BEAM BASED SYSTEMS AND CONTROLS

"What we want" a review from the operation team

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Abstract

This presentation will give a review from the operations team of the performance and issues of the beam based systems, namely RF, ADT, beam instrumentation, controls and injection systems. For each of these systems, statistics on performance and availability will be presented with the main issues encountered in 2012. The possible improvements for operational efficiency and safety will be discussed, with an attempt to answer the question "Are we ready for the new challenges brought by the 25ns beam and increased energy after LS1? ".

INTRODUCTION

2012 has been another amazing year for the LHC [1], with a good availability and total delivered luminosity beyond expectations. This was achieved thanks to the good performance of the controls software and equipment, only possible with the commitment and talent of all the experts. This good result didn't come without struggle, some limitations and problems have been identified along the year, some addressed already and some other to be solved during the long shutdown. The main issues and needed improvements for each of the beam based systems are presented hereafter.

ORBIT AND TUNE MEASUREMENT AND FEEDBACK [2]

The tune and orbit feedbacks are essential to operate the LHC in the best condition, and the operation efficiency suffers a lot from each issue or bad behaviour of these very complex systems.

Tune measurement and feedback

In 2012 the quality of the tune signal was affected by :

- The ADT gain that has been doubled since 2011¨
- The octupoles strength that has been tripled
- The 50Hz and 8 kHz perturbation that is difficult to compensate.

As a consequence, it was very difficult to get a precise measurement of the chromaticity at injection, the operation team spent more time to tune it to the desired value.

At the same time, the tune feedback kept stopping as bad measurement stability was detected, or was driving tune away from the target values when the tune measurement was locked on the wrong peak. As the feedback trims couldn't be completely trusted, the operation team was relying on the current in the quadrupoles to estimate if the tune was at the right value once at flat top.

At the end of 2012, the gated acquisition was tested and put in place. Its principle is to reduce the damper gain for the first six bunches of the beams, while the tune acquisition is gated in these six bunches for which the ADT doesn't degrade the tune signal. The tune measurement was much better at injection. The chromaticity measurement and tune feedback much more efficient. But still at flat top the measurement was not fully reliable and the feedback was kept off during the squeeze.

Orbit measurement and feedback

The quality of the beam position measurement has improved in 2012, some issues are nevertheless remaining:

- Temperature dependency of the measurement
- Non linearity in the strip lines
- Beam pattern effect
- Accuracy of the measurement in and around the common vacuum chambers.

In addition, issues with the interlocked BPMs in IR6 have been source of downtime in 2012. The BPM signals were very noisy for certain ranges of intensity per bunch, giving false position readings and consequently triggering the beam dump. The LHC beams were dumped thirty-two times at injection by this spurious BPM interlocks. It was a struggle for BI to find the optimum combination of gain and attenuator to get an acceptable signal for nominal intensity, but after May these spurious beam dumps occurred rarely. The problem remains for non-standard operation with different intensity per bunch like machine development (access is required to change the attenuator when the range of intensity per bunch changes)

Linked to this problem, the interlocked BPMs trigger as soon as a single bunch sees its intensity decrease, despite there is absolutely no potential danger for the accelerator.

The orbit feedback that relies on good BPM measurement is one of the key elements of the LHC operation, it stays ON from start of ramp to collisions and no beam could survive without it. Despite an overall good reliability, many issues where encountered and not less than twenty-one beam dumps (mostly in ramp and squeeze) were triggered by a wrong behaviour of the orbit feedback.

- Orbit reference not loaded properly, the feedback corrected on the wrong trajectory.
- Optics reference not loaded, the feedback couldn't converge with the wrong optic
- Corrector mask corrupted, the feedback used the common correctors in the IPs
- There was periods were the OFSU (controller for orbit feedback) was very unstable and crashed often. As it doesn't recover properly from a crash, it was decided to dump the beam as each crash in ramp or squeeze mode to protect the machine from unexpected behaviour of the feedback.

To be noted that if the feedback doesn't behave properly, it is not possible to recover the situation once we have started the ramp and the beam have to be dumped. There is another annoying issue: the BPM status (enabled/disabled) is frequently flickering every few seconds because data is missing from some crates. This issue is due to FESA latency in sending out the BPM data paquets which should be solved if possible at the source, else at the level of the data collection algorithms of the OFC.

What we want

A solution has to be found to provide a reliable tune measurement so that the chromaticity could be controlled and the tune feedback ON along the operational cycle. The gated acquisition is a promising solution to the problems encountered in 2012.

For after LS1, the IR6 interlock BPM system has to be revisited, a solution has to be find to stay safe and not dump the beams unnecessarily.

More reliability is also needed for the orbit feedback system. Most of the time, an unexpected behaviour of the feedback is not completely understood even by the expert. This shows that the system is very complex and more diagnostics and consistency check between all the layers of the system have to be implemented. The management of the optics and references to be used by the feedback could also be simplified.

BEAM SIZE MEASUREMENT [3]

LHC is equipped with different kinds of instruments for the beam size measurement: BGI, BSRT and wire scanner for transverse beam size, LDM and abort gap monitor for longitudinal distribution. Unfortunately in 2012 operation has been often missing diagnostics for the beam size, the instruments having two kinds of problems.

Hardware robustness issues: the BSRT mirror moved toward beam because of deformation induced by the temperature. It had to be retracted completely for safety reason and no BSRT measurement was possible since end of August. The wire scanners also showed signs of weakness and OP was recommended to use it as little as possible. No wire scanner possible at all for horizontal plane of beam 1.

Calibration issues: BSRT doesn't give coherent data along the cycle: it is difficult to calibrate the data with the energy. The BGI data are difficult to analyse, it is still an expert tool. The wire scanners give different result for the same beam with different working points (filters + gain settings)

What we want

For good operation efficiency and analysis of instabilities and losses, operation needs a bunch by bunch beam size measurement that is coherent along the LHC cycle, and also along the accelerator complex. The hardware issues have to be addressed, more robust instruments are needed. To ease their usage by operation, the tools in the control room could be improve. For the BSRT a lot of effort has already been made to improve and simplify the application but it is still expert oriented. The wire scanner application should also be simplified and useful functionalities implemented. LDM is a very useful tool that would be largely used if given with a proper operational application.

BUNCH/BUNCH INSTABILITIES MEASUREMENT

In 2012, with smaller emittances and higher intensity per bunch, the bunch by bunch instabilities started to be a limitation for the LHC performance. If better observation tools were available for the beam/beam effect experts, these instabilities could have been better understood and appropriate solutions put in place.

The existing tools in the control room for bunch by bunch measurement all have limitations and need to be improved. For example the ADT pick-ups give an accurate measurement of the bunch/bunch position, however one can acquire only 8 bunches for 6 seconds or 1374 bunches for 72 turns because the memory is limited. The BBQ peak-up could also give bunch by bunch tune and position measurement if another signal processing was implemented. The instruments like shottky monitors and diamond detector are promising but are not yet fully operational.

What we want

For bunch by bunch measurement, there are common requirements for all types of instrumentation:

- High measurement resolution because the instabilities are fast and appear within a few hundred turns.
- Large data buffers to acquire a maximum of turn for all bunches.
- A triggering system that would detect instabilities and trigger the acquisition of the appropriate instruments.

For a complete analyses of the instabilities, the following bunch/bunch measurements are required:

- Bunch by bunch position
- Bunch by bunch tune
- Bunch by bunch emittance
- Continuous chromaticity measurement along the cycle.
- Transverse motion inside a bunch to identify the type of instabilities

INJECTION AND DUMP SYSTEMS [4]

IQC and Steering

It is difficult for the operation team to evaluate what is acceptable or not for an injection in term of trajectory and beam losses. The IQC (injection quality check)[5] is the tool that helps for this evaluation by analysing several key parameters and comparing the measured values with pre-defined references and tolerances. The injection process is stopped when the quality as analysed by the IQC is not good enough to let the operation team take corrective actions. In 2012, it was not rare to have the IQC complaining on losses or trajectory errors that were judged acceptable by operation (i.e. only one bunch out of the tolerance at a single BPM), no special action was then taken and the injection process continued. The IQC should only stop the injection when correctives actions are absolutely necessary. Otherwise not only does it slow the injection process, but it also increase the risk that a real problem is involuntarily discarded. Therefore, the thresholds and tolerances for the IQC have to be reviewed.

It is a general feeling of the operation team that too much time is spent with the steering of the lines. First, the steering process itself is long because with time the trajectory diverged from the golden trajectory references established at the beginning of the run. So instead of just trying to reach the reference that would not be possible without huge kick on some correctors, steering the lines meant compromising between minimal beam losses and acceptable trajectories. Secondly, the stability of the lines degraded after the change of optics from Q26 to Q20 and the frequency of the steering increased. The reasons of this degradation are still being investigated. Due to this instabilities and out of date trajectory references, even specialists could not be 100% sure when the trajectory was good or not. As a consequence, several important steering campaigns were put in place to try to minimize injection losses without success because the trajectory was already very good and the losses came from longitudinal plane (satellites from the injectors or unbunched beam in the LHC). In this case, also a training of the operation team on the interpretation of injection losses is needed.

TDIs

The TDI has known several hardware problems in 2012 and was responsible for 26 hours of downtime. Two significant examples are presented.

Heating problem for TDI IR8: the LVDTs of the TDI in IP8 drifted outside the limits position due to the deformation of one jaw. This deformation is due to the heating induced by the beam.

Mechanical problem for TDI IR2: a pin broke and one jaw of the TDI fell across the beam aperture while preparing for injection.

In addition to the time needed recover from a failure, in some cases the TDIs needs to be re-aligned. This beam based alignment is time consuming but necessary to guarantee the protection in case of MKI failure.

MKIs

The MKIs have been a source of downtime mainly because of the heating induced by the beams during physics. The strength of the injection kickers is guaranteed only if the temperature in the tank is below a given thresholds and any injection is forbidden otherwise. As a consequence, after long physics fill, injection was not allowed before several hours after the beams had been dumped. In total, eighteen hours were spent waiting for the temperature to decay. To mitigate this problem, the hottest tank has been replaced during TS3. This implied conditioning and scrubbing for several days that was incompatible with physics.

Another limitation of the MKIs impacting operation was the vacuum interlock in place to prevent flashovers. As it is defined now, this interlock level is incompatible with the 25ns beam. As a consequence, the 25ns run has been pushed to the end of the run so that the vacuum thresholds could be increased without compromising the proton run in case of serious MKI failure.

LBDS

42 hours of downtime has been assigned to the LBDS systems. The main problems have been:

- Offset in the energy tracking system due to the failure of a power supply, power supply replaced but set point to be adjusted.

- A machine protection issue was discovered, the lack of redundancy of a 12V power supply could have led to a situation where dumping the beam where impossible. Immediate corrective actions were put in place.

As the LBDS systems are critical for machine protection, the quality control after a failure requires time consuming testing and revalidation.

What we want

With better trajectory reference, appropriate position and beam losses thresholds, the time spend at injection could be reduced: IQC shouldn't stop the injection process when not necessary and steering would be easier and faster if trajectory stayed closed to the reference. Of course improving the line stability would also help a lot.

LS1 will be the occasion to improve the hardware for the TDI and MKIs that has shown worrying limitations during the run. The LBDS systems also need some consolidation to reduce the source of downtime.

RF SYSTEMS [6]

The performance of RF systems, hardware and low level, have much improved in 2012 with respect to 2011. Nevertheless it remains one of the major sources of downtime for the LHC. Sixty-height hours of downtime have been assigned to the RF hardware, mostly due to crowbar problems. These faults came in waves and there also were several weeks passed without any recorded RF fault. On the low level side, the thirty-one hours of downtime came mostly from some crates to be rebooted or replaced. All in all, the RF performance has been very good, despite an increased intensity per bunch and new challenges like the batch by batch blow-up and the preparation for proton-lead run.

What we want

The operation team has nevertheless identified several points that could be improved. Of course the reliability of the hardware needs further improvement, as operating with more power and at higher beam energy may also impact the availability. More diagnostics on RF interlocks would also be needed; especially in case of low level problem it would ease the diagnostic of a fault and help the operation team to call the right experts. Now the injection phase measurements give the average phase of all bunches in the machine, a batch/batch measurement is needed to see the injection phase error at each injection. The bunch longitudinal profile measurement is now available only for expert, it would be useful also in the control room. The batch by batch blow-up recently made operational still needs diagnostics and control for the operation team.

TRANSVERSE DAMPER SYSTEMS [7]

The transverse damper has shown lots of flexibility and has been used for many different applications: injection oscillations damping, injection area cleaning, abort gap cleaning, transverse blow-up that has simplified a lot the loss maps procedure. The ADT pick-ups are also used to measure beam instabilities and the tune measurement with transverse dampers is almost operational. The ADT hardware has been quite reliable with only 12 hours of downtime assigned.

What we want

With the new functionalities implemented along the year came a lot of new parameters and settings. Some of these settings belong to function beam processes, some other to discrete beam processes that are different for the type of the beam and along the LHC cycle. At the end it becomes difficult for the operation team to manage this parameters and settings and still rely a lot on the experts. This will have to be reviewed and an attempt has to be made to simplify the parameter space. At the same time a better solution has to be found for the intensity dependent settings that have now to be set manually by experts.

CONTROLS SOFTWARE [8]

Main issues

A total of 21h of downtime has been assigned to the control systems, mainly pieces of hardware to be rebooted or replaced. Some other problems impacted the operation efficiency:

- The CMW middleware is unable to manage bad client, the server gets stuck and doesn't send update to the good clients, the major consequence being that the software interlock system triggered several time the beam dump because of subscription timeout.
- The CBCM (timing system that orchestrate the injection requests and beam production and destination in the injectors) has shown potentially dangerous issues with the dynamic destination management: twice the destination has not been updated as it should and the beam has been injected in the wrong ring.
- The LSA database becomes very slow when accessed by several processes (i.e. during database back-up) and the incorporation and regeneration of beam processes takes too much time. This problem has already been addressed during the run but further improvements are foreseen.

What we want

Some improvements have already been requested by the operation team since 2010 [9]. They have not yet been addressed either because considered as low priority or by lack of manpower. They are still valid today:

- Diamon: Clearer information is needed on the connection between applications, proxy, middletiers, front-end… The display of the server status in diamond still doesn't reflect the real status of the server that could have perfect behaviour with a red status or be completely stuck and happily displayed in green.
- Alarms: the alarm system will never really been used in operation until it becomes mode dependent: i.e. some alarms are important at injection but can be ignored during physics.
- Sequencer: the sequencer should allow for automatic parallel execution of sub-sequences. It should be possible to pass arguments to a sub-sequence, offline and at the execution time by the user.
- Timing sequence edition: more and more flexibility is requested to the injectors with the edition of the sequence of cycles to be played by the timing. Even if the situation has already much improved thanks to the use of spare cycles for intermediate intensity, lots of time is spent with the edition of the sequences. This time could be reduced by improving the timing manager application. In addition switching from one sequence to another takes several supercycles, it has to be investigated if time could be gained at this level.

The last years of LHC operation brought also other requirements to improve the efficiency:

- The console manager could propose more user friendly tools for the edition of the menus and an automatic periodic refresh of the menu configuration from the database should be implemented to avoid using old application versions by mistake.
- Fidel (process that compensate for the magnetic field decay at injection [10]) worked very well, but the existing fixed display that indicates the LSA trims performed by the process needs to be improved. It has to be investigated how to improve Fidel behaviour in case of hypercycle change: now in some cases it requires a precycle to "reset" the Fidel trims that has been done with the previous hypercycle active (often the case during MDs)
- RBAC is a powerful tool to keep control of what is done during the physics run [11]. The drawback is that it becomes painful and inefficient to enter login several times in all operational consoles. An alternative solution could be investigated, like biometric identification methods. In addition, LS1 would be a good occasion to rationalize the roles distribution and review the roles management.
- The state machine has been fully used and has shown a lack of flexibility, especially during MDs. It has to be reviewed to propose two levels of checks and distinguish between what is absolutely necessary whatever the type of operation (i.e. main magnets being at injection when going to inject state) and what should simply be checked, like the state of the tune feedback. After LS1, the action "force without check" should be exceptional as it has the risk to change state when the machine is not fully ready.
- The FESA navigator tool has been used a lot in the control room and shown very useful to check some settings directly in the FESA classes. This application that was first designed only to be used as an expert tools would need to be improved, made operational and user friendly.

DATA MANAGEMENT

The demand for bunch by bunch and turn by turn data is increasing rapidly with the need to track and understand the beam instabilities in the LHC. Presently, lots of data are stored with individual ad-hoc solution instead of going to the official logging database.

What we want

A common system is needed to log this large amount of data. This data could be automatically deleted after a configurable time period with the possibility to keep the interesting data.

There is also a need to do fill by fill data analysis. It should be possible to extract predefined set of key parameter for a given fill to analyse these parameters along the fill or from one fill to another with tools for easy comparison. It would have the advantage to immediately see the effect of one parameter change from one fill to another and give a common tool for fill analysis that would allow to follow long term evolution of given parameters.

CONCLUSION

Issues, weakness and needs for improvement has just been presented for the beam based systems. This shows that the great performance of the LHC during 2012 run has not been achieved easily. Huge work has been done by all these equipment's experts to push the performance and availability of their systems, and the operation team had the luck to rely on their help, involvement and reactivity. LS1 will be the occasion to consolidate and improve all the systems and controls to have them ready for the new challenges that will have to be faced in 2015.

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