HOW CAN WE REDUCE THE "NO BEAM" TIME?

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Abstract

The operational efficiency of the LHC is analyzed by looking at the downtime statistics over the 2010 run. Hardware reliability is reviewed along with the mitigation actions put in place for the 2011 run. Recovery, duration and frequency of scheduled technical stops are also discussed. Finally, possible ways to reduce the setup time without beam are considered.

INTRODUCTION

The first year of LHC operations was dominated by a commissioning program aimed at establishing collisions at 3.5 TeV, and then pushing on the beam parameters (β^* and beam intensity), to reach peak luminosities in excess of 10^{32} cm^{-2} s^{-1}. Furthermore, despite clear focusing on commissioning, a significant set of data was delivered to the experiments. Here, starting from the assessment of the operational efficiency reached in 2010, possible ways of increasing the beam time in the future runs will be elaborated along three lines. Actually the time without beam can be split into three components: downtime due to faults, scheduled technical stops, and operational inefficiencies.

Fault statistics were analysed to highlight the top 5 systems responsible for downtime. For each of them, the mitigating actions undertaken will be outlined.

The scheduling of technical stops will be reviewed with a critical look.

Finally, the optimization of the phases without beam in the LHC cycle will be addressed, while the phases with beam are dealt with in a separate contribution [1]

MACHINE STATISTICS 2010

The machine statistics for 2010 were collected by inspection of the e-logbook. Each of the 6600 hours in the time span considered (March-November) was attributed (with an average time resolution of half an hour) to one of the following machine states: setup without beam, beam setup, stable beams, technical stop, and fault (machine not available due to some system fault). Time spent in supplementary hardware commissioning was included in technical stops, while the recycling time occasioned by faults was ascribed to the faulty system. As the information in the e-logbook by its nature is only a human reporting of a much richer scene, one should not expect extremely high accuracy from these figures, the aim of which was just to identify the major causes of downtime, thereby setting priorities for consolidation work. Several effects limit the accuracy of the time breakdown. The finite time resolution leads to an overestimation of the beam presence, as easily recovered problems, for instance small software bugs, go unnoticed no matter how frequent they may be.

Multiple faults are problematic as the criterion of attributing the downtime to the "leading" faulty system, i.e. the bottleneck, is not always of easy application.

Also, beam presence may coexist with stalled situations, typically when handling software issues.

The machine statistics for 2010 are shown in Fig. 1

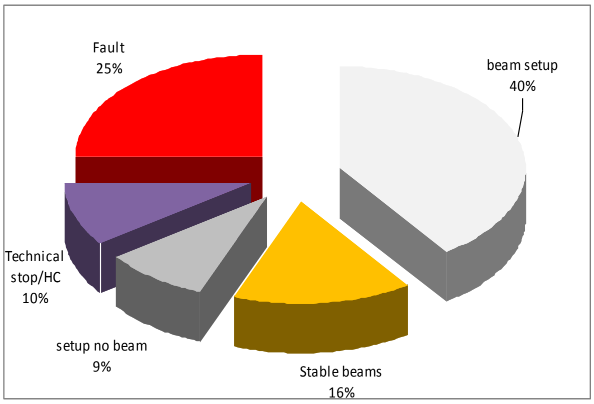

Fig. 1 Global 2010 machine statistics

The overall machine availability, as given by the sum of the setup without beam, beam setup and stable beam times, was 65% of the total time. The downtime due to faults reached 25%. The scheduled technical stops covered the remaining 10%. Setup with beam dominated, as expected for a commissioning year.

More insight can be gained by looking at the time evolution over the run of the time breakdown slices, displayed in Figs. 2-5.

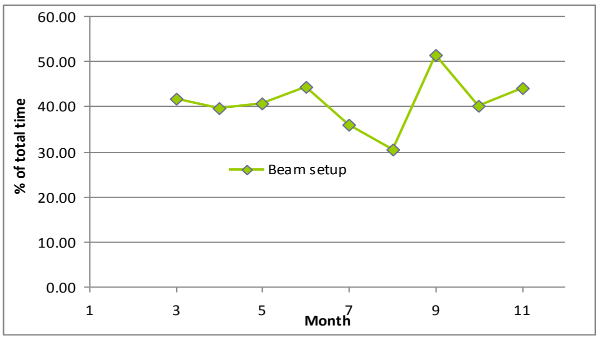

Fig. 2 Beam setup fraction along the run

The fraction of beam setup shows two maxima: in June and in September, when intense beam commissioning was concentrated. Correspondingly, the fraction of stable beams was a minimum (Fig. 3).

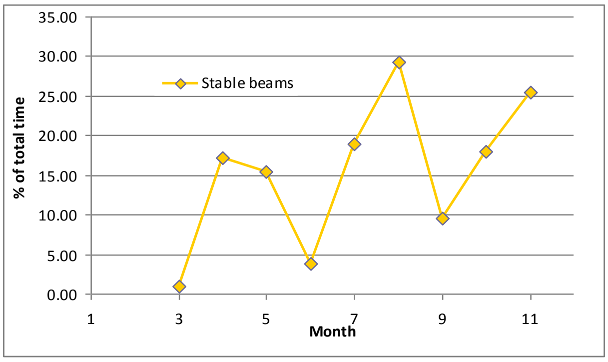

Fig. 3 Stable beams fraction along the run

The machine availability grew steadily during the run, reaching the record value of 80% during the ion run in November (Fig. 4)

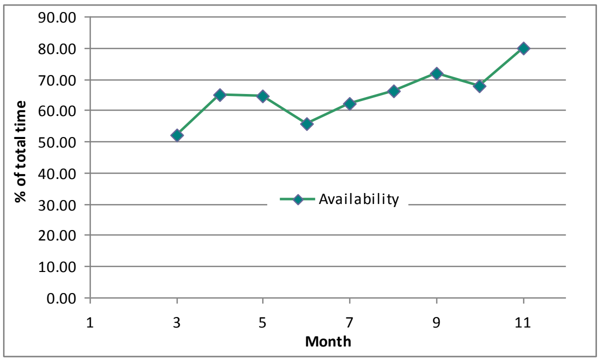

Fig. 4 Machine availability along the run

Finally, the downtime due to faults seemed to level off at around 20% towards the end of the run, which seems to indicate that further increase of the machine availability would have been unlikely (Fig. 5).

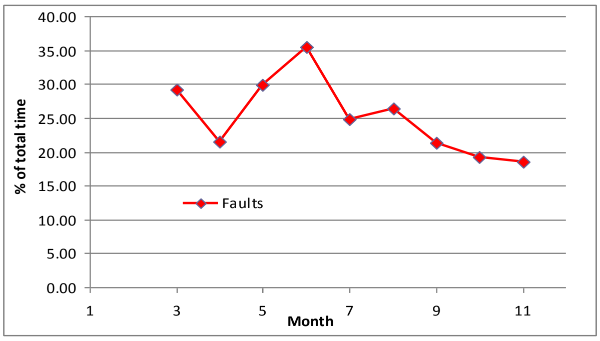

Fig. 5 Fault downtime evolution along the run

Several considerations on efficiency for physics can be made based on these data. One should distinguish between machine efficiency and operational efficiency. In all cases we consider the useful time to be the one spent in stable beams. Operational efficiency can be defined with respect to the minimum turnaround time, while machine efficiency must include all the machine non availabilities. Luminosity forecasts are usually based on the so-called Hübner factor, which accounts for machine efficiency and luminosity lifetime.

In the last two weeks of August 2010 the only aim of the operations crews was to deliver collisions to the experiments. During that time, the operational efficiency was 50%, while achieving systematically the minimum turnaround time would have brought that figure up to 83%. Finally, all estimates being based on short periods, it is advised to assume Hübner factors in the 0.2 – 0.3 range when trying to anticipate the 2011 luminosity harvest.

FAULTS AND MITIGATION ACTIONS

As shown in Fig. 6, about 70% of all the downtime due to faults was due to the "top 5 systems": QPS, cryogenics, power converters, electrical supply (network perturbations), and injectors. The latter are covered in [2].

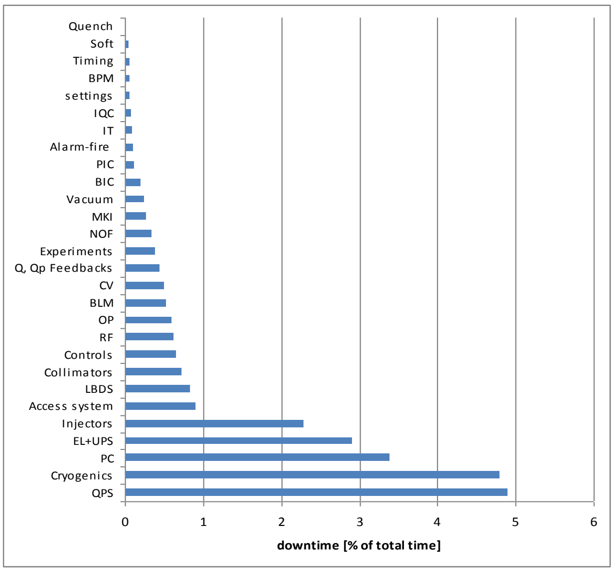

Fig. 6 histogram of LHC fault downtime

QPS detailed statistics and mitigating actions

Almost 5% of the runtime was taken by failures of the Quench Protection System. This is no surprise given its complexity. Table 1 gives a breakdown of the faults per subsystem, highlighting very high availabilities.

The majority of QPS faults were due to the failure of a single component, an input switch of the quench heater power supply. The switch was redesigned and after validation of the new version, replacement of some 5000 items in the tunnel has started. About 20% of them, serving for the main quadrupoles, will be changed during the 2010/11 winter stop. The quench heater circuits for dipoles, differently from quadrupoles, are redundant, and a single failure of this kind will not lead to a beam stop.

Equipment type	Faults	Quantity	Availability [%]	MTBF [hours]
Quench heater power supplies	26	6076	99.998	1145760
Quench detection systems	19	10438	99.999	3362135
DAQ caused by radiation (SEU)	12	1624	99.997	828240
DAQ other causes than radiation	8	2532	99.999	1936980
EE600	6	202	99.988	206040
EE13 kA	5	32	99.939	39168

Table 1 Detailed QPS faults statistics

Also, the quench detection system will be made more robust against electromagnetic interference, by removing the obsolete global bus bar detector for the main circuits, by increasing the signal to noise ratio for Q9 and Q10, and by re cabling the current sensor of the undulators.

Finally, the firmware of the systems most exposed to radiation will be upgraded to cope with SEU [3].

Cryogenics downtime and mitigation

Failures in the cryogenics systems come as the second cause of downtime. This is not driven by the fault frequency but rather by the fact that some cryogenics faults, typically those involving the cold compressors, have very long recovery times. The cold compressors were consolidated over the winter stop and new instrumentation was added to prevent unnecessary trips.

The long lasting issue of sub atmospheric filters clogging was addressed during the year; the last leaks were found and repaired during the end of the year stop. This issue had dictated the frequency of the technical stops in the past, as the filters needed regular de-icing.

A huge campaign to replace the regulation valves for the flow control on the current leads has reached 50% of all valves replaced, and no major contribution to the downtime is expected now from this particular issue.

Instrumentation failures were as well tackled during the winter stop. However the large number of gauges will still imply failures impacting the machine availability in 2011.

Finally, the decision to reduce to a minimum preventive maintenance in the winter stop is likely to bring as a consequence some additional faults, which the cryogenics team estimate in 2-5 events for the next run [4].

Power converters

The detailed fault statistics of the power converters is documented in [5]. Fig. 7 shows the number of faults occurred for the various converter typologies. Most problems affecting the statistics were fixed during the first part of the run and did not reappear. The main concern was given by the 600A circuits, where 70 faults have occurred, most of which not understood. The types of fault leading to a converter stop have been reviewed for the 2011 run; most faults occurred in 2010 in the 600 A converters will be downgraded to warnings, not leading to a beam dump [6].

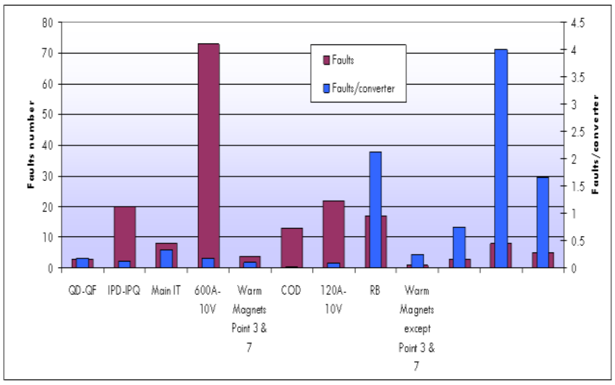

Fig. 7 Power converter faults, absolute and normalized

Electrical perturbations

The LHC is particularly sensitive to electrical perturbations from the supply network. Fig. 8 shows all the events which have shut down the collider in 2010. The innermost rectangle (zone specified in EDMS 113154) defines events which may occur during the normal operation of the network, to which the other CERN accelerators are not sensitive. The dashed region defines the LHC sensitivity area. The weak point is in the warm magnets circuits. Fast current changes are interlocked with the beam dump for machine protection purposes, and filtering is made difficult by the high power involved. The cryogenics were sensitive to electrical perturbations at the start of the run, but later on the cryogenics team managed to increase their immunity. No further improvements in this area are expected for 2011.

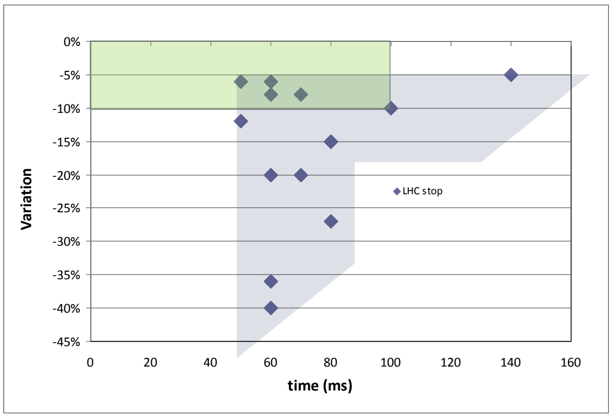

Fig. 8 Electrical perturbations leading to LHC stop [7]

TECHNICAL STOPS

During the 2010 run the LHC was stopped for six times for scheduled maintenance activities. The average duration of technical stops was 4 days, and the average spacing was 39 days.

The philosophy of preventive maintenance is to invest some runtime in order to increase the overall availability. It is therefore important to tune frequency and duration of the scheduled stops to balance costs and benefits.

Data seem to indicate that in 2010 the two parameters were not well optimized. For instance, considering a period of 72 hours and comparing the downtime due to faults before and after each technical stop, it is clear that the effect of the first three stops was detrimental to the machine availability. More problems were created by the many interventions in the tunnel than were actually solved. The effect was gradually reabsorbed in the course of the year, as shown in Fig. 9.

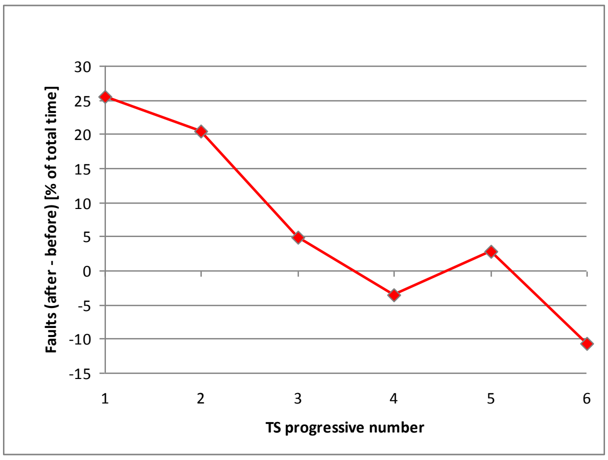

Fig. 9 Increment of faults after technical stops

A preliminary survey of the equipment groups has indicated a preference for longer but less frequent stops. However this might be difficult to accommodate, especially in view of the heavy machine development programs for the injectors, which are scheduled during LHC maintenance periods.

SET UP TIME WITHOUT BEAM

Ramp down times of unipolar power converters

The theoretical minimum turnaround time of the LHC is determined by the durations of the beam processes that compose the operational cycle. These in turn are limited by the voltage ratings of the power converters. In particular, unipolar power converters, supplying several types of quadrupole circuits, cannot provide negative voltages. This fact limits, in some cases severely, the ramp down speed. The times to ramp down the Q4 circuits from 3.5 TeV to injection are shown in Fig. 10. The figures in the plot do not include the time needed to complete the ramp, without overshoot, within the very strict specifications for the LHC power converters: in the case of the RQ4.R2 circuit, which is the slowest circuit of the LHC, soft landing takes about 10 additional minutes, just to bring the circuit from 100.3 A to 100 A. Note that the ramp down times for a given circuit type vary as a function of the warm cables resistance. In some locations the warm cables are shorter, and this trivial circumstance costs more than 10 minutes per fill.

Fig. 10 also shows the times needed to accomplish the same ramp if the circuits were left discharging with their natural time constants. A large margin of about 15 minutes appears to be available to all the circuits.

It should be noted that in the LHC, the ramp down from top energy is used as pre cycle to regenerate the magnetic fields, ensuring optics reproducibility.

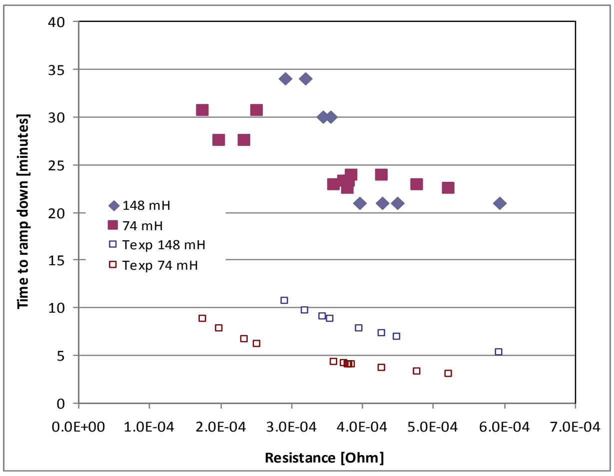

Fig. 10 Ramp down times of Q4 circuits versus resistances of the warm cables

From what has been shown above, two possible solutions can be envisaged to decrease the ramping down time. The first possibility does not entail hardware changes; it just consists of relaxing the specifications on current tracking for the phases without beam. In particular, ramping down in open loop mode would bring the discharge times close to their physical minima. This was tested successfully on the RQ4.R2 circuit, achieving a 19 minutes gain with respect to 2010. The overshoot was of a few tens of mA, not enough to change the magnetization of the superconducting filaments. However, running in open loop is not an option for the inner triplet quadrupoles circuits, which would trip because of the different current ramp rates of the nested circuits and the constraints on the diode voltages. The ramp down time will thus be limited at about 25 minutes, once the software parameters of the RQX circuits will be optimized.

The second possibility is to add extra resistance to the slowest circuits. An elegant way to do so, already proposed [8] as a means to achieve the high β* optics for TOTEM, is to double the intermediate cable which is presently shared between the B1 and B2 circuits. This would remove the resistive coupling between magnet apertures. The advantage of this solution is that it is applicable as well to the phases with beam, and would therefore speed up the squeeze to very low β*. However these changes cannot be implemented in a normal winter stop, and can only be considered for a long shutdown.

Pre cycling policy after short access

Out of safety considerations, in the previous run the superconducting circuits were switched off during access in the machine. This compelled to carry out a pre cycle before taking beam back; otherwise the magnetic machine, and therefore the beam parameters, would not be reproduced.

In the course of 2010 the safety conditions have been revised and reformulated in terms of the energy stored in the circuits. It was considered [9] that the probability of having an electric arc strong enough to piece the beam pipe is negligible below 100 kJ stored in the circuit. This condition is satisfied if the circuits sit at injection current and the (standby) current of the main dipole circuits is downgraded at 100 A. A new access procedure has been prepared [10], allowing to give access in the above described powering state. The advantage of not switching off the circuits is mainly a reduction of the failure probability. Moreover, it becomes possible to make identical powering histories after physics and after access, thus eliminating the need to pre cycle the machine after access. To this end, it is sufficient to set the minimum current of the ramp-down function to 100 A.

It should be noted that pre cycling will still be needed in case the beam is lost at injection and access is required.

SUMMARY

In the light of 2010 experience, improvements of the machine availability are pursued by tackling the main failure contributors, by reviewing the frequency and duration of technical stops, and by minimizing the length of the operational cycle.

The breakdown of systems failures pointed at QPS, cryogenics, power converters and electrical supply as the major sources of downtime. For some of these, mitigation actions in place for the next run were enumerated.

The operational efficiency was good considering that this was the first year of operations; however there seem to be margins to improve it even further.

From estimates carried out on short time periods fully dedicated to physics, it seems that Hübner factors in the range 0.2 – 0.3 can be assumed for the next run.

Analysis of the machine availability before and after technical stops showed that in 2010 technical stops were scheduled too frequently, at least for some systems. It is advised to increase the duration of technical stops up to 5/6 days, and reduce accordingly their frequency, which in 2011 will not be any more constrained by the need of de icing the cryogenics filters.

The bottleneck in ramp down time was located in the Q4 circuits in point 2. The ramp down of unipolar power converters can be considerably accelerated by running in open loop. This is not possible in case of the inner triplets, which will need some fine tuning in order not to become the next bottleneck. The feasibility of such an option was demonstrated, also in respect of the reproducibility of the superconductor magnetization. This change will allow saving about 20 minutes for each fill.

Finally, a necessary condition to skip pre cycles after short accesses was identified and will be implemented for the 2011 run. The related gain in time is about 50 minutes for each access following a beam dump at top energy.

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