EXPERIENCE WITH THE PROTON BEAM LOSS MONITORING SYSTEM AT HERA

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Abstract

The beam loss measurement system is an integral part of the quench protection system of the HERA superconducting magnets. As a result of technical limitations in the system, beam losses can, under certain conditions, induce quenches. An overview of the system will be made, general Battle-Field experience will be covered, and the Small Holes in the Interlock will be described.

1 WHY DO YOU NEED A BLM SYSTEM?

Beam losses can induce quenches of the superconducting magnets (I apologize to the reader for the scandal in the lack of references). An important function of the interlock is to dump a doomed beam before the losses become so great that a magnet quenches. In the first level of protection, component failures automatically trigger an alarm to dump the beam. This may sound sufficient to prevent catastrophic beam losses, but in a complicated system there are many grey areas, including:

- Not all components should be connected to the alarm. An example is tripped correction coils; if the coil has zero current, then an emergency dump is not necessary.
- Not all failure-modes should trigger an alarm, for example warnings. But a quadrupole power supply regulation problem may shift the beam tunes enough to produce a bad lifetime, i.e. high losses.
- Alarm Information may not be transferred fast enough. The information that a PS is tripping/has tripped moves from the PS electronics to the alarm system through relays, SPS controllers, etc. This time delay can easily be of the order of tens of milliseconds. In this time, a critical PS can cause significant losses.
- Component information is not completely infallible. There are examples at HERA of pathological conditions where the PS electronics were producing maximum output current, with the controller in a zombie state reporting that the output was zero.
- Not all Failures are technical. There are numerous examples of "operator error" where heavy losses were induced by misjudgment, or by a simple error (e.g. correcting the orbit with the wrong data base information). And beam instabilities can also produce losses which are very fast.

So many possible situations exist in which the beam should be dumped, but a technical interlock system would be hard-pressed to make such a decision. A Beam Loss System is a direct way to protect the magnets even in these situations. Such cases are most frequent during commissioning; At HERA, the frequency of such situations is always going down, but they still occur.

2 SPECIFYING YOUR BLM SYSTEM

The goal is to specify a loss-measurement system with which a doomed beam can be detected and the dump triggered. I will cover this problem in the reverse order: I will describe how the BLM system at HERA is laid-out, and then cover the experience with particular failure-situations and the corresponding loss pattern.

2.1 Layout of Monitors

Losses are measured using PIN Diodes, strategically located around the ring. Please consult Kay Wittenburg's papers for more technical details.

- Cold Sections: One monitor on each Quadrupole. A VERY important exception to this is near the beginning of the arcs, around the first dispersion maximum, where 4 monitors are stacked one on top of the other.
- Straight Sections: Monitors are located on the warm quadrupoles near the interaction regions; they serve a VERY important role in generating alarms.
- Collimators: Installed, but only for diagnostics. The monitors are NOT connected to the alarm system. Please note: the collimators are NOT part of the machine protection system, they are for controlling backgrounds at the experiments.

The losses at each diode are counted; the maximum loss rate is one count per bunch crossing. The counts are summed in 5.2 ms time intervals and a LOCAL ALARM is produced when the sum is above a (software controllable) threshold. When more than a (software controllable) number of monitors simultaneously register local alarms, a global alarm is generated by the Alarm-Zentrale and the beam is dumped. The "summing" of the alarms is done in analogue electronics, and corresponds to between 4 and 5 alarms.

2.2 Alarm Information

After fixing the beam loss conditions which trigger the dump, information must be collected and stored to be able to understand WHY the dump was triggered. Complete technical status information is important. Years ago there were certain cases where it was difficult to distinguish, in the chicken-or-the-egg problem, which component INITIATED the chain of events. For example, did the RF trip, triggering the dump, or did the dump of the beam, and the resulting transient beam-loading, trip the RF? Did an error in the main dipole PS trigger the quench electronics, or the other way around?

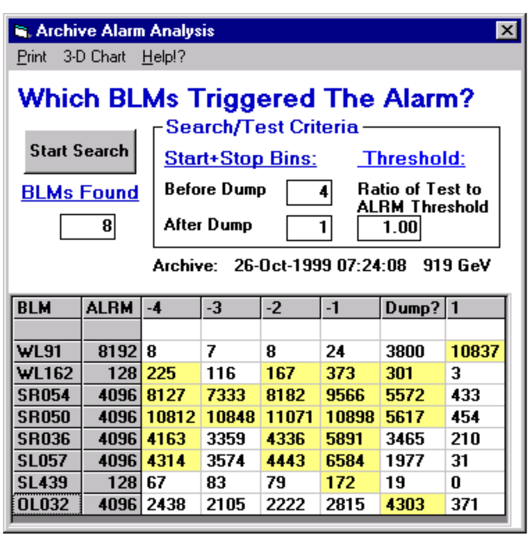
If the trigger was generated by excessive losses with no apparent technical reason, then one needs beam diagnostics to piece together what happened. At HERA, the Post Mortem histories of the losses and the beam positions are frozen in hardware to be collected and stored for viewing with software.

- Losses: The last 128 bins (of 5.2 ms) and 85 sec (in 128 bins)
- Position: The last 1024 turns (20 ms) and 600 ms (in 128 orbits)

With this large amount of data, well written display software is important; there are a number of mysteries which were difficult to disentangle without the help of useful software to help the operators understand what happened. These types of Post Mortem Events have been generalized in the scope of the HERA Archive-Event server to include, for example, injection-triggered events.

2.3 A simple example: Correction Coil Trip

An alarm triggered by losses caused by a PS trip is a good example to get started with. In Fig. 1 is shown the console application used to filter through the 2-D data (losses versus monitor and time), to find those monitors which had high readings near the time of the dump.



BLM	ALRM	-4	-3	-2	-1	Dump?	1
WL91	8192	8	7	8	24	3800	10837
WL162	128	225	116	167	373	301	3
SR054	4096	8127	7333	8182	9566	5572	433
SR050	4096	10812	10848	11071	10898	5617	454
SR036	4096	4163	3359	4336	5891	3465	210
SL057	4096	4314	3574	4443	6584	1977	31
SL439	128	67	83	79	172	19	0
OL032	4096	2438	2105	2222	2815	4303	371

Figure 1: Console application showing monitors with high losses near the time of the dump-trigger.

In Figure 2 can be seen the relatively slow development of the losses at selected monitors in the 600 ms before the dump trigger.

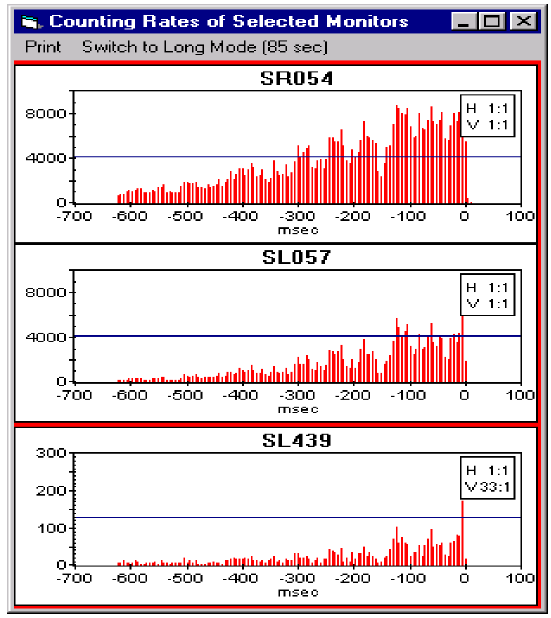


Figure 2: Losses versus time for selected monitors.

The 2-D orbit data (position versus monitor and time) is visible using another application, with which one can select orbits and looking at individual monitors one can see the time development of the orbit deviations. In Figure 3a is shown the difference orbit generated over 600 ms before this dump, and in 3b the relatively show change in monitor SL397.

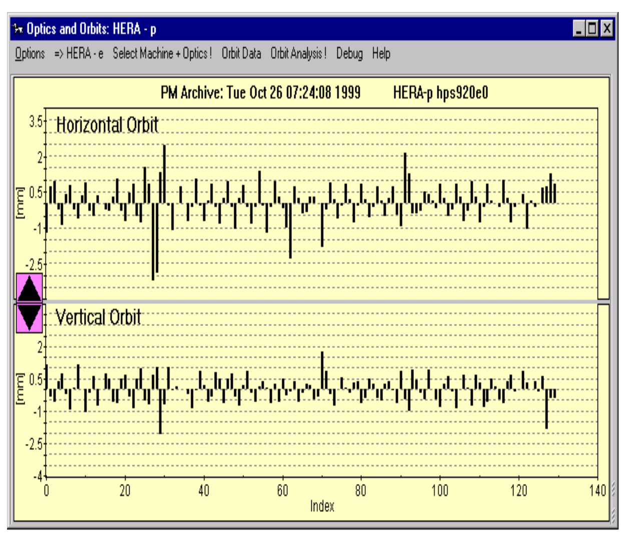


Figure 3a: Difference of orbits at the start and end of the Post Mortem file.

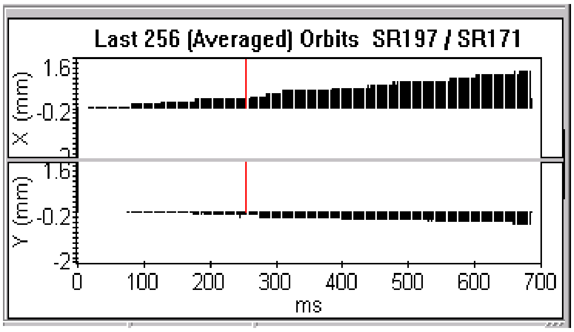


Figure 3b Position versus time for a single monitor during the 600 ms before the dump trigger.

3 MORE EXAMPLES OF LOSSES

3.1 An Instability

Shown in Figure 4 are the losses during a head-tail instability at 142 GeV, which triggered the dump during a ramp on 10-Mar-99 at 00:48. No effect in the orbit was seen; the losses reach the alarm threshold after about 300 ms.

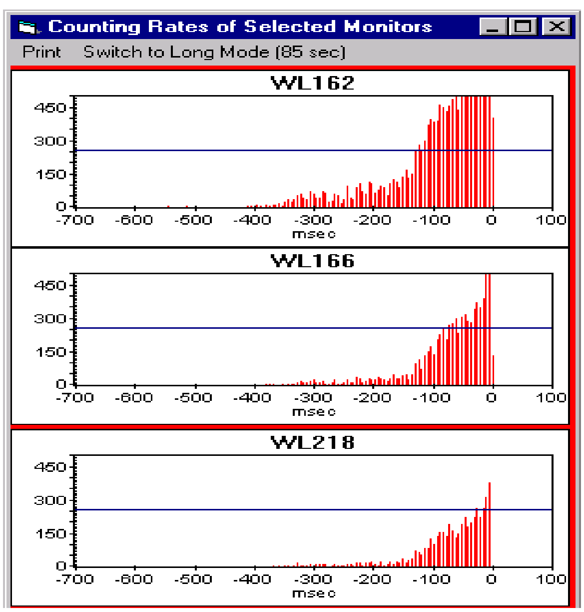


Figure 4. Losses during an instability at 142 GeV.

3.2 Spikes

Often the time development of the losses is not as smooth as one might expect. Shown in Figure 5 are the losses during a beam-scraping exercise on 12.Oct.98 at 10:08. In Figure 6 are shown the losses which triggered the dump on 31.July.00 during "stable" conditions. There are numerous examples of such "oscillations" in the losses with no observed motion in the beam orbit recorded by the position monitors.

There is some evidence that these effects are related to coasting beam halo.

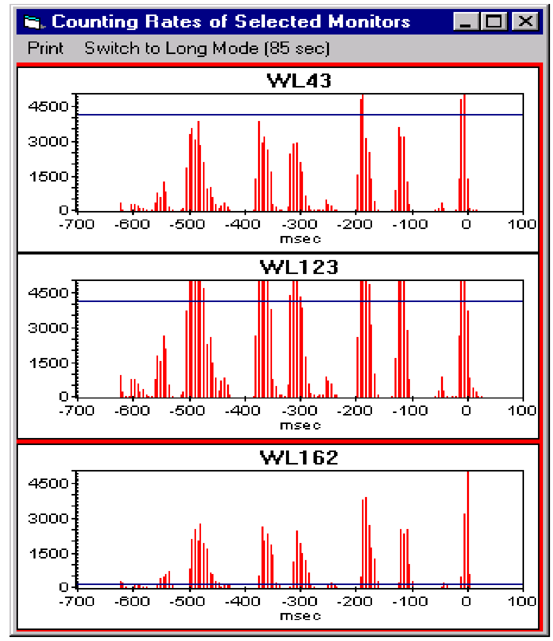


Figure 5. Oscillations in the losses observed during movement of the main collimator.

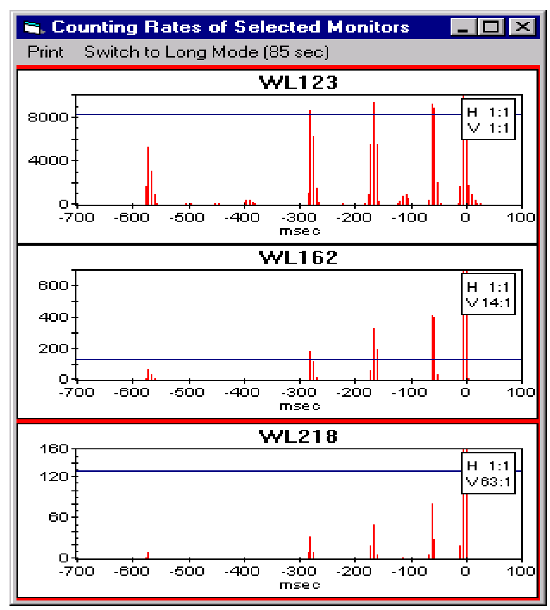


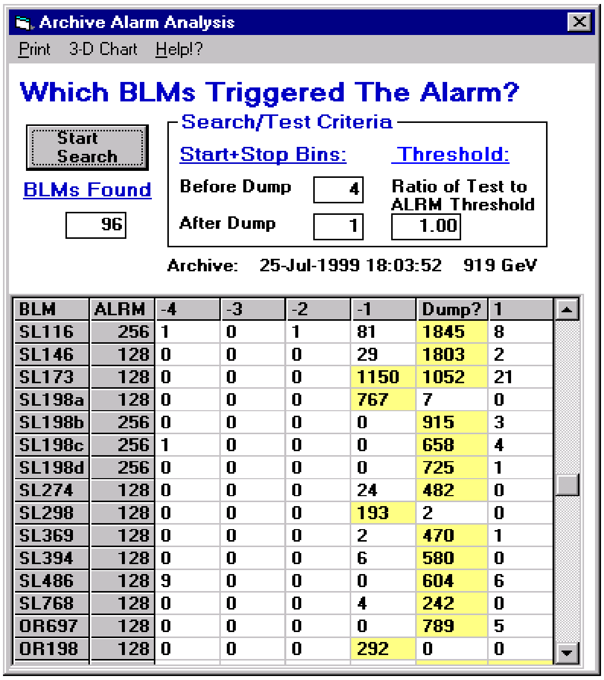
Figure 6. Spikey losses which triggered a dump during stable beam conditions.

3.3 RF Trip

The RF interlock now directly generates an alarm to dump the beam. In the past when the RF tripped the dump was fired by very fast losses (about 20 ms) which begin long after the RF trip (on the order of a second later). Looking at orbit data, one sees that the beam oscillated on a dispersion orbit for a long period (on the order of 0.5 sec) before the losses start. The long time between the RF trip and the first losses and the short time until the losses exceeded the alarm threshold is rather startling.

3.4 *Trip of Quadrupole Power Supplies*

Trips of PS for quadrupoles near the interaction regions can produce very fast, intense losses. Shown in Figure 7 is the loss pattern of a quad trip on 25.July.99 at 18:03.



BLM	ALRM	-4	-3	-2	-1	Dump?	1
SL116	256	1	0	1	81	1845	8
SL146	128	0	0	0	29	1803	2
SL173	128	0	0	0	1150	1052	21
SL198a	128	0	0	0	767	7	0
SL198b	256	0	0	0	0	915	3
SL198c	256	1	0	0	0	658	4
SL198d	256	0	0	0	0	725	1
SL274	128	0	0	0	24	482	0
SL298	128	0	0	0	193	2	0
SL369	128	0	0	0	2	470	1
SL394	128	0	0	0	6	580	0
SL486	128	9	0	0	0	604	6
SL768	128	0	0	0	4	242	0
OR697	128	0	0	0	0	789	5
OR198	128	0	0	0	292	0	0

Figure 7. Dump triggered by losses during stable beam conditions.

One sees that the losses for each monitor are contained in one time bin, meaning they lasted less than 5 ms. The losses were distributed around the ring – 96 monitors exceeded their alarm threshold in that time. The losses increased too fast for the BLM system to dump the beam before the magnets quenched. The collimators were closed. This PS is connected directly to the Alarm-Zentrale, but the losses are faster than the error-information. The beam is off-center in this quadrupole, and orbit deviations in the 20 ms before the dump are seen.

Other BLM alarms with beam induced quenches occur without a clear cause – for example no PS gave itself up and admitted to having tripped. In these cases there are also no effects in the orbit observed, so the suspicion is that the trips are of PS for quads near the interaction regions where the beam is well centered.

Transient recorder pictures (from events in 1996) recording the analogue outputs of PIN diodes on the collimators show losses with very fast rise-times lasting less than 1 ms with sufficient intensity to quench magnets.

3.5 *Localized Losses*

An assumption in the layout of the BLMs was the distribution of the losses – at least 4 monitors were expected to see high losses to be able to trigger the dump before a quench. Losses can be much more localized – with a single monitor well over its alarm threshold (a factor of 10), and its neighbours have nearly zero losses. For this reason monitors have been installed in the warm straight sections (the nominal geometric aperture). A typical loss-trigger involves a combination of monitors in the warm and cold sections.

3.6 *Summary of Loss Information*

A few points to just to summarise:

- Losses can be so localised that a single quadrupole quenches but neighbouring monitors show minimal losses.
- The time intervals between trip to loss-begin to loss-alarm can be surprising. The losses after an RF trip take nearly a second to be seen, but quench levels are reach in 20 ms.
- Losses can reach quench levels in less than 5 ms.
- Quadrupole trips can quench magnets even with closed collimators, with losses around the ring.

4 LOSSES AND THE COLLIMATORS

The loss monitors are meant to protect the superconducting magnets but not the experiments or the collimators from high losses. Damage of the proton collimators is shown in Figure 8.

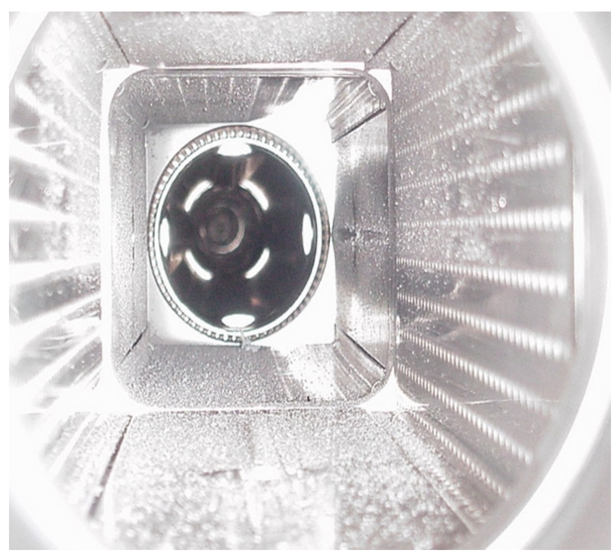


Figure 8. Dump triggered by losses during stable beam conditions.

Channels have been “gouged” in the surface, a few mm deep and a few mm wide. “Crumbs” of the tungsten-alloy DENSIMENT are sprinkled on all surfaces. This seems to indicate explosive events, the cause of which are not known.

5 SUMMARY

- The BLM system at HERA is still used to prevent beam-loss induced quenches, though with stable operations the number of events is goes down.
- Limitations in the hardware related to very fast and very localized losses allow for beam-loss induced quenches.
- These events happen infrequently so that changes in hardware to plug these holes are not planned.
- Losses still trigger beam dumps without clear cause. Suspicions exist as to possible causes, but again, the events are so infrequent that additional diagnostics for these cases are not planned for.

REFERENCES

[1] A.N. Other, “A Very Interesting Paper”, EPAC’96, Sitges, June 1996.