LHC OPERATION

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Abstract

The time spent in Operations in 2017 was about 30% of the total time for physics, much larger than what achieved in previous years. This is analysed and possible causes drawn. Operations is then split in its separate phases and some considerations and suggestions for optimization are proposed.

DATA MINING

The machine time breakdown, which is now routinely used to draw the availability statistics [1], considers four modes: *Stable Beams, pre-cycle, fault/downtime* and *operations*. The *operations* phase is that part of the time spent in manipulating the machine to put the beams in physics. In absence of faults it is essentially the time between the dump of a fill and the moment when a new one is set in Stable Beams. Statistics show that in 2017 *operations* took 30% of the machine time, while in 2016 this value was at 23%. Such an increase is mainly explainable with the increased number of cycles and the interruptions caused by the 16L2 problem [2].

For what concerns the data mining, the analysis which follows is mainly based on the machine modes, but not only (e.g. *Beam Dump* is just before *Ramp Down*, but one might have dumped and not changed the status). All MDs and other non-operational periods are removed from the statistics; the intervals considered in the analysis are (see Figure 1):

- from end of scrubbing to MD1 (commissioning excluded);
- from end of TS1 to MD2 (excluding the 50 ns tests);
- from end of VdM scans to MD3;
- from end of TS2 to end of run, excluding the Xe run and few days of setup of the special runs.

For the filling time, only fills above 1500 bunches have been considered.

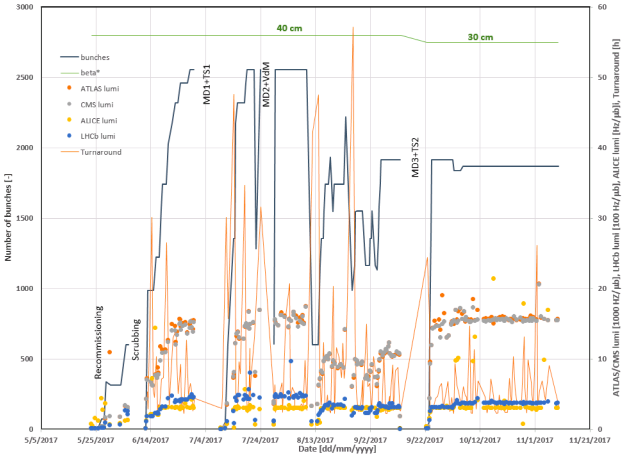

Figure 1: Machine parameters for the operation in 2017, in particular turnaround time (solid orange line), experimental luminosities β* and number of bunches along the year.

SPLITTING THE CYCLE

To understand the machine performance and possible management improvements or degradation, we now split the operational cycle into all its phases. The statistical values are shown in Table 1 for each of these phases.

Beam dump to ramp-down

The time spent in bringing the machine back to injection after the dump of a previous fill is somehow a physiological time, on which one cannot gain much.

In case of premature dump, some time is often needed to analyse the dump (*beam lost to beam dump* in the table), if one doesn't want to lose important information, above all when some circuits tripped or a system is faulty. To reduce this time, equipment owners could possibly work in providing more diagnostic tools.

Some time is also lost due to breakpoints in the sequences (i.e. XPOC check or MKI soft-start) and some gain could come from parallelizing all non-critical steps like checks.

	BEAM LOST TO BD	**BD TO RD**	**RD TO INJ**	**PILOT INJ & SETUP**	**FILLING TO PREP.RAMP**	**INJ-END TO RAMP**	**RAMP TO FT**	**RAMP TO SQUEEZE**	**SQUEEZE TO ADJ. 40 CM**	**SQUEEZE TO ADJ. 30 CM**	**COLLIDE**
MEDIAN	00:02:01	00:00:36	00:58:05	00:15:46	00:39:00	00:03:51	00:20:22	00:24:47	00:08:15	00:14:23	00:07:55
AVERAGE	00:04:25	00:01:57	02:31:16	00:18:57	00:58:09	00:04:58	00:20:27	02:01:00	00:12:17	00:18:04	01:56:48
STDEV	00:05:46	00:05:09	04:14:19	00:12:30	00:59:08	00:12:01	00:00:42	04:53:13	00:36:56	00:19:35	05:00:44
MIN	00:00:03	00:00:04	00:35:53	00:03:15	00:24:44	00:02:18	00:20:14	00:23:07	00:08:11	00:13:23	00:03:18
MAX	00:24:01	00:56:12	32:55:32	01:25:43	07:05:53	03:13:28	00:30:55	29:32:24	07:06:13	02:22:18	39:18:37

Table 1: Time spent in each phase of the machine cycle.

Ramp-down to injection

This is obviously the period most affected by faults, mainly appearing in physics. In particular big faults (18 kV transformer, cryogenics, LBDS,..), even if not extremely long in 2017, dominate the average: the excess average 2h account for about 17% of the total machine time!

The median is also very large (25 min more than the minimum needed time), because of the many small faults, sometimes requiring investigation by experts and possibly access. Another reason for the large median is the pre-cycle of few tripping elements (not declared as *precycle*) and of the EIS (= éléments importants de sécurité): access for the experiments is sometime asked during the ramp-down as declared in the shadow, but then requiring the pre-cycle of the EIS. No beam from injectors or beam being set up is an additional reason for it.

For what concerns the ramp-down, it is fixed and limited by the slowest elements: the individually powered quadrupoles are presently in the shadow of the inner triplets (IT.L2 is the slowest and it is ~6 min longer than the RQ4.R2, accounting for 0.8% of the "lost" time; one could think about a major modification though when the median reaches the min time).

Again, some time is lost during the ramp-down due to trips of circuits, mainly 600 A due to 0-V crossing: these are nevertheless most a concern of MPE for the energy extraction maintenance, since they are not pre-cycled after a trip. This could be improved by tuning the ramp rate, but it requires time and the commissioning period is typically short.

The preparation of the machine during ramp-down is often parallelized by-hand to avoid discovering issues at the last moment, but this might be sometimes not appropriate as not all tasks can be run in parallel. Things could be better with an increased parallelism in the sequencer. An additional improvement could come from an automatic selection of the MKI soft-start (i.e. waiting time and length of the soft-start automatically selected and started, with operator's approval), as this would avoid mistakes and improve efficacy (too many times it was not done when ready to inject!). Last, the injection handshake should be earlier in the preparation, as this could save time, realizing earlier that the experiments are not ready.

Injection of pilots and set up

The statistics for this phase is based only on cases where the previous dump energy was above 450 GeV (so that we exclude cases where the machine is already set up at injection).

Problems in this phase are a repetition of the issues of the previous part (handshake, MKI soft-start, missing beam from injectors, tripping circuits). In addition, sometimes the injection is missed due to uncaught interlocks (missing PM signature, QPS not OK): an automatic check could be included in the *Machine State*.

A common reason for delay at injection are also the injection oscillations with the pilots: they should not latch the IQC and could be maybe more often fed-forward into the orbit.

Quite some time is finally needed to measure tune, chromaticity and coupling: even if all is now in a single application, they are long measurements, above all for the coupling where the algorithm should be made faster.

Filling to Prepare Ramp

In this case, the statistics is based only on cases where injecting more than 1500 bunches.

The most common reason for an average much longer than the median are:

- missing injections, due to beam quality in the injectors;

- injection scheme mixing, requiring the change of SPS cycle, often with re-verification;
- steering of the transfer lines;
- wrong chroma/octupoles settings, leading to blow-up (discussions are ongoing to automatically set the value from LSA);
- wirescans, even if not mandatory (this is planned to be fixed by automatizing them);
- the stability of 8b4e seems to be worse (or it is more difficult to tune, or there is less experience in the injectors with this beam).

On the longest period in the statistics, a series of problems (missing XPOC data, BPMs@6 triggering, kicker fault, steering, wrong settings) were at the origin of more than 7 hours of time needed, while it is interesting to observe that the shortest one was during a fill for physics with 1868b done overnight.

From end of injection to flattop

This phase is composed by two parts. The first one is where we setup the machine after injecting and the other where we execute the ramp. For the setup, it takes about 5 min to move the collimators, close the handshake, incorporate and load all power converters functions. Definitely, one could profit from parallelism of tasks (people are already parallelizing, with the risk of mistakes) and also executing most of the steps while filling (all but collimators, incorporation of spools and handshake).

For what concerns the ramp, in the future the time lost will be less thanks to a new and shorter ramp(&squeeze): tested in MD in 2017, could allow saving about 2 min; a bit of time will have to be invested during commissioning, but it will be transparent with respect to the rest.

The longest *prepare ramp to ramp* was dominated by a collimator triggering at the preparation of the ramp, but also by wrong masking/SBF status. An automatic set of masks could be included in the sequencer, according to the operational state (working with pilot or nominal bunches, during MD, etc.). Alternatively, one could populate the sequences of warning messages.

Squeeze to Adjust

The tune change before squeeze takes typically between 2 and 4 minutes. To save part of this time, it could be included in the R&S or moved to the end of the squeeze.

The squeeze itself has a physiological length, which cannot be shortened, apart merging the two segments from 1 m to 40 cm and from 40 cm down to 30 cm.

Collide

The approach to this phase should be maybe more systematic, as different persons declare Stable Beams in different moments, depending on whether they optimize the luminosities before of afterwards. As a baseline, one should declare Stable Beams as soon as possible.

In addition, conditions changed several times during the year. For example, in 2017, for IP1 and 5, the strategy used was to optimize the 2 planes and then separate to reduce the luminosities to the target values; in 2018, a strategy similar to the one used for the other experiments could be used, which foresees a preventive separation. This would allow saving few minutes in declaring SB (1 plane less to optimize and no waiting time to steer down).

COMBINING ALL DATA

Wrapping up

Summarizing the data above, one can compare the performance across all years of Run II, as shown in Table 2. The performance is essentially constant throughout all years.

Beam modes	**2015**	**2016**	**2017**
Beam dump	n.a.	n.a.	2.6
Ramp-down	n.a.	n.a.	58.1
Injection probe	14.7	15.7	15.8
Injection Physics	34.9	36.7	39.0
Prepare Ramp	5.4	4.9	3.9
Ramp	20.4	20.5	20.4
Flat Top (Q change)	5.9	5.6	4.3
Squeeze	14.1	18.1	14.4
Adjust	13.7	16.1	7.9

Table 2: Median times spent in the different phases of operation, compared with previous years (all values expressed in min).

Turnaround time and ideal cycle

In particular, one can calculate the turnaround time and the ideal length of a cycle. Considering only fills with more than 1500 bunches for the calculation of the turnaround, the median value obtained is very good, but the average is almost the double, strongly biased by the big faults (16L2 first of all).

Median	4:41:28
Average	7:33:19
StDev	8:25:55
Min	2:12:42
Max	57:06:19

Table 3: Turnaround time values, calculated on fills with more than 1500 bunches only.

If we combine the minimum time spent in each phase, one can then get an ideal (real) cycle length, which is 1h47m28s.

THE IMPACT OF 16L2

The troubles caused by the defect in position 16L2 are pretty evident from the dump statistics: in 2017, 52 out of 277 fills did not reach the end of the ramp; many of them were lost because of the 16L2 problem. In fact, 31 dumps before the squeeze (59 in total) are recorded in AFT as caused by 16L2.

In addition, the longest period with beams constantly dumped on the ramp was almost 30h and, in other four cases, this period was above 16h.

Time was also spent in studies aimed at finding a different working point and at least 2 long fills of scrubbing were performed to mitigate its effects. Multiple filling schemes were used and time was lost in setting them up.

Definitely, the impact of 16L2 on machine availability and performance was important.

DEALING WITH IT

Managing the faults: diagnostics and access

One of the most recurrent risks during the occurrence of a fault is that a problem could hide another one. Typically, after a quench/trip, a secondary problem might appear, which is important to discover soon and not only after the recovery. That's why all circuits should be prepared as soon as conditions allow. An option to be investigated could be the removal of the Global Protection Mechanism in case of need, to speed up the recovery of the small circuits in case of problems on the big ones. MPE is already discussing about de-activating it at injection from after LS2.

In general, the machine should be prepared as soon as possible to avoid bad surprises from other systems. In addition, some improvement on the diagnostics of some equipment could be done and automatic entries in the equipment logbook suggesting who to call/ what to do, could be of valuable help.

Finally, the question is often raised if the tunnel accesses are always prepared when needed or all circuits are switched off uselessly when not needed. In fact, an inefficient preparation of an access might cost much more than the access itself. If the individual knowledge of the underground areas is not enough, the Layout DB is always a valuable option.

Interlocks and masks

Among the operational mistakes in 2017, 8 out of 11 were due to the *SETUP* beam flag forced to *UNSAFE* with active interlocks during commissioning. Only 2 of them above injection energy.

Other mistakes came from settings issues: 4/12 due to *pilot* intensity too high (left over from the previous fill), 2 during physics production (ALICE trims).

Most of the OP mistakes appeared when switching from the OP sequence to special ones (i.e. trying to inject a pilot with forced beam flag). Automatic (un)masking by the sequencer could come in help.

Managing the communication

Communication, between CCC islands and coordinators is a critical topic. Checking the status of the injectors before dumping is now automatic, but the injectors are not always aware of the requested beam, which means that they are sometimes not ready with the proper beam when the time to inject comes. A closer collaboration between the different machines and coordinators should be envisaged. A (careful) use of the mailing lists would be certainly appreciated by the teams on shift, which cannot always take part in the 8:30 meeting (and, often, post meeting).

CONCLUDING REMARKS

After a lot of work done in the past years, it seems that "operation" performance is levelled in the last triennium. Still something could be gained, but not much from settings and hardware. A lot with some rigorousness and improved diagnostics plus procedures.

In addition, one should maybe try to be more conservative and less inventive along the year with parameters, beam type, etc: a remarkable example is the luminosity production during the last period.

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REFERENCES

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[2] L. Mether, "16L2: Operation, observations and physics aspects", same proceedings.