OPERATIONAL CYCLE

Matteo Solfaroli Camillocci, CERN, Geneva, Switzerland

Abstract

The LHC has been successfully operated at 4 TeV during 2012 run. An analysis of the critical points of the standard operational cycle has been made, aiming at increasing the performance and the efficiency of the machine. An outlook at the changes that will be faced with the 7 TeV operation after LS1 is given, with particular attention at some possible scenarios. A consideration on the differences of the magnetic behavior is also made.

2012 LHC COMMISSIONING

2012 LHC commissioning was very effective. Only 2 days after the first beam injection, the first ramp at 4 TeV was carried out and only 20 days later, stable beams was declared for the first time with 3x3 proton bunches in the machine. This operation was done in perfect agreement with the planning and the physics program started on the foreseen date.

2012 operational changes

In order to increase the operational performance and diminish the time of the standard cycle of the LHC, thus raising the integrated luminosity, quite a few changes had been made with respect to 2011 operation. These major modifications had an impact on the commissioning time:

- Ramp to 4 TeV;
- B3 decay compensation at flattop separated from the ramp of the other circuits;
- ATLAS and CMS interaction points squeezed to 0.6 cm beta*;
- Further optimization of optics distribution during the squeeze;
- LHCb collision planes were tilted.

Ramp at 4 TeV

The first ramp with beam was carried out only 2 days after the first injection in the LHC; both pilots arrived at 4 TeV and B2 was dumped after few minutes at flattop due to a glitch on the safe beam flag. As well as the 2011 ramp, most of the orbit and tune changes were found around 1 TeV. Few more ramps have been performed in order to measure chromaticity, tune and orbit then calculate and feed-forward their corrections. Some minor tune spikes are still present during the snapback and they will be further analyzed during LS1.

A big time gain was obtained by the separation of the B3 decay compensation at flattop from the ramp settings. As it can be seen in Fig.1 this was achieved by separating the settings of the spool piece power converters from the others of the machine. This allowed starting the squeeze while the B3 decay compensation is still ongoing, with the result of a gain of about 15 minutes per cycle.

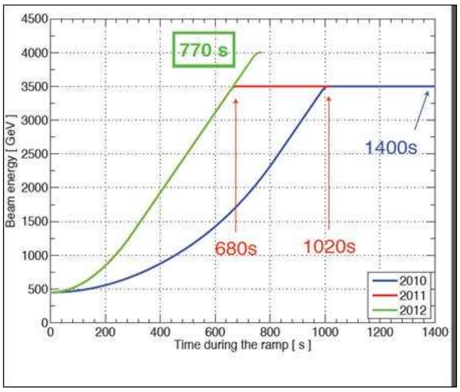

Fig.1 Comparison of the ramp power converter settings in the last 3 years of operation

Squeeze

Two major changes in the squeeze strategy have been made in 2012.

In the light of 2011 experience the matched points distribution was optimized, by eliminating some points and by permitting different β* values in the IPs; this allowed to consistently reduce the squeeze time. Nevertheless, the global length of the squeeze passed from 475 seconds to 925 seconds due to the change in final β* from 1.5 meter to 60 centimeters.

In 2011 some orbit spikes of about 0.1mm r.m.s. were observed around the matched points. In order to increase the reproducibility of the machine and the stability of the beams, the smoothing of the K functions was changed and the amplitude of the orbit spikes strongly diminished, as shown in Fig.2.

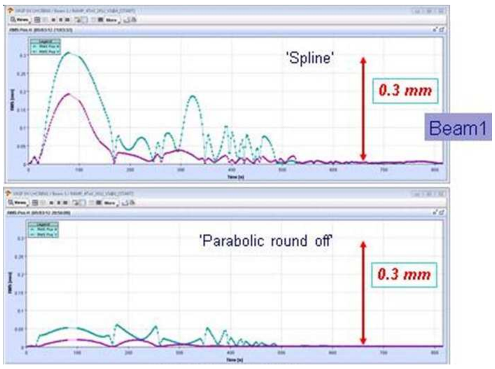

Fig.2: Amplitude of the orbit spikes with different smoothing of the K function

Optics

Optics measurements were performed at flattop and at different matched points during the squeeze to calculate the corrections to be implemented.

Around 20% of peak beta-beating was found at 4 TeV, very well compatible with the values found on 2011 operation at 3.5 TeV.

At the end of squeeze (60 centimeters β* in IP1 and IP5), very large values of beta-beating were found, up to 100%. A very accurate correction calculation and implementation allowed reducing this value up to 7%, ensuring very high machine performance [1].

Collisions

The commissioning of the collision beam process has been a bit laborious due to the tilting process of the LHCb collision planes, which resulted in an increase of time from 56 seconds to 220 seconds. In particular, the orbit drift while collapsing the separation bumps was as large as 100 μm, but was reduced up to about 30 μm after feed-forward.

2012 LHC OPERATIONAL CYCLE

With the aim to define the best strategy to be used when operating the machine at 7 TeV after LS1, an analysis of the different phases of the cycle was done and used to estimate the expected changes.

A homogeneous set of fill was taken as sample: only physics fills with more than 1000 bunches and 60 centimeter β*. For the fills in the sample, the average of time spent for each beam mode (excluding "Rampdown" and "setup" as their declaration is not consistent from one fill to another and their length is strongly affected by the presence of hardware faults) was calculated.

The result of the analysis is shown in Tab.1

Beam mode	Theor	Mean	Comparison
INJPRO	n.a.	52 min	~0.86 h
INJPHYS	n.a.		
PRERAMP	n.a.	259	259
RAMP	770	791	21
FLATTOP	n.a.	377	377
SQUEEZE	925	996	76
ADJUST	220	513	293
RAMPDOWN	2100		
TOT		1h41	
TOT (with rampdown)		2h16m	

Tab.1 Average beam mode time in 2012 operation

In Tab.1, the second column contains (where applicable) the length of the beam process settings for the hardware; the third column shows the mean value for 2012 operation (in seconds) and the last column shows the time spent in the beam mode that exceed the settings length; this last value is meant to be used for comparison with the previous years data when the settings time was different.

The comparison with the data of 2010 and 2011 shows a strong improvement. The global cycle time was reduced by almost a factor 2 between 2010 and 2011 [2] [3] and further by 21% in 2012, despite all changes implemented to increase the LHC performance.

OPERATIONAL CYCLE AFTER LS1

After the consolidation foreseen for LS1, the LHC will be operated at an energy close to 7 TeV. The settings for the machine hardware can be easily calculated; in this analysis it was assumed an operational energy of 6.5 TeV. The following cycle has been taken into account:

- Injection at 11 m;
- Ramp to 6.5 TeV;
- Squeeze to 40/45 cm β*;
- Collisions (with tilted planes in IP8);
- Rampdown.

Estimating the length of the cycle from the 2012 analysis is easy, although not fully exhaustive. The calculation shows a hypothetical increase of about 51 minutes (37%), mostly dominated by the rampdown time. This means more than 3 hours cycle, which would decrease the efficiency of the LHC.

Many different options are possible for post LS1 operation and are being considered to improve the quality of the physics production. Some of these options would also affect the cycle time like combining ramp and squeeze or performing beta star leveling as well as beam injection at a lower beta. Some other options like colliding while squeezing, flat beams or 25 ns beam would improve stability or luminosity, but do not impact the LHC cycle time.

In the view of a speculative analysis, the most aggressive scenario was considered to estimate the shortest possible cycle:

- Injection at 5 m (with collision tunes);
- Ramp & Squeeze to 6.5 TeV / 1 m;
- Collisions without LHCb tilting;
- Beta* levelling from 1 m.

The estimated time length for each beam process would result in a 29 minutes (15%) shorter length with respect to the standard scenario of post LS1 operation. Nevertheless, it is important to notice that these changes are presently under study as they have machine protection implications that might make them not suitable for operation.

Some other important aspects have to been taken into account when studying the after LS1 operation scenario. At 6.5 TeV, the dipole magnets are expected to enter a week saturation regime; the dynamics effects are expected to double; the decay and snapback of tune and chromaticity will also have to be carefully measured and corrected. The precycle will also change: it has to be done at 6.5 TeV, which would result in about a factor 2 increase in time. A bigger impact could come from a further squeeze to 40 centimeters β*; in this case, in fact, the precision of the model of the interaction region quadrupoles is critical. The MQM and MQY magnets are less problematic as they will go down in current; the hysteresis effect is known and can be implemented in the functions. The inner triplet magnets represent the major problem, as they will be operated in a large saturation regime and the precision of measurements and models could not be enough for operation.

CONCLUSIONS

At the end of the analysis some conclusions can be drawn.

The 2012 commissioning and operation were very effective. The machine is very reproducible and the operational time has been improved so much that it is now approaching the limit given by the hardware setting; however, some part of the cycle like flattop and rampdown can still be improved. Despite the longer settings and more complex operational envelope the LHC has been operated in 2012 on an average of 36 minutes less per fill; a big improvement was in the time spent to inject the beams from the SPS.

The post LS1 operation will be a challenge and the strategy taken can drastically change the efficiency of the machine. The higher operational energy will result in a consistent time increase that can be limited depending on the envelope chosen up to about 15%.

It is for all these reasons important to converge quickly on a strategy in order to carefully and properly prepare after LS1 operation. The analysis proposed suggests to start as a baseline with the well known 6.5 TeV standard cycle, then steer the strategy during the first year of operation.

ACKNOWLEDGMENT

The author wishes to express his sincerest thanks for the useful discussion, corrections and suggestions to the operation team, the FIDEL team and the optic measurements team.

REFERENCES

[1] R.Tomas & al. "Record low β beating in the LHC", Phys. Rev. ST Accel. Beams 15, 091001

[2] S.Redaelli "How to improve turnaround", 2010 LHC Beam operation workshop, proceedings

[3] W.Venturini "Turnaround - analysis, Possible improvements, combined R&S, precycles, injection", 2011 LHC Beam operation workshop, proceedings