity gain by 1.5% over 9 hours compared to 10 µrad steps, and having a smaller impact on the beam lifetime.

For this reason, during 2018 a new continuous crossing angle levelling feature will be added to the LumiServer, which will be able to perform 1 µrad crossing angle steps automatically as soon as the intensity decay leaves sufficient margin on the Dynamic Aperture.

β^* levelling

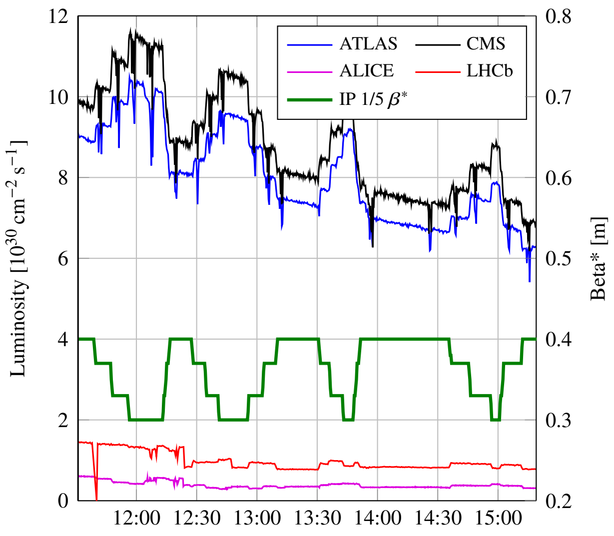

Figure 3: Luminosity evolution during β^* changes between 40cm and 30cm in IP 1 and 5. The data refers to MD2427 and fill 6424. The luminosity correctly follows the expectations. At each step a luminosity optimization is performed resulting in very small adjustments, indicating that the beams were kept almost head-on during the β^* transitions.

β^* is a key parameter of the collision optics and was traditionally established at the beginning of the run and not

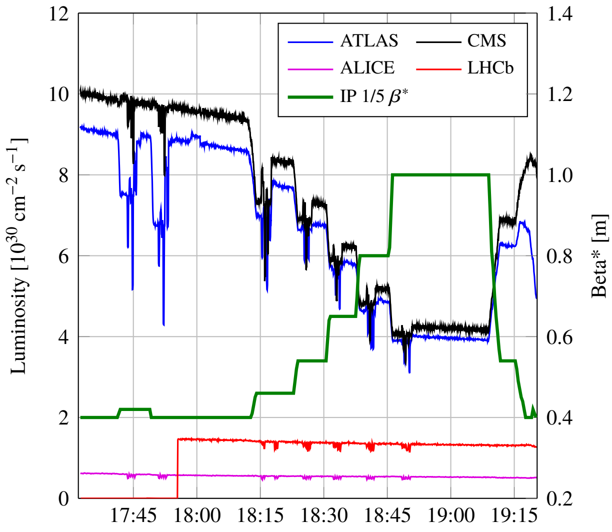

Figure 4: Luminosity evolution during β^* changes between 1m and 40cm in IP 1 and 5. The data refers to MD2427 and fill 6425. This is not likely to be an operational scenario, but the results are useful for the validation of the β^* adjust mechanics. The luminosity followed change of β^*. At each step a luminosity optimization was performed to find the head-on positions. The test was performed at the end of the MD, and the beams were immediately dumped as soon as the β^* squeeze back to 40cm was validated.

changed. In the nominal LHC cycle, the beams are squeezed to the designated collision optics before colliding. Changing β^* in collisions could be useful for luminosity levelling as it allows to control the luminosity without the potentially deteriorating effects of a beam separation.

The ability to change β^* during collisions has been implemented in the LumiServer in 2017. In MD 2427 (December 2017, [1]), it was demonstrated that the LumiServer could play β^* changes while keeping the beams in collisions.

The first test (fill 6424) was performed by squeezing the beams from β^* of 40cm to 30cm in IP 1 and 5, with intermediate steps at 37cm and 33cm. Due to the telescopic nature of this squeeze, the TCT collimators were not moved. The orbit control during the β^* steps was almost perfect with an orbit feedback gain of 1.0 and 200 eigenvalues. At each β^* step, the luminosity was optimized resulting in very encouraging corrections smaller than 2 µm. The luminosity curve followed the expectations as shown in Fig. 3.

During the second half of the MD, a de-squeeze from 40cm to 1m was successfully tested (fill 6425). While this is not likely an operational scenario in the upcoming operational settings, it is interesting from the experimental point of view, since the nominal squeeze (and corresponding de-squeeze) cycle was never commissioned in collisions. For this squeeze segment, the collimators (TCTs) needed adjustments for both the center position and the gap due to the changes in the triplet strengths. The orbit was effectively corrected by the OFB with the same parameters as established during the the 40cm to 30cm β^* levelling test (1.0 gain and 200 eigenvalues). The luminosity followed the β^* changes all the way up to 1m. At each step in β^* a luminosity optimization was performed resulting in correction in the order of 40 µm. Figure 4 shows the luminosity curve during the test.

For more detailed information about the β^* levelling MD, please refer to the corresponding MD note [1].

SUMMARY

During 2017, Software development for the LHC operation focused on precise coupling measurement and luminosity levelling. A new application has been developed for measuring the coupling in the LHC. It uses the ADT in "AC-Dipole" mode for exciting the beams and it processes the BPM reading data. This application has been used during 2017 operations for effectively reducing coupling down to $|C-| < 2 \times 10^{-3}$ at injection. In 2018, the coupling measurement application will be further improved in order to reduce the analysis time and to implement bunch-by-bunch tune measurement. The latter will provide useful input for incrementing the precision of the analysis for the coupling correction.

In the 2017 run, due to pile-up constraints, LHC luminosity was levelled to $1.5 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$ in ATLAS and CMS by separating the beams in IP 1 and 5. A new software component was added to the LumiServer in order to keep the luminosity at the desired level by changing the beam separation.

At a later stage of the fill, the integrated luminosity was maximized by reducing the crossing angle of the beams in IP 1 and 5 in steps of 10 µrad. Reducing the crossing angle from 150 µrad to 120 µrad in steps resulted in a 5% luminosity increase over a 16 hour fill. An improvement of the software foreseen for 2018 will automatically follow a pre-programmed dynamic aperture limit, reducing the crossing angle in small steps as the intensity decays (continuous crossing angle anti-levelling).

For the 2018 LHC run, the new β^* levelling functionality will be commissioned. The software implementation has been successfully tested during MD 2427 in December 2017 [1].

REFERENCES

[1] M. Hostettler, A. Calia, K. Fuchsberger, M. Gabriel, G.H. Hemelsoet, M. Hruska, D. Jacquet, and J. Wenninger "β^* levelling using the LHC Lumi Server (MD 2427)", *CERN-ACC-NOTE-2018-0001*, https://cds.cern.ch/record/2300212

[2] J. Wenninger, X. Buffat, F.S. Carlier, J.M. Coello De Portugal, K. Fuchsberger, M. Hostettler, T. Persson, R. Tomas, D. Valuch, and A. Garcia-Tabares, "LHC MD2877: Beam-beam long range impact on coupling measurements", *CERN-ACC-NOTE-2018-0026*, https://cds.cern.ch/record/2307590

[3] T. Persson and R. Tomas, "Improved control of the betatron coupling in the Large Hadron Collider", in *Phys. Rev. Spec. Top. Accel. Beams **17** 051004*, 2014, https://cds.cern.ch/record/2135848.

[4] T. Persson, J.M. Coello de Portugal, A. Garcia-Tabares, M. GĂĚsior, A. Langner, T. LefĂÍvre, E.H. Maclean, L. Malina, J. Olexa, P.K. SkowroÅĎski, and R. TomĂąs, "Experience with DOROS BPMs for Coupling Measurement and Correction", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, paper MOPMR029, pp. 303–305, doi:10.18429/JACoW-IPAC2016-MOPMR029, 2016.

[5] https://github.com/pylhc/Beta-Beat.src

[6] https://github.com/pylhc/harpy

[7] https://github.com/grpc