VERY FAST BEAM LOSSES AT HERA, AND WHAT HAS BEEN DONE ABOUT IT

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Abstract

During the Luminosity upgrade of HERA in 2000/2001 more than 50 new magnets were installed close to the interaction region to provide a stronger focussing of the two beams. Some of these magnets are located at very large values of the betatron function and therefore can act with a large gain on the beam. Sudden changes in the power supply currents generated very fast beam losses, creating quenches and increased radiation levels. This talk will discuss the improvements made to the HERA machine protection system to make sure that the beam is dumped in time in case of these events.

INTRODUCTION

HERA is a 6.3 km long electron/proton collider at DESY in Hamburg, Germany, presently running at 27.5 GeV for electrons and 920 GeV for protons, with superconducting magnets in the arcs of the proton ring. The accelerator is equipped with four interaction regions (IR's), two of them are foreseen for colliding beam experiments with the detectors ZEUS and H1. To reduce the spot size of the colliding beams and to increase the luminosity, the β-functions in the collision interaction regions (IR) were reduced and more quadrupoles were installed in 2000/01, some very close to the IR. The number of power supplies (quadrupoles) in the high β region increased from 6 to 14. These new power supplies had an about factor 3 smaller reliability than the old but well known power supplies from before the upgrade. Both, the higher number of power supplies and their smaller reliability led to a smaller mean time between failures.

The beam has a high sensitivity to field changes of these low-beta quadrupoles. It was calculated [1] that a 1% change of the magnet current already leads to dramatic beam losses and beam induced quenches. Therefore a trip of such a power supply will lead to intense and very fast beam losses (<<5 ms) even if the time constant τ_M of such a coil is in the order of some hundred milliseconds.

Also other contributions to fast beam losses were observed in the history of HERA which will also be discussed in the following.

ALARM SYSTEM IMPROVEMENTS

History

The HERAp Beam Loss Monitor (BLM) system and the Machine Protection System (MPS) are described elsewhere [2], [3]. Both systems were designed for HERA parameters before the Luminosity upgrade, especially the systems were not designed to resolve and act against fast beam losses below the 5 ms scale. At least the BLM system needs ≥ 5.2 ms integration time to produce an abort alarm in case of too high beam loss rates.

Since the beginning of HERA very fast beam losses were observed, but only very few of them had led to quenches. These events were called "5 ms events" due to their signature in the BLM post mortem archive. The main reasons for these events at that time were fast drops or glitches of the RF System. Therefore the RF failure alarm system was connected to the MPS in 1998. This improvement already reduced the rate of 5 ms events from much more than 10 events/year to about 5 events/year. The rate of beam loss induced quenches (5 ms events only) was also reduced from about 3-4 / year to about 1-2 /year, 4 in total between 1999 and 2001. The reason for the remaining events was not fully understood. Beam aborts caused by fast electron beam losses which triggered the BLM alarm were not counted in this statistic. However, the small number of 5 ms events did not hurt HERA's performance, so no effort was done to solve this problem.

After the luminosity upgrade in 2000/01 the quench rate due to 5 ms events increased to 4–5 /year. Most of the beam loss induced quenches affected a whole string of successive magnets and produced unacceptable high radiation levels even outside the accelerator shielding. Detailed analysis and experimental studies led to the conclusion that the main source for these events were caused by the low beta quadrupole power supplies. A trip of such a power supply generated very fast beam position drifts, beam size blow up and fast beam losses within a few turns.

Therefore the whole alarm concept had to be improved to achieve the goal of reliable beam aborts within a few turns delay after loss relevant failures. Several improvements were implemented in 2004 to overcome this situation (discussed below), with the success that in 2004 up to now nearly all of the remaining 5 ms events (5/year) were detected before a quench occurred (by dumping the beam in time). The remaining 2 quenches occurred due to accidental faulty triggers of some kickers within a beam store. This generated very high and very fast beam losses (within very few turns) which were below the reaction time of the already improved MPS. The reason of one recent 5 ms event (no quench) in 2006 is still unclear.

A complete statistic of 5 ms events over the past 12 years of HERA operation is shown in Fig. 1

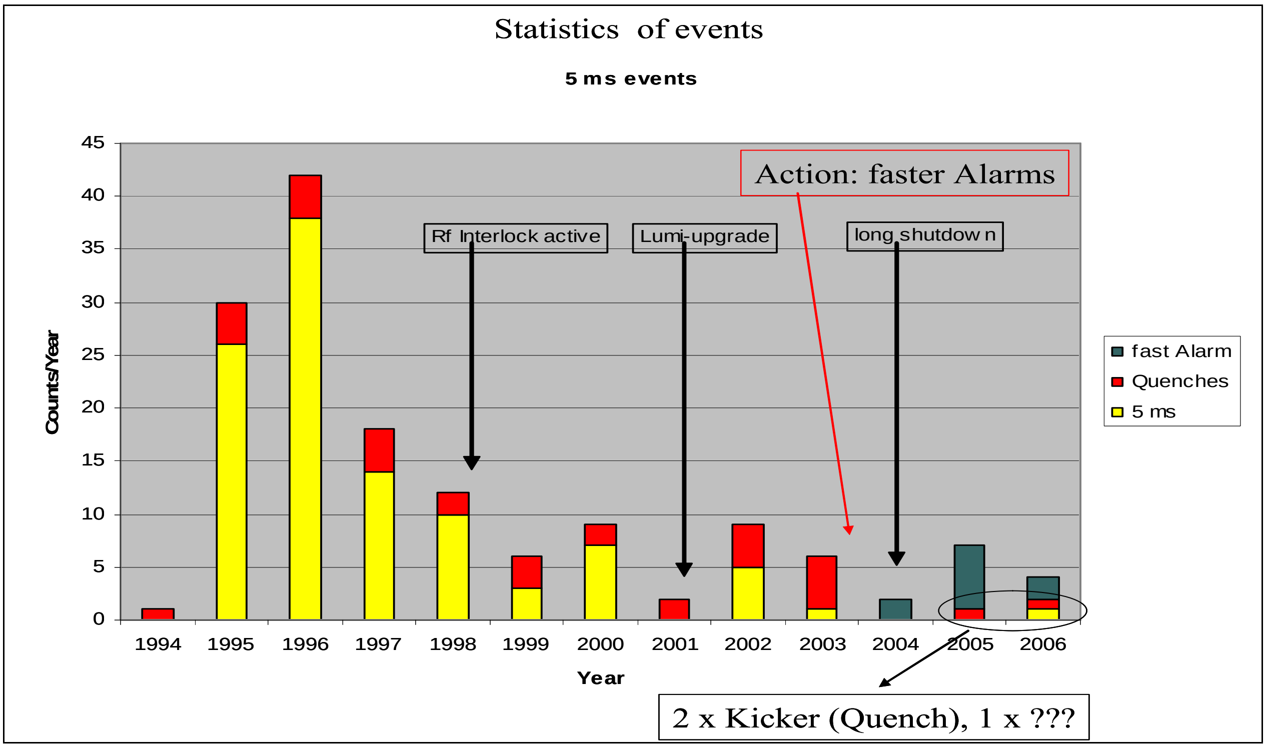

Fig. 1 Statistic of 5 ms events in HERA between 1994 and 2006. Details see text.

Improvements in 2004

Several improvements were done in 2004 which increased the speed of alarm generation, additionally considerations are added which were not realized:

<u>Beam based:</u>

- Beam current monitor alarm
- Considerations on BPM alarms (not realized)
- Considerations on faster BLM alarms (not realized)

<u>Alarm loop based:</u>

- Faster alarm loop
- Dump trigger speed

<u>Power supplies:</u>

- More and better maintenance of the power supplies
- Faster internal Power supply alarm
- New magnet current alarm

<u>Beam based:</u>

Beam current monitor alarms

HERA has two types of beam current monitors; the DCCT measures the DC component of the beam, while the ACCT measures the current of each bunch. Both monitors can detect general beam losses with a high precision and very fast. However, the broad bandwidth of the ACCT enables for differential current comparisons on a turn by turn base. Therefore a combined analogue and digital signal processing circuit, called “AC alarm”, was installed in parallel to the readout of the ACCT. It compares the beam current with a certain threshold while this threshold is tracked with the current. The response time of the ACCT alarm is one turn (21 μs) + 10 μs and is therefore one of the fastest loss detectors and alarm generators. After enabling this circuit in 2005, it has shown its efficiency already two times without any additional faulty trigger. This alarm circuit is connected directly to the beam dump, bypassing the MPS, to provide the fastest beam abort in case of an alarm.

Consideration on BPM alarms (not realized):

The BPM system of HERA [4] offers the possibility to define a region of allowed beam positions (symmetric around the centre). As soon as the beam leaves this region an alarm can be generated, which is a much faster method for alarms than waiting for beam losses. The setting of the MPS then defines the required number of alarms to dump the beam. Preliminary tests had shown that the regular beam movement during acceleration and luminosity steering is large enough to trigger faulty dumps. Therefore this feature of the BPM system was and is still disabled.

Consideration on faster BLM alarms (not realized):

The threshold for an alarm of the BLMs in the superconducting part of HERA is already low; at some places 64 counts/5.2ms generate alarms. A factor 10 shorter integration time (520 µs ≈ 25 turns) reduces this rate down to 6 conts/0.5ms. This rate is still far above the dark count rate of < 1 Hz, but it reduces the dynamic range of the system and makes the system more sensitive to short and harmless loss spikes. Also it requires a major change of more than 240 BLM readout modules without achieving the goal of a few turns delay. Therefore it was decided not to speed up the system.

<u>Alarm Loop based:</u>

Faster alarm loop:

The main alarm handler of the MPS is the alarm loop interface (ALI). This module has to process all alarm signals from BLMs, BPMs, Power supplies, etc. and it has to transmit the alarms to the MPS central electronic and to the beam dump trigger. Therefore a faster processing in the ALI is most helpful. Its internal clock speed was increased from 5 kHz to 90 kHz. Together with some replacements of slow relays by opto-couplers, the overall delay time in the complete MPS chain including ALI was reduced from typ. 300 µs down to typically 50 µs, corresponding to about 2 – 3 turns in HERA [5].

Faster beam dump

By analysing the fast beam losses, it was detected that the beam dump responded to an abort trigger with a delay of 570 µs (≈ 27 turns). By replacing an opto-coupler by a faster type the delay was reduced to 10 µs or ½ turn. Note that the dump kickers always have to be synchronised with the abort gap, which adds up to one turn (21 µs) delay.

<u>Power supplies:</u>

Maintenance:

Obviously a better maintenance of the power supplies might reduce the amount of events, but not the consequences of an event. Therefore this improvement will count for a better reliability but it was concluded that additional improvements, beside a better maintenance, has to be done.

Faster internal power supply alarm

The alarm handling of internal power supply alarms was done via SPS processing. This caused a delay of more than 5 ms between the failure and the transmitting of the alarm to the ALI. The delay was significantly improved to less than 100 µs by bypassing the SPS and collecting the alarms by an analogue electronic circuit. Additional filters were necessary to avoid faulty triggers due to EMI noise which increased the delay to 300 µs [6].

Magnet current alarm

The internal power supply alarm does not work for failures of the power-supply-current-control system. Since some of the power supply trips were result of current controller problems, a new detection device [7] was designed to detect <u>all kind</u> of fast changes of the power supply current which will result in significant changes of the magnetic field of the connected magnet(s). To ensure a reliable and fast detection of very small current changes without being affected by voltage spikes and the large noise in the vicinity of high power systems, a new method was applied: the magnet current changes are calculated in real time from the magnet voltage by an estimation filter modelling the magnet behaviour. In this way, for example, noise in the range of 2 kHz is suppressed by a factor of 1000 while the desired high sensitivity to small current changes in this frequency range is still unaffected. The intrinsic delay is about 20 µs (1 turn), not to be confused with the step response time for appropriate threshold setting. For commissioning, the thresholds were carefully adjusted to about 10^{-4} of the magnet current at 920 GeV/c by observing the result of the digital peak detector of the device during several days and all relevant operational states. After this, the system was activated at all 14 critical power supplies. Since then, no faulty trigger was observed, but the system already dumped the beam in time at a handful of real power supply failures.

A development is under way to equip also the LHC collider and its transport lines with this kind of devices.

CONCLUSIONS

After the development and implementation of a number of improvements in the chain of the alarm loop, the whole alarm system has now a response time of a few turns only. This is fast enough to dump the beam in time and to avoid beam loss induced quenches and high radiation levels in case of most failures. The system acts fast on faults of various beam loss relevant system (e.g. RF, etc.) and newly on faults of power supplies. Critical power supplies were equipped with new developed “magnet current alarm” circuits which extents the fast failure detection in the power supplies. Additionally any loss of beam current is analysed within one turn by a new circuit connected to the ACCT. In case of too high fast beam losses an alarm will dump the beam. In combination with the HERA BLM system, all kind of losses (fast and slow) can be handled now very effectively.

All improved and active alarm circuits worked very reliable, no false dump was observed since their activation in the beginning of 2005, but some true emergency dumps were already released showing the importance of the systems.

ACKNOWLEDGEMENTS

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APPENDIX (ACCORDING TO THE DISCUSSION SESSION)

The following pictures 2 and 3 show a 5mm grove in the HERA proton beam collimator. The pictures were taken in 2003 when the collimators were inspected. The machine was probably running with these collimators for some years. Note that a specific accident resulting in this damage could not be identified! The damage could be a result of many years of operation as well as a result of a few intensive unintended beam losses.

Fig 2, 3: 5 mm grove in the HERA proton collimator detected in 2003 after many years of operation. Courtesy of Mike Seidel, DESY.