

# TURNAROUND ANALYSIS

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## Abstract

The machine turnaround was defined and analysed focusing on operational efficiency in a “fault-free” machine. Statistics of spent times in the different operational phases were collected on homogeneous sets of fills. Possible improvements considered include merging energy ramp and beta squeeze, a different handling of the chromaticity correction on the flat top, and reducing the ramp down time from high energy.

## TURNAROUND DEFINITIONS

Machine turnaround can be looked at from different perspectives. From the point of view of the users, what really counts is the average time it takes to get back to stable beams after a beam dump. This number is needed to formulate forecasts of future integrated luminosities. For the LHC 2011 run, the turnaround times defined in this way are shown in Fig. 1. Interestingly, only a very small fraction of fills reached turnaround times of the order of two hours, approaching the theoretical minimum. Data were extracted with a top cut at 24 hours, but already from this view, one can readily see that the actual turnaround time is dominated by the machine availability. Long recovery times from hardware faults shadow totally operational inefficiencies and systematic bottlenecks that might be present.

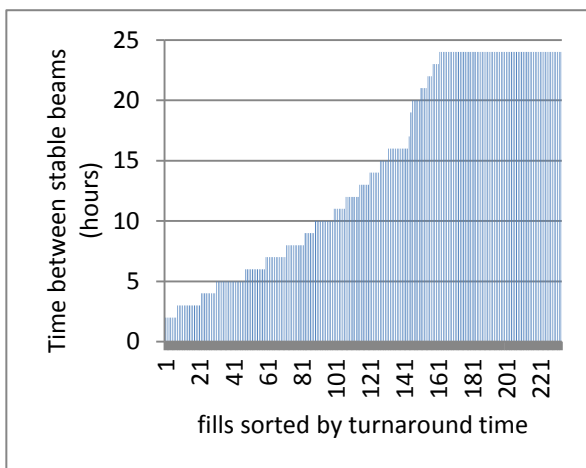


Figure 1: Turnaround times between stable beams.

From the operations standpoint however, a more precise assessment on the process intrinsic efficiency is important in order to continue optimizing sequences and procedures. Speed should not be pursued at the expense of careful beam preparation. On the other hand, a continuous effort should be made to minimize the time spent with high intensity beams stored at injection energy, where emittance blow up is most severe. Moreover, the

LHC is of course dependent on the availability of the whole chain of injectors only during the injection phase, and becomes insensitive to faults of some of its own systems, once the stable beams phase has been reached.

To study operational efficiency, a definition of turnaround independent on downtime due to major hardware faults is more adequate. In what follows, the turnaround time is defined as the sum of the times spent over all the beam modes of a normal cycle, computed from the start of injections. The time needed to ramp down the magnets is then added, knowing that all the preparation after a clean beam dump should be made in the shadow of the ramp down. The method yields an optimistic estimate of the operational efficiency, as it does not catch inefficiencies in the preparation phase without beam. This is apparent by inspection of Fig. 2, which shows the distribution of turnaround times computed according to the above definition. Fills of 1380 bunches with beta squeeze down to 1 m were considered in the analysis. The average turnaround time falls down to 185 minutes, with a minimum of 106 minutes

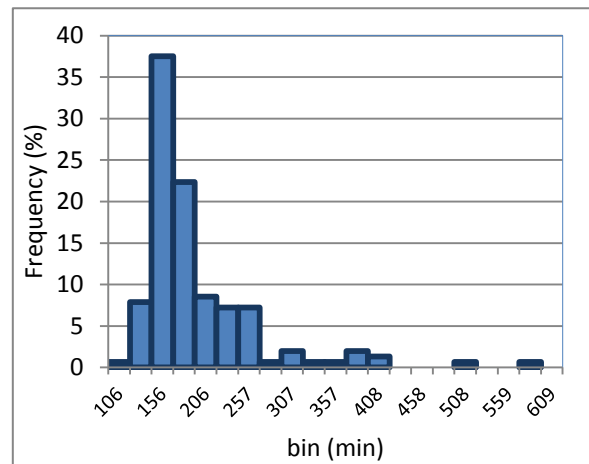


Figure 2: Distribution of operational turnaround times.

## IMPROVEMENTS SINCE LAST YEAR

With respect to the 2010 run several improvements were implemented and are discussed herewith:

### Chromaticity correction

The correction of chromaticity on the flat bottom used to be one of the bottlenecks of the operational cycle in 2010. Due to the long decay time constants it was necessary to wait at least half an hour with the pilot circulating, in order to make sure that the decay would be sufficiently small during the subsequent injections of high intensity beam, when the chromaticity cannot be measured. A first FIDEL dynamic correction was put in place in April 2011, but with fixed parameters. The powering history

introduced a spread in the decay strength which was not taken into account. This resulted in either overcorrection or under-correction, and the sign of the decay was not known in advance. In May 2011, the powering history started to be used to get the parameters of the dynamic correction. The resulting excellent stability of the chromaticity at injection (within one unit) allowed being confident enough to inject high intensity beam after adjusting  $Q'$  with a static trim.

### Injection improvements

The analysis done last year [1] had pointed at the injection phase as one of the most promising possibilities to improve the turnaround time. Some details in the mechanics of the injections caused unnecessary delays and were corrected for the 2011 run. We introduced the possibility to inject in one of the rings while the outcome of the previous injection in the other ring was analysed, and even if the result of the latter was bad. The Injection Quality Checks tool was made more flexible as well: BLM thresholds and the policy to handle their occasional overcome were both modified, in such a way to make the whole process much smoother. The reading of the Beam Current Transformer in the transfer lines and that of the Beam Quality Monitor in the LHC were subjected to a consistency check which helped to avoid spurious triggers of the IQC. Moreover, differently from last year, pilot over injection was either eliminated (keeping the pilot bunch circulating in the physics beam), or the over injection was moved to a stage when high intensity beam is already present. This avoided losing time whenever the over-injection process did not succeed, as it was no longer necessary to switch SPS super cycle in such a case. The main problem of injecting high intensity beams in the LHC in 2011, however, was the instability of the transfer lines, which is the subject of a separate contribution [2]

### Optimization of power converter functions

The duration of the energy ramp was reduced with respect to 2010 by increasing the initial current acceleration. The full available voltage of the main power converters could therefore be exploited starting from earlier in the ramp. As a result the ramp duration passed from 1400 to 1020 s. Moreover the removal of the parallel beam separation was in part anticipated to the energy ramp, profiting from the natural reduction of the beam size with energy. This allowed gaining 52 s in the final collision process. Finally, the squeeze functions were optimized and the total squeeze duration was reduced from 1041 s to 548 s.

### Other improvements

Less quantifiable but not less important were the efficiency gains which resulted from the introduction of dynamic references for the feedbacks. The need for human intervention was reduced and with that the risks of errors. Generally speaking, the automation of sequences progressed beyond the already high levels of last year. A short access procedure allowed restarting the machine without pre cycle under specific conditions [3]

## STATISTICS OF OPERATIONAL PHASES

The standard LHC cycle is displayed in Fig. 3 for reference. As discussed, it is assumed that the setup without beam can take place entirely during the ramp down of the magnet circuits, so the correspondent beam modes are grouped together.

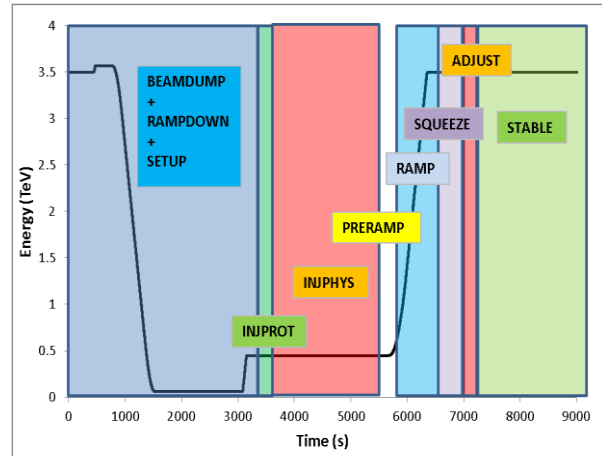


Figure 3: Operational phases.

For each mode, detailed statistics of the times spent were collected on the samples described above. As an example Fig. 4 shows the distribution of the times spent injecting the physics beams with 1380 bunches.

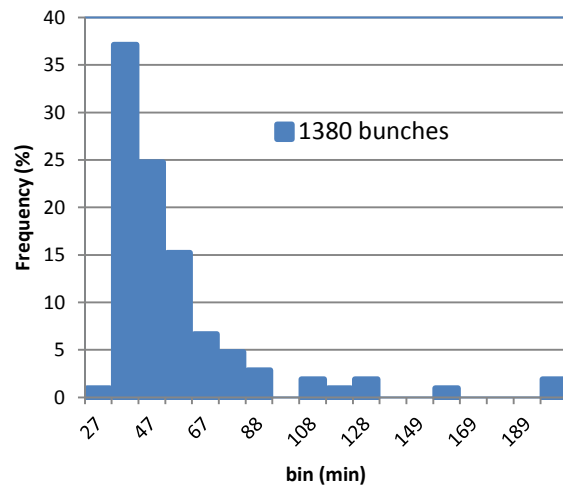


Figure 4: Injection statistics.

The minimum theoretical time for each mode was defined, in some cases making some assumptions for the tasks which were not precisely determined. For instance, setting up the machine with pilots was deemed to take 5 minutes in optimal conditions, while it was considered that injecting the high intensity beams requires at least 32 SPS super-cycles (of which 24 are used actually inject in the LHC, and the rest are used by the SPS crews to check the beam parameters). For the ADJUST phase, when the beams are collided and the luminosity is optimized, it was considered as a standard to carry out the optimization of

ATLAS and CMS luminosities, and to bring LHCb luminosity in the levelling range before declaring stable beams.

Beam mode	Theoretical (s)	Min. achieved (s)	Mean achieved (s)
BEAMDUMP + RAMPDOWN+ SETUP	2490	2490	n. a.*
INPRO 1092	300	336	2206
INPRO 1380	300	206*	2205
INPHYS 1092	1574	1249*	2731
INPHYS 1380	1574	1599	3034
PRERAMP	120	126	270
RAMP	1020	1026	1088
FLATTOP	0	13	130
SQUEEZE 1.5 m	475	558	655
SQUEEZE 1 m	548	663	846
ADJUST	270	270	654
TOTAL (1380b, 1m)	1h 45'	2h 07'	3h (**)

Figure 5: Summary table of mode statistics.

The table above summarizes the statistics. The main thing to be noticed is that the injection phase dominates the overtimes. The minimum turnaround achieved between stable beams was 2 hours and 7 minutes. The average turnaround was still a factor two higher than the theoretical minimum. As it is visible in Fig. 5 this factor comes mainly from the injection process.

Smaller time savings could still be gained by increasing task parallelization in the sequence, and by standardizing manual operation proceedings.

## POSSIBLE IMPROVEMENTS

### Chromaticity correction at top energy

At the end of the energy ramp, the b3 component of the main dipole field continues to decay. Since the decay amplitude scales with energy, the correspondent chromaticity change is much less than at injection. Still, the phenomenon caused beam dumps in 2010. An empirical correction was then put in place, using the lattice chromaticity knobs. This worked well, but prolonged the energy ramp by 6 minutes, as the lattices sextupoles, which are needed for the squeeze, are busy correcting the chromaticity decay. A better solution would be letting the spool pieces sextupoles to take care of the decay as they do at injection. These magnets are not used during the squeeze, so the process can continue in the background with no need to stop at the end of the ramp. Detailed implementation solutions are under study at the time of writing.

### Ramp and Squeeze

The possibility of combining ramp and squeeze was studied in 2011 in MD sessions. The baseline for 2011 was to squeeze during the ramp IP1 and IP5 to 3.5 m, and IP8 to 3 m. The gain in time was quantified in ~ 400 s [4]. The time gain scales with energy, making this solution more interesting in the long term. Settings were produced

and dry runs were successfully carried out, whereas tests with beam could not be done due to machine unavailability at the assigned MD slot. Some more work was still needed to generate settings for the tertiary collimators. After discussions, it was decided to run in 2012 still with separated ramp and squeeze.

### Fast ramp down

The duration of the ramp down is limited by the unipolar power converters for the independently powered quadrupoles. The possibility of a faster ramp down had been investigated at the end of 2010 [3], and hardware type tests were carried out in 2011.

Fig. 6 shows the fast ramp down of the RQ4.R2 circuit, which is the slowest magnet in the machine. Tests with the inner triplets (the next bottleneck) confirmed that it would be actually possible to save 11 minutes on the ramp down. The solution will be tested systematically in the 2012 re-commissioning campaign.

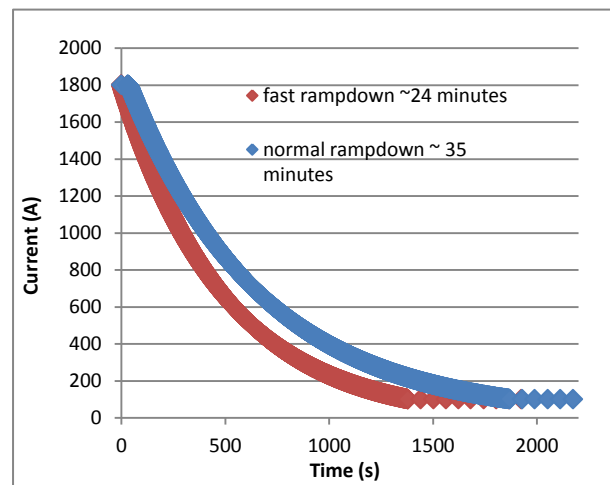


Figure 6: Fast ramp down of RQ4.R2.

## CONCLUSIONS

The actual machine turnaround is dominated by hardware faults, and, secondly, by the chances of the injection phase. Significant improvements in the operational efficiency were already obtained in 2011 with respect to the previous year. The shortest turnaround time was closer to the theoretical minimum than in 2010. Following the three possible improvements described in this paper, the theoretical minima could still be decreased by about 23 minutes.

## REFERENCES

- [1] S. Redaelli, Evian 2010
- [2] L. Norderhaug Drosdal, this workshop
- [3] W. Venturini Delsolaro, Chamonix 2011
- [4] S. Redaelli and N. Ryckx, Priv. Comm.