POST LS1 OPERATIONAL ENVELOPE & MPS IMPLICATIONS

M. Solfaroli Camillocci, CERN, Geneva, Switzerland

Abstract

Post LS1 operation will face multiple problems due to the high energy and intensity of the beams. Some machine parameters can be reviewed in light of the last three years of operational experience and the operational scenarios adopted. The different levels of the Setup Beam Flag can be re-discussed, as well as the "stable beam" flag, which, in the present configuration, would be incompatible with beta* leveling. The management of the critical settings is also to be discussed to improve quality and flexibility for non-standard operational configurations and machine developments.

THE SETUP BEAM FLAG

During the LHC beam commissioning in 2011 and 2012 the so-called Setup Beam Flag (SBF) was used many times to carry out measurements and test like collimators alignment, loss maps and optics measurements.

This functionality, without compromising machine protection, makes it possible to commission the machine in a faster way as it limits the risk of lost fills due to non-critical problems; consequently it allows to use a fill for multiple purposes. The SBF condition allows masking several channels in the Beam Interlock System (BIS), such as Beam Loss Monitor (BLM) (maskable), RF, collimator movements, AC dipole, Power Interlock Controler (PIC) (maskable) and IR6 Beam Position Monitor (BPM).

The origin - the safe beam flag

Some experiments [1] were carried out in 2007 to establish the effect of a high intensity beam impacting on equipment. This effect depends strongly on many parameters (e.g. impact angles, beam size) and it is therefore not easy to evaluate. A controlled beam experiment was performed in the SPS transfer line, by impacting a 450 GeV beam orthogonally on a target made of multiple layers of tin, steel and copper, varying the intensity of the impacting beam. The results clearly show that an intensity of $1.2 \cdot 10^{12}$ p^+ has no effect on the material, while tests done with higher intensities produce damages from visible effect up to creation of holes in the target. The intensity of $1.2 \cdot 10^{12}$ p^+ at 450 GeV was consequently considered safe; a factor 2 was then applied to account for the lower emittance used during LHC operation, resulting in a value of $5 \cdot 10^{11}$ p^+ at 450 GeV. The corresponding beam intensity was then calculated for all energies, establishing the maximum safe beam intensity for a given LHC energy. The Safe Beam Flag curve was then defined (blue curve in Fig. 1).

From Safe Beam Flag to Setup Beam Flag

For operational purposes there was a need of having at least one nominal bunch in the machine at high energy. As the possibility of an orthogonal impact in the machine is negligible, three different layers of safe beam flag were defined, invalidating the name of safe beam flag. The name was consequently changed to SETUP Beam Flag:

- **NORMAL:** it is a factor 2 above the damage limit at 7 TeV (it is assumed that the probability of an orthogonal impact is negligible)
- **RELAXED:** it was established to allow 1 nominal bunch at 4 TeV (resulting in a factor 5 higher than the normal, thus becoming a factor 10 above the damage limit at 7 TeV)
- **VERY RELAXED**: it was established to allow 3 nominal bunches at 4 TeV (resulting in a factor 13 higher than the normal, thus becoming a factor 26 above the damage limit at 7 TeV)

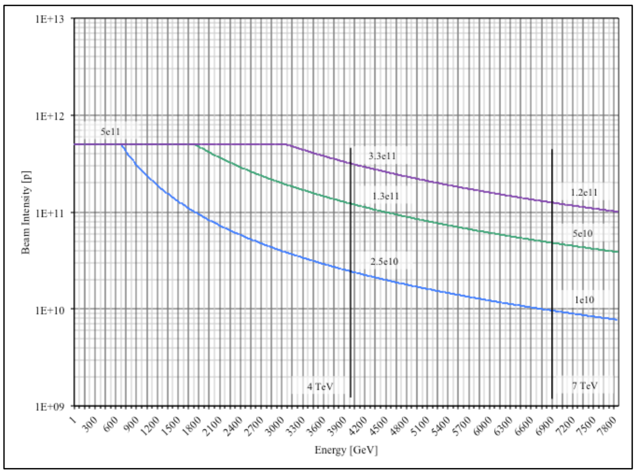

Figure 1: The setup beam FLAGS: normal-blue, relaxed-green, very relaxed-purple

Applying the same principle (to allow 1 and 3 bunches at maximum energy) to 7 TeV, the relaxed beam flag would result being 13 times higher than the safe limit and the very relaxed flag a factor 34 (there is an additional factor 2 due to the lower operational emittance). These numbers clearly show that the concept of SETUP beam flag has to be re–discussed for after LS1 operation.

On the other hand, assuming to accept the same level of damage in case of failure, up to 1 nominal bunch can be used at nominal energy of 7 TeV.

Commissioning at 7 TeV

After LS1 the LHC will be commissioned and operated at energy, close to 7 TeV. During the commissioning period many activities, presently done under setup beam conditions, have to be carried out. The impact of reducing the maximum allowed intensity would then have an impact on the commissioning efficiency and the time needed. In Table 1 these activities are listed, together with a comment about the impact of reducing the maximum allowed value.

Table 1: Activities affected by the allowed intensity change

Activity	Comment	Result
Betatron loss maps	It can be done with unsafe beam, adjusting the ADT parameters	Not affected by the change in intensity value
OFF momentum loss maps	It can be done with 1 pilot, but only 1 LM per fill	
Collimator alignment	It must be done with nominal bunches to have the right orbit reading	With unsafe beam would add complexity and time consumption
Optics measurements	Presently done with safe beam. It can be done with 1 pilot	More fills required as some intensity can be lost
Chromaticity measurements	Done with pilot	Not affected by the change in intensity value
Asynchronous beam dump	Done with pilot	Not affected by the change in intensity value

Some studies [2] show that it is theoretically possible to acquire off momentum loss maps without losing the full intensity on the collimators. Reducing the number of fills needed for commissioning would clearly increase the efficiency of the operation, however, it has to be noticed that nominal beam intensity is needed. A careful study on the timing of dump inputs received during measurements of off momentum loss maps performed in 2012 clearly shows that this operation can be done only if certain interlocks are masked. In fact, the following three (masked) interlocks trigger systematically before the beam losses needed to check the collimator hierarchy have been attained:

- RF frequency
- IR6 BPMs
- BLM-maskable

This technique could then be used only in presence of a setup beam flag system.

The Safe/Setup Beam Flag at 7 TeV

As said, the acceptance of the same level of beam energy as for the very relaxed beam flag in 2011 and 2012 would allow one nominal bunch at 7 TeV. This possibility would make the commissioning easier and faster, reducing the number of dumped fills due to non-critical problems.

The definition of a “relaxed” setup beam flag is not strictly mandatory as the beam commissioning operations can be done with nominal bunches. Nevertheless, its implementation is recommended, as it would increase the commissioning efficiency and it could be necessary for carrying out machine development studies; consequently some investigations will be carried out to review the safety scenario.

7 TeV operation

Many scenarios are being discussed for operation after LS1, such as a combined Ramp & Squeeze, injection at lower beta and beta* leveling. All these options have to be carefully studied as they have a large impact on the machine operation. Besides, as they require substantial changes in operational tools and software they might compromise the safety of the machine.

The generation of settings for Ramp & Squeeze is being investigated, as the optics optimization cannot be carried out within the present system. However, studies have indicated that the beams can be squeezed up to 3m during the ramp to 7 TeV. Many operational challenges have to be faced, like collimator function generation and tune corrections. Nevertheless, from a machine protection point of view the Ramp & Squeeze option does not create any particular problem.

In order to limit the pile-up in the experiments, the possibility to collide the beams at a higher beta* than the one used in 2012 is considered. The beams would be further squeezed in steps at a later stage, keeping the luminosity almost constant. With this option the beams could be put in collision after a short squeeze or even at the end of the ramp. The policy of the beta* levelling is very important. A fixed scheme where the beta* of all interaction points changes together and always in the same way is easy to implement and from an operation point of view pretty easy to manage. Allowing changes in beta* separately for each IP would drastically increase the number of machine protection checks to be done, as each possible configuration should be tested. Besides, the beta beating corrections in the arc would not be effective each time a local beta* is squeezed further, as they use correctors in the IRs. The beta* value is currently used in the safe machine parameters for the generation of the stable beam flag; this parameter should be changed or removed.

The possibility to inject the beams at a lower beta is also considered. The time spent in the squeeze would drastically decrease compared to 2011 and 2012 operation, but some machine protection implications have to be taken into account. In particular a solution should be adopted where the available aperture in the Inner Triplets is used for smaller beta*, without reducing the global aperture limit (thus avoiding changes in collimators settings at injection).

Possible improvements

After 3 years of operation, all teams involved have acquired a large experience. Many improvements are being discussed and they will be studied during LS1. If used, these improvements would increase the efficiency and the safety of the operation.

The reproducibility of machine settings and the limitation of the risks connected to erroneous trims is an important example. The implementation of an orbit-correctors-like system by creation of frozen beam processes (non-trimmable copies of the original ones) against which checking the settings in critical phases of operation (i.e. using the State Machine) are being considered.

The implementation of a dynamic settings check (as presently done for the collimators), improving the usage of beam process categories and the limitation on "non-CCC based" trims, are also under study.

A big effort also has to be spent by all teams involved in the LHC project to standardize the way hardware and software interventions are done and validated before releasing the machine for operation. To avoid using a non qualified machine, indeed, a rigid system has to be put in place that forces a requalification of the affected changes.

CONCLUSIONS

In the light of what was discussed in this paper, some conclusions can be taken.

The concept of setup beam flag has to be revisited in view of the gained experience. Simulations and studies have to be carried out to identify a safe scenario for post LS1 operation that allows the minimum flexibility needed to commission the machine without compromising its machine protection. The definition of a "relaxed" setup beam flag can be considered, this would help the commissioning process and it would be important for machine development studies.

From a machine protection point of view, there is no a priori showstopper to use Ramp & Squeeze and/or beta* leveling options. Nevertheless, it is important to continue the investigation in order to identify all possible operational problems.

Some improvements can be done on settings management and hardware re-validation to increase the protection as well as the reliability and reproducibility of the machine.

ACKNOWLEDGMENT

The author wants to express sincere thanks to all people involved in LHC operation for their inputs and help.

REFERENCES

[1] V. Kain "Machine Protection and Beam Quality during the LHC Injection Process" CERN-THESIS-2005-047 Vienna Tech. U., 2005

[2] B. Salvachua "Beam-based validation of settings" These proceedings