BEAM SYSTEMS WITHOUT FAILURES – WHAT CAN BE DONE?

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Abstract

The beam dumps triggered by interlocks not related to the magnet powering are discussed. This concerns the systems like the RF, the transverse feedbacks, beam instrumentation, beam dumping system, collimators and control systems. An analysis of the reasons of these dumps is presented together with a possible strategy to mitigate the effect of these failures.

BEAM DUMP ANALYSIS

This study was meant to analyze the major causes of beam dumps not related to the powering system, in order to identify solutions and possible bottlenecks in view of the operation beyond 5 TeV. All beam dumps of 2010 and 2011 have been analyzed, excluding those related to powering system and those happened during MD periods as not representative of the sample needed for the analysis. They have finally been sorted by energy on:

- Dumps at 450 GeV
- Dumps during the ramp
- Dumps at 3.5 TeV

Injection energy

In order to avoid compromising the results of the analysis with a large number of not fully significant dumps at injection energy, only the fills with intensity of both beams higher than 3E10 p have been considered. As the beam intensity in 2010 was sensibly smaller than what used in 2011, this choice resulted in a very weak statistics. Indeed, only 2 events were found; one due to losses in injection region and the other one to a BLM card electronic failure. More interesting is the statistics for the 2011 when 38 events took place, as shown in Figure 1.

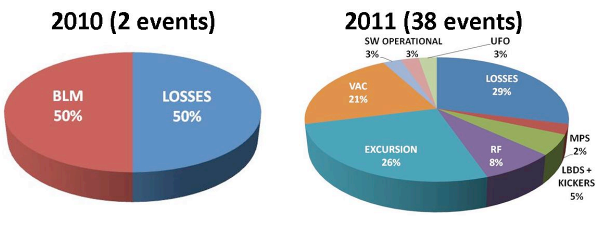

Figure 1: beam dumps at injection energy

In Table 1 the details of the beam dumps at 450 GeV are shown. It can be noticed that most of the events are due to beam instabilities (leading to losses and beam excursion) rather than system failures.

Table 1: Events at injection energy in 2011

Beam dump cause	Number of events (2011)
Losses	11
Excursion	10
Vacuum	8
Radiofrequency	3
LBDS + kickers	2
Machine Protection System	1
Software	1
Operation	1
UFO	1

A more detailed analysis of the dumps caused by beam losses showed that in almost all cases they are provoked by losses in the injection regions during injection; several improvements are foreseen for the future [1]:

- Moving/adding TCDIs in the transfer lines to reduce showers in injection region (LS1)
- BLM sunglasses or Little Ionisation Chambers
- Possibly increasing BLM thresholds at injection
- SPS MSE ripple reduction
- SPS MKE4 beam position with respect to the waveform delayed (possible intervention on the magnet (out of specification) during LS1).

Ramp

The source of the beam dumps happened during ramp is shown in figure 2 and table 2. A total of 40 events took place in 2010 and 15 in 2011.

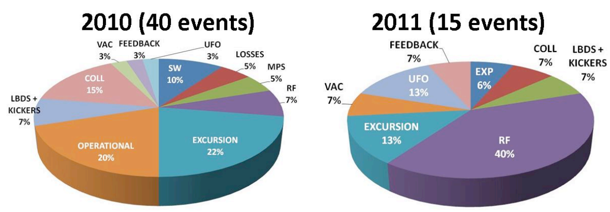

Figure 3: beam dumps during the ramp

Table 2: Events during the ramp

Beam dump cause	Number of events (2010)	Number of events (2011)
Excursion	9	2
Operation	8	0

Collimator	6	1
Software	4	0
Radiofrequency	3	6
LBDS + kickers	3	1
Losses	2	
Machine Protection System	2	0
Vacuum	1	1
Feedback	1	1
UFO	1	2
Experiments	0	1

Table 2 clearly shows an improvement from 2010 to 2011 during the ramp, with the global number of events reduced from 40 to 15. The major changes can be identified in the increased reliability of the operation and of the control software as well as of the collimation system. It can also be noticed that in 2011 almost 40% of the dumps were due to RF system.

Nominal energy (3.5 TeV)

The statistics of beam dumps at maximum energy is surprising as exactly the same number of events was found in 2010 and 2011 operation. This has to be seen as a big improvement on machine performance and reliability, considering the increased number of bunches and bunch intensity in 2011 operation with respect to 2010.

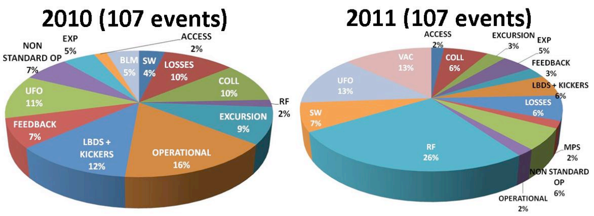

Figure 3: beam dumps at 3.5 TeV

107 beam dumps in this category took place in 2010 as well as in 2011; the details are presented in Table 3.

Table 3: Events at 3.5 TeV

Beam dump cause	Number of events (2010)	Number of events (2011)
Operation	17	2
LBDS + kickers	13	6
UFO	12	14
Losses	11	7
Collimator	11	7
Excursion	10	3
Feedback	8	3
Non standard operation	7	6
Experiments	5	5
BLM	5	0
Software	4	8
Access	2	2
Radiofrequency	2	28
Machine Protection System	0	2
Vacuum	0	14

Table 3 clearly shows a significant improvement of the operation that allowed reducing the number of dumps from 17 (2010) to 2 (2011). A big improvement is also visible on orbit control and LBDS performances. The number of dumps, on the other hand, increased for the RF system (26% in 2011) and vacuum (13%) due to the much higher operational intensity. The number of dumps due to UFOs is still high and it could be the real bottleneck for the high energy operation.

SYSTEMS OVERVIEW

With the cause of beam dumps analysed, it is important to check in details the performance of every system and see what can be done in the future to improve the situation. In this chapter the most critical systems are treated and possible actions to be taken are identified.

RF

The main reason of the increased number of beam dumps provoked by the radiofrequency system is the connection to the Beam Interlock System of all RF interlocks. This operation, performed on June 17^{th} 2011 is required to protect the RF equipment from reflected beam power in case of an RF failure. This is required if the beam current is above half nominal (1.54E14 p). Since this operation was carried out, 25 dumps were caused by the RF system above injection energy.

After the long shutdown 1 (LS1), foreseen for 2013, some RF interlocks could again be separated from the BIS; in this case if the beam intensity is below half nominal some RF interlocks would not dump the beam. Some studies are proposed to implement a “safe RF” beam intensity flag, able to mask some interlocks in case of low intensity beam. Clearly, a fully reliable beam intensity measurement, also taking into account unbunched beam, is needed. Disconnecting the RF interlocks from the BIS would anyway not save any high intensity fill as in this case the beams have to be dumped to protect the RF system.

Some other improvements [2] are foreseen to be carried out during the 2011/2012 Christmas break on the RF system, estimated to reduce by 50% the number of 2011 trips; this number will be further reduced by 20% due to the interventions planned for 2013.

Vacuum

The beam dumps initiated by the vacuum system can be mainly divided in two categories:

- RF fingers
- Electron cloud

In the first case, a vacuum spike appearing in the injection regions initiated the dumps. These spikes were due to a loose spring on the RF fingers. These faulty vacuum modules generated a large number of dumps (17 between injection, ramp and high energy). A fix of these modules is foreseen to take place during the 2011/2012 Christmas break. Depending on the case, the vacuum interlock threshold can be increased locally, but beyond a certain level the BLM system would react and dump the beams anyway. A definitive solution is foreseen for LS1 with the complete redesign of the modules.

A minor number of beam dumps were generated by electron cloud. This problem only concerned the operation at 25 ns, which will most likely only take place after LS1. In this case, the problem can be solved, by performing a more intense scrubbing (an estimated time between 20 hours and 2 weeks is needed [3] [4]).

In the vie of the nominal LHC operation at 7 TeV with 2808 bunches spaced by 25 ns, some additional problems might influence the machine availability [5], such as vacuum dynamic effects in non-NEG coated components in the arcs and long straight sections as well as heat load and photoelectrons due to synchrotron radiation.

Collimation

The collimation system also led to some beam dumps. The analysis of these events showed that no structural problems are present. The main causes of dumps were temperature readings and single event upset (SEU). To mitigate the first cause, some thresholds have been increased and the monitoring system has been largely improved. On the other hand, the new shielding installed during the Christmas stop should reduce the impact of the SEUs, at least for the same radiation level.

After LS1, the LHC will be operated with nominal energy and intensity and the integrated radiation dose could become an issue, affecting equipment lifetime. Moreover, the collimator position limits will be tighter (as defined to be a fraction of sigma), but the reliability of the system is not expected to be affected. As a complementary mitigation a new PXI chassis, with added redundancy, is being developed, to increase availability of the collimation system. It is foreseen to be installed during LS1.

Beam injection and extraction

Most LBDS failures were due to instabilities in the power converters of the MKD and MKB generators. Over the Christmas stop, all MKD and MKB power converters have been sent to the manufacturer and have been repaired for a known weakness. This should improve the tracking performance. Nevertheless, if the problem reappeared, the MKB generator tracking window could be enlarged. The vacuum pumps on MKB were also replaced during Christmas break and should decrease the number of dumps generated by vacuum interlock.

In 2 cases, the beam dump was generated by an injection kicker MKI erratic; this event clearly needs to generate a beam dump and no mitigation is possible. This consideration is also valid for LBDS MKD erratic, although such an event was not experienced so far.

Operation

The number of operational mistakes leading to a beam dump has been reduced from 25 in 2010 to 3 in 2011; this substantial improvement was due to:

- Extensive work on the establishment of solid operational procedures.
- A large improvement of software tools used.
- An increased knowledge of systems and beam behaviour.

Miscellaneous

A minor number of dumps was initiated by other systems or mechanisms, such as UFO's, access system, BLM failure, software, machine protection system. Due to the limited statistics of these cases it is not easy to identify whether a systematic source of problems exists.

The case of UFO's deserves anyway a particular attention as it might become more serious with increased beam energy. The global number of UFO's is presently dominated by MKI UFOs (limiting on Q4 and D2). Some improvements [6] are already being considered, but more studies will be done during the 2012 run. Arc UFOs are expected to dominate the statistics after LS1 as their number increases with energy faster than the MKI UFOs'. A strategy to further increase the BLM threshold is under discussion [7].

CONCLUSIONS

The analysis presented in this paper only concerns beam dumps not related to powering system failures. A large improvement has been achieved between 2010 and 2011 operation, despite the beam intensity increase. Although it will not be easy to continue on this line, some key points have been identified to further limit system failure events after LS1 when, due to the foreseen increase in beam energy and total beam current, the global number of beam dumps is expected to increase.

The largest improvement has been achieved thanks to more rigours discipline and operational procedures.

It is very important to notice that no system has been identified to have any structural problem.

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