RAMP: EXPERIENCE AND ISSUES

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Abstract

The experience with energy ramps during the 2009 LHC run is summarized with a particular regard on the evolution of beam parameters and the related beam loss mechanisms. Procedures, controls and software used are reviewed. Lessons learned, issues needing follow up and possible future guidelines are outlined.

HISTORICAL OF RAMPS

A total of eight energy ramps were performed during the 2009 LHC run. Table 1 collects the timestamps and the intensities at injection and at top energy of each ramp Logging of timing events was requested and made available during the run; the timestamps correspond to the "start of the ramp" event.

Important information is whether or not the magnets had been properly pre cycled, as the reproducibility of beam parameters depends critically on pre cycling the magnetic machine. This is not only true at injection, but during the ramp as well. It has to be stressed that, to ensure reproducibility during the ramp, *it is not sufficient to start with the same beam parameters at injection, if these are obtained by different sets of trims*. In general the discipline with the pre cycle was satisfactory, and only a couple of ramps (1 and 3) were done with incorrect pre cycles.

Probably the single most important ingredient was the activation or not of tune feedback and the presence of feed forward corrections to the tune trim functions. Tune feedback was off in the first 3 ramps; it was on for beam 2 only during the fourth ramp and was on for both beams during the last four ramps. Feed forward corrections for the tune evolution were implemented as well starting from the second ramp.

Table 1: History of energy ramps

#	timestamp	B1 in	B2 in	B1 out	B2 out
1	2009-11-24 00:23:08.	2.6E9		No	
2	2009-11-29 21:47:51.844	2.5E9		Lost at the end	
3	2009-11-30 00:33:16.356	2.2E9	1.25E9	1.5E9	1.9E8
4	2009-12-08 21:32:06.994	**Not**	**logged**		
5	2009-12-13 22:41:33.821	≈ 8-9E9	≈E10	≈ 8.2E9	Dumped
6	2009-12-14 02:31:30.575	≈ 9.6E9	≈1.1E10	≈ 9.6E9	≈1.1E10
7	2009-12-15 21:12:33.680	1.52E10	1.62E10	1.52E10	1.58E10
8	2009-12-16 00:49:06.019	1.15E10	1.9E10	1.15E10	1.89E10

General conditions which remained true during all the ramps were those concerning the RF, the collimation system, orbit feedback, chromaticity measurement, separation bumps, trim incorporation rules and machine protection.

The RF was ramped with feedback on the frequency (function) and on the RF phase. The RF voltage was kept constant and there was no attempt to blow up the longitudinal emittance.

The collimation system was kept at injection settings during the ramp.

The orbit feedback was off as well as the separation bumps, and there was no continuous chromaticity measurement.

The software interlock on the BPM in IP6 was masked.

Finally, all injection trims were incorporated into the ramp with constant strength.

PROCEDURE AND SOFTWARE

A dedicated beam process is used in the LSA to manage equipment settings in the form of functions for accelerating cavity frequency, magnet currents, collimator positions, etc. Settings are generated, loaded into the front ends, and then played in unison, triggered by a timing event (start of ramp); all these tasks are included in a standard sequence. The procedure starts with stored beams at injection energy; injection settings constitute the first points of the ramp functions (Actual settings in LSA parlance). Adjustments of the beam parameters are done via the trim application, and then the trims must be "incorporated" in the ramp functions to ensure continuity at the start of the ramp. The incorporation step was not included in the standard sequence and was executed manually using the Generation application.

Tune measurements during the ramp were retrieved from the logging database and used to compute corrections to be feed forwarded into the next ramp. This was accomplished by the use of a dedicated tool [1].

Fixed displays monitoring energy, intensities, losses, and the tune viewer application allowed to follow the essentials of the process in real time.

SNAPBACK CORRECTION

The snapback effect was one of the main concerns around the energy ramp, since many years [2], [3]. The FIDEL model implemented in the LSA assumed a fully developed decay (infinite waiting time before injection) and, more importantly, had been rescaled to take into account the low flat top current in the main dipoles, corresponding to 1.2 TeV. The scaling with the flat top current is part of the FIDEL parameterization. This particular dependence was based on a small set of measurements, and the extrapolation at such a low flat top current was affected by a significant error: running at such a low energy had not been anticipated at the time of the magnetic measurements that were used to establish the model. More recently a new campaign of magnetic measurements was carried out to investigate more closely the scaling of the decay and snapback amplitudes with the flat top current. Moreover, the new measurements were done with a fast rotating coil system, which is much more powerful in resolving the effect. As a result the scaling law was updated. However the correction of the snapback effect during the 2009 run was still based on the old scaling law, and this meant that according to our best knowledge, the snapback was uncorrected by about 0.2 units of b_3, corresponding to about 10 units of Q'.

LOSSES AND TRANSMISSION

The main observation to be retained is that losses were closely related to the evolution of the betatron tunes when these were crossing resonance lines in the tune diagram (see below). The main losses were located at primary collimators in IP7, also at high energy. On the first ramp, some losses were also observed at primary collimators in the momentum cleaning insertion, but this was not reproduced in subsequent ramps. On the last four ramps, transverse losses occurred just before the start of the ramp and in the first moments thereof. This is believed to be related to poor lifetime conditions before the ramp and is therefore not considered a problem of the ramp procedure in itself. On the contrary, the energy increase during the ramp appeared to reduce the losses: likely reasons of that are the adiabatic shrinking of the beam with energy, which is equivalent to a retraction of the collimators when these were left at injection settings, and the increased magnetic rigidity of the stray particles.

EVOLUTION OF BEAM PARAMETERS

Closed orbit, betatron tunes, and coupling were continuously measured during ramps; chromaticity was only occasionally measured at injection and at 1.18 TeV.

Orbit

Small closed orbit drifts were observed during the ramps: for beam 1 the mean moved of about 10 and 30 µm (H and V) and the rms increased of about 0.4 and 0.7 mm respectively. The changes were about double for beam 2 and were systematic.

It is anticipated that the increase of rms orbit will trigger the interlocks on the beam position around the dump region, which were masked during the 2009 run as we were always running with safe beams. During ramp 5 the safe beam flag was lost end the beam was dumped (see Table 1). This highlights the need of commissioning orbit feedback before increasing the intensity.

Tunes

Systematic drifts of the betatron tunes occurred, and caused beam loss through resonance crossing, during the first ramps (with no feedback and with feed forward not yet effective). Fig. 1 shows the “bare” tunes evolution for ramps 7 and 8, i.e. what the tunes would have done had the feedback system not maintained them constant.. The tune drift was systematic and different for the two beams.

At the end of each ramp, the tunes were observed to drift at constant energy (decay); and at the beginning of the ramp the tunes moved in a direction opposite to that prevailing during the ramp (snapback). The magnitude of the effect is as expected from the magnetic model.

Coupling

The evolution of coupling is shown in Fig. 2. Also this parameter displayed a systematic behaviour, different for the two beams and more pronounced for beam 2.

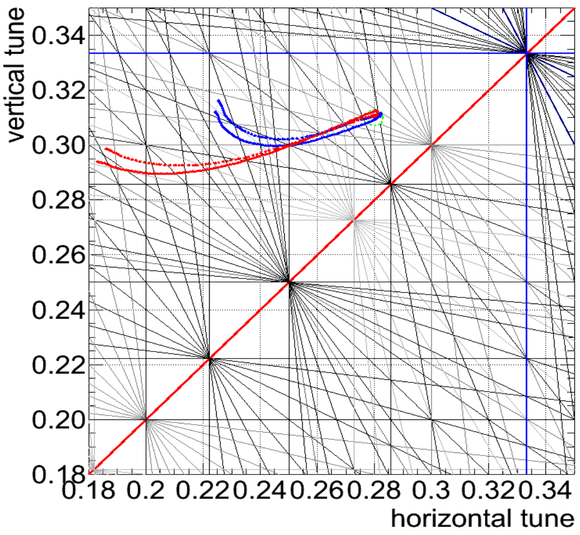

Figure 1: Reconstructed bare tunes during ramps 7 and 8: blue beam 1, red beam 2

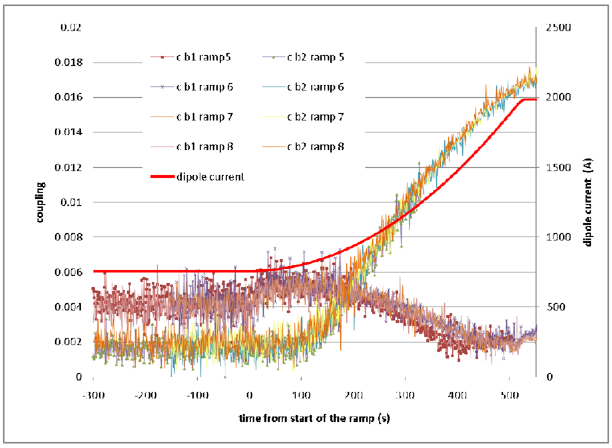

Figure 2: Coupling evolution

Chromaticity

A systematic trend to decreasing chromaticity during ramps can be seen in the measurements listed in Table 2

Table 2: Chromaticity changes between injection and top

Ramp	Beam	$\Delta Q'_H$	$\Delta Q'_V$
4	1	-6.3	-14.7
5	1	-2.7	-13.2
6	1	-3	-10.8
6	2	-9.2	-8.1

The observed drift seems compatible with the expectations from the uncorrected b_3 in the main dipoles, due to the old FIDEL scaling for the dependence of the snapback on the flat top current.

DISCUSSION

The deterministic evolution of beam parameters observed during the ramp is not fully understood. In particular, the pronounced difference between the two beams (orbit, tune and coupling drifts are much larger for beam 2) seems difficult to justify, as the main magnets do not show systematic differences between apertures, not to mention that the beams swap magnet aperture from one sector to the other.

Concerning the tune evolution, its possible sources are tracking errors (B_1/B_2), errors in the quadrupoles, or feed down from the sextupoles. The tunes move in the same direction during decay and snapback (tracking error), while they tend to split during most of the ramp.

The feed down effect from closed orbit errors in the lattice sextupoles was calculated using the measured orbit, the measured optics, and the settings of the MS circuits. The resulting quadrupole errors give rise to a tune drift during the ramp, but the value (of the order of 10^{-4}) is much too small to explain the observations.

The feed down effect from closed orbit errors in the random b_3 field of the main dipoles (which is left uncorrected as the spool piece sextupoles are connected in series) was also computed and translated into a tune drift during the ramp. The result ($\approx 10^{-3}$) also in this case is much smaller of the observed tune shift.

A third feed down effect arises from the misalignments of the MCS sextupoles with respect to the beam axis. Assuming that the MCS correct perfectly the b_3 of the dipoles, the feed down effect from the closed orbit errors is cancelled. On the other hand, if the MCS is displaced, the beam will see a quadrupole error proportional to the RCS powering and which is not outbalanced by the b_3 the dipole. This effect gives a tune shift of the right order of magnitude, but we have to assume a systematic misalignment of the spool pieces in the tunnel of the order of a fraction of mm, implying a change of shape of the installed cold masses.

A further possible source of feed down from sextupoles is the non perfect correction of the static b_3 of the dipole (MCS tracking from FIDEL, same as for the chromaticity drifts).

Finally, warm quadrupole calibration errors, which might explain the observed beta beat change between injection and 1.18 TeV, would also give a tune shift of the same order of magnitude as the one observed.

CONCLUSION AND OPEN ISSUES

Overall, ramping the LHC was easier than anticipated. Already on the second attempt, beam was accelerated from 0.45 to 1.18 TeV.

Beam losses were mainly due to tune shifts during the ramp which brought the tunes to cross resonance lines. The main losses were located at the primary collimators during all the ramps.

Once the tune feedback was operational, the beam transmission from injection to high energy was excellent.

The origin of betatron tunes evolution during the ramp, as well as the drifts of other beam parameters, is not fully clear and would need to be further investigated, possibly with dedicated experiments with beam.

For future runs, an updated FIDEL model, incorporating the best estimate of the snapback correction, will be deployed. This should reduce the chromaticity drift.

In general, transfer function updates will have to be tested on the bare machine, removing the empirical trims.

Obit feedback, at least in collimation and dump regions, is one of the preconditions to increase the intensity above the safe beam limit. Also, orbit stabilization will help clarifying the origin of the tune drifts.

Longitudinal emittance blow up still needs to be commissioned, as well as ramping with the separation bumps.

On the procedural side, the trim incorporation step should be integrated in the nominal LHC sequence.

Finally, logging of beam parameters should be linked to the machine mode and the filtering policy reviewed.

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