NOMINAL CYCLE AND OPTIONS

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Abstract

During Run 2 the LHC operation will be based on the experience gained in Run 1. However the LHC will be operated near to its design energy. Many operational configurations can be considered to improve efficiency and reduce the impact of the longer time required by each operational phase. The expected changes in the magnetic model and the impact of the data updates with the corrections calculated during LS1 are presented together with a general overview of the operational cycle, including time, challenges and possible improvements of each phase.

THE MAGNETIC MODEL CHANGES

LHC operation requires the calculation of the required currents of the magnet circuits for all phases of the cycle. These settings are based on a parametric model whose coefficients are calculated from magnetic field measurements. The core of the so-called FIDEL model is already present in LSA and has been used extensively during Run 1. Due to improvements of the model, incongruences discovered, and changes implemented during LS1, some modifications to the parametric model need to be implemented for Run 2. These changes should improve the machine quality. The recalculation of the MQY and MQM warm to cold data correlation will impact the field quality for some magnets, resulting in lower local magnetic errors. The impact of this change has been already evaluated with a machine study during Run 1. The new data also contains the hysteresis implementation for MSF/MSD magnets, which could potentially solve some differences noticed during Run 1 between the measured and calculated chromaticity. The geometrical contribution to the field quality of the exchanged dipole magnets has been also re-calculated; the effect of this change should nevertheless be transparent for machine operation.

Some changes in behavior are also expected because of the energy increase:

- The tune decay amplitude at injection will increase and the snapback amplitude will increase accordingly (to be carefully measured and corrected) [1][2][3];
- The decay amplitude at flat-top will likely become negligible (to be measured);
- The calibration curves for the different classes of magnet have to be reviewed;
- Some magnets (MB, MQD/F and MQX) will enter the saturation regime. Nevertheless, no surprises are expected, as saturation is implemented in FIDEL.

Maximum energy	4 TeV	6.5 TeV
Tune	-0.022	-0.035
b3	0.4	0.5 – 0.6

Table 1: Expected tune and b3 decay amplitude at 450 GeV

THE NOMINAL CYCLE

Precycle

All LHC magnets (both superconducting and resistive) need a pre-cycle to ensure reproducibility of the magnetic field. This means powering the magnets up to the nominal operational current, down to below injection current, and then to injection current before injecting the beam. The level of current and duration of the flat-top needed vary considerably from one type of magnet to another. The strategy for precycle that was established for the first LHC run [4] will be used also for the second one:

- MB: Ramp to nominal current, 600 s plateau, ramp-down
- MQMs: Ramp to maximum operational current, 1000 s plateau, ramp down
- MQYs: Ramp to maximum operational current, 300 s plateau, ramp down
- Magnets with negligible decay (MBRs, MQD/F, MQX,…): Ramp to maximum operational current, 300 s plateau, ramp down
- Magnets with no decay: Differences according to uni/bi-polar PC, and optical functions
- Warm magnets: Differences according to uni/bi-polar PC, several cycles

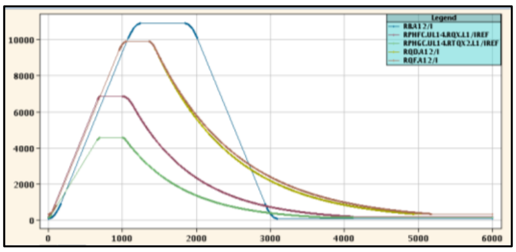

Figure 1: Precycle at 6.5 TeV

Due to the much higher energy at which the main circuits will be operated during Run 2 the precycle for the main quadrupoles is potentially the longest. This is due to the fact that these circuits have a 1-quadrant power converter - the current cannot be driven down – and has to decay via the L/R time constant of the circuit. The length of a precycle for the quadrupole circuit will be around 5200 sec. In order to increase machine efficiency, some improvements are foreseen; however the main quadrupoles and potentially the inner triplets will define the length of the precycle.

Injection

The injection process is less affected by the energy change. Many parameters and processes that proved to be efficient can be used in the same way. The BBQ gating and ADT un-gating on the first 12 bunches, for example, proved to be a good solution to ensure good signal-to-noise for tune measurements. Setting the tune work-point at .28/.31 also allows reasonable measurement and control.

Nevertheless, some changes are expected due change in energy and beam intensity. The highest energy plateau will require careful measurements and parameterization of b2 and b3 to ensure good response of the magnetic model and reproducibility. The use of 25 ns beams will result in higher beam intensity, larger emittance and higher intensity per injection.

Besides all this, the recently discovered weakness of the SPS high energy dump will required careful SPS setup that might have a potential impact on LHC operation. The vacuum situation around ALICE after the LS! interventions and the TDI consolidation will have to be checked to assess whether the de-coupled injection of B1 and B2 (as done during Run 1 to reduce the background) is still required.

Ramp

The ramp process has been well optimized during Run 1, passing from an initial length of 1400 sec (to 3.5 TeV) to 770 sec (to 4 TeV). The ramp to 6.5 TeV will take 1200 sec. The large gain has been obtained thanks to two main changes: a faster start and the separation of the settings of all system synchronized with energy from the spool pieces. The former was possible as the effects of the snapback were mitigated by a very careful measurement and efficient parameterization of the magnetic model. The latter because the spool pieces correctors have settings longer than the other energy synchronized systems to compensate the flat-top decay.

Finally the highest energy foreseen for Run 2 requires ramping the octupole correctors to their maximum strength.

Flat-top

During Run 1 the instability of the tune feedback during the ramp due to a complex tune spectrum forced the re-adjustment of the tune, once the ramp was completed. This was done by adjusting the current of the tune correction circuits with respect to a reference. This manipulation proved to be effective. During Run 2, if still needed, it will be automated.

Squeeze

Several changes are foreseen. The LHC will be initially commissioned to 80 cm beta* in IP1/IP5, 10 m in IP2 and 10 to 3 m in IP8. Nevertheless during the commissioning phase test will be performed to prepare the operation up to 40 cm.

Some of the intermediate optics that were removed to reduce the overall length will be reinserted to optimize beam parameter behavior.

As discussed in [5] the tune change during the squeeze can be performed using the quadrupole trim correctors rather than the matching quadrupoles. De-coupling the two operations provides flexibility - the tune change could also be done after the squeeze, improving the resolution of the tune signal in the process.

At 6.5 TeV there is still no need for initial pre-squeeze of IP2 and IP8 as the triplet gradient limit is only reached at 6.78 TeV.

Collisions

Three main beta* collision configurations are considered for Run 2 :

- Low: between 40 and 80 cm
- Medium: 20 m (30-40 m for LHCb) for LHCf runs and vdM scans
- High: 90 m

The collision process has been optimized during Run 1 and is not expected to change (little gain might come from the performance increase of the RCBX correctors)

The separation between collisions in IP1/IP5 and IP2/IP8 proved to reduce beam-beam effects, thus increasing the beam stability. For this reason the strategy will be maintained.

COMBINED RAMP AND SQUEEZE

Operation at 6.5 TeV requires a 1200 sec long ramp. It might be possible to perform some optics changes in the ramp to reduce the time needed for the squeeze (Combined Ramp and Squeeze). These changes should be performed during the linear part of the ramp. Assuming an optics change to 3 m beta* (Run 1 measurements show that large beta beating arises below this value) would result in overall gain of 430 sec per LHC fill.

Despite the problem discussed in [6], settings for CRS have been generated and prove the feasibility of the process. Machine development studies performed in 2012 demonstrated that both optics measurements and loss maps can be also performed during the ramp. The new tertiary collimators equipped with BPMs could also ease the problem of closed orbit variations from simultaneous crossing angle reduction and bump shape change.

CONCLUSIONS

Run 2 start-up machine configuration will be similar to the one used during Run 1, with an identical operational cycle (but to 6.5 TeV). Some minor changes have to be implemented to the magnetic model. These should have a small but positive impact on the beam quality.

Many changes are possible in the near future including: smaller beta* and CRS. The latter seems to be possible and has the potential to increase the LHC efficiency.

Some additional studies will be done during machine development periods, to finally assess its feasibility and integrate it in the LHC operation at a later stage.

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