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PRESERVATION OF BEAM LOSS INDUCED QUENCHES, BEAM LIFETIME AND BEAM LOSS MEASUREMENTS WITH THE HERAp BEAM-LOSS-MONITOR SYSTEM

by
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Abstract

The beam-loss-monitors (BLMs) in the HERA-Proton-ring (HERAp) must fulfil the following requirements: They have to measure losses sensitive and fast enough to prevent the superconducting magnets from beam loss induced quenching; the dynamic range of the monitors must exceed several decades in order to measure losses during beam lifetimes of hundreds of hours as well as the much stronger losses that may quench superconducting magnets; they have to be insensitive to the synchrotron radiation of the adjacent electron-ring (HERAe); and their radiation hardness must allow a monitor-lifetime of a few years of HERA operation. These requirements are well satisfied by the HERAp-BLM-System.

Introduction

The HERA collider consists of two storage rings in the same 6.3 km long tunnel, in which 820 GeV/c protons collide with 30 GeV/c electrons. The proton ring consists of 422 superconducting dipoles and 220 superconducting quadrupoles. A beam loss in these magnets increases the temperature of the liquid Helium cooled coils and may cause a quench. The BLMs are mounted on top of each superconducting quadrupole. Losses are measured by the BLMs every 5.2 ms. If the losses reach an energy-dependent threshold within this time, the proton beam will be aborted automatically within one turn. Therefore the total loss in the superconducting magnets can be keep small enough to prevent a quench.
In the normal operation of HERA the proton beam lifetime is longer than 50 h. Most of the losses occur at the collimators and in the non-superconducting parts of the machine, where the aperture is limited by special quadrupoles. These positions have also been equipped with 42 BLMs. These BLMs are most helpful in steering the beam to achieve small losses and long lifetimes.
Positions where the beta-function of HERA reaches a maximum (quadrupoles) and positions with a limited aperture (e.g. collimators) are the most probable places for beam-losses. All of these locations are equipped with BLMs. Therefore it is possible to calculate the lifetime of the beam from the loss rates. This method gives more accurate data than calculating the lifetime based on differential current measurements. This is especially true for very long lifetimes.

The BLM-System

A lost particle from a high energy beam hits the beam pipe of the accelerator and creates a shower of charged and neutral particles. At very high energies, like in HERAp (40-820 GeV/c), the shower penetrates the surrounding magnet and particles leave the surface of the magnet. A small number of these particles will reach and can be detected by the BLM positioned on top of the magnet. The monitors consist of two reverse biased PIN-photodiodes, mounted face-to-face. Charged particles which cross both diodes produce coincident signals with a high efficiency while the efficiency of coincident signals from other particles is very small. The dimensions of the photodiodes are 2.75 x 2.75 mm^2 (Siemens BPW 34) or 7.5 x 20 mm^2 (Hamamatsu S2662) depending on the sensitivity required at each position. The dimensions of the BLMs are 5 x 5 x 5 cm^2, which includes the electronics of the preamplifiers and the coincidence. The radiation hardness was tested and found to be adequate up to more than 5×10^5 rads [1, 2]. The monitors are calibrated in terms of lost protons/signal for each individual position at the HERAp-ring with the help of Monte-Carlo calculations and efficiency measurements[3, 4][1].

The maximum counting rate of the monitors is related to the bunch crossing rate of HERA (10.4 MHz) while the dark count rate is less than 0.01 Hz because of the noise suppression due to the coincidence. Therefore a dynamic range of more than 10^9 is available, which exceeds that of conventional loss-systems by several orders of magnitude [6]. A second advantage of the coincidence is the insensitivity of the monitors to synchrotron radiation. The yield of coincident signals from synchrotron radiation is suppressed strongly because a photon interacts in one diode only. With a 3 cm lead shield, it is expected that the synchrotron radiation from the HERA electron

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[1] New measurements [14] and [5] indicate that the efficiency of the monitors for the detection of charged particles (minimum ionising) is about 30%, which is higher than assumed in [1].

ring at 30 GeV/c and 25 mA contributes with about 1 Hz [3]. At the current values of HERAe (26.67 GeV/c, 15 mA) no additional counts in the BLMs have been observed.
The properly amplified signal of each BLM is fed into individual counter modules which are connected via a serial link to a personal-computer (PC). Each counter module sums the counts over a time period of 5.2 ms. The count rates of the last 128 successive periods are stored in the electronic memory of each counter ("short" memory). Additionally, 128 successive mean count rates of the "short" memory are stored ("long" memory). Thus, the "short" memory gives a view of the loss rates of the last 128 * 5.2 = 0.666 s while the "long" memory shows the mean loss rates of the last 128 * 0.666 = 85 s. One of these memories can be selected and read out by the PC with an update rate of less than 1s. This gives a quasi analogue display of the loss behaviour at a selected BLM. A complete readout of all 262 BLMs takes about 15 s and gives a view of the loss distribution around the entire ring.

In each counter module, the number of counts within the 5.2 ms period is compared with a threshold which is a function of the momentum of the proton beam. In addition, the operator can select an individual threshold for each monitor. An alarm signal is sent to the HERA Alarm Loop [7] if the threshold is reached. The Alarm Loop System tolerates a defined number of alarms (current value: 9) before it fires the beam abort system. The memories of all counters will be frozen if the Alarm Loop detects too many BLM alarms at one time or an alarm from the Quench Protection System [8]. The data of all memories are stored in an archive of the HERAp PC-net to allow post analyses of the events. Fig. 1a shows the "short" memory of a certain monitor after an accidental beam loss triggered by a trip of a power supply. The periodic change in the rates is subject of further investigations [9]. Fig. 1b shows the "long" memory of the same BLM, indicating the increase in the loss over a few seconds. In this case the beam abort system fired after 9 different BLMs had reached theirs given threshold , indicated by the dashed lines in Fig. 1.

Quench Protection

The protection against beam loss induced quenches becomes very important since HERAp runs normally for luminosity with a proton beam current of more than 10 mA in 90 bunches. The expected maximum tolerable proton loss rate inside a superconducting magnet (before a quench) is between 1.6×10^{10} protons/5.2 ms at 40 GeV/c and 1.6×10^{7} protons/5.2 ms at 820 GeV/c [10] corresponding to a count rate of 1.2×10^{5} counts/5.2 ms to 9×10^{2} counts/5.2 ms, respectively [1][2]. The adequate threshold for the prevention of loss induced quenches has been found to be a factor 10 less than these rates. In principal there is no need for a threshold at the non-superconducting magnets but because of the aperture limitations of HERAp in these regions, the adjacent BLMs give a sensitive indication of beam losses. Therefore their threshold was set a factor 5 lower than the maximum tolerable rate in the superconducting region. During accidental beam losses nearly all of the "non-superconducting" BLMs (distributed in the 4 straight sections of HERA) were affected as well as a few "superconducting" BLMs (Fig. 2).
Fig. 2a displays the mean loss rates of the last "short" memory of all BLMs distributed along the entire ring. This picture has been archived after a strong beam loss triggered by a trip of the HF-system. The main losses happened in the non superconducting parts of HERAp. Fig. 2b shows the loss rates of 4 selected BLMs ("short" memory) archived at the same moment. The upper part of the figure shows the losses measured by BLMs located in the non-superconducting part while

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[2]The calibration counts/proton increases linearly with momentum while the allowed count rate decreases exponentially.

the lower pictures are from BLMs located in the superconducting region. The dashed lines indicate the individual threshold of the monitors. After 9 BLMs had reached their threshold, the beam was aborted. This is the reason for the abrupt drop in the rates just before the memories were frozen (right side).

Before the BLM-alarm-system had taken action, a rate of about 6 beam loss induced quenches per month was present (causes include malfunctions of power-supplies, HF-system, operators). After the installation of 1/4 of the BLM-alarms, the rate was reduced to 3 quenches per month. No beam loss induced quench has been observed since all BLMs (262) have been connected to the Alarm-Loop, while the rate of dangerous beam losses has remained constant at about 6 per month (Fig. 3). During nearly one year of operation, 6 beam aborts were produced by an error in the serial link to the counters. Except these events, no beam aborts were initialised by BLM-alarms without strong preceding losses.

Lifetime

The method of counting coincident events has the advantage that the number of dark counts is negligible. Therefore very small loss rates are detectable. Assuming that all possible positions of losses are covered with BLMs (collimators, quadrupoles, aperture limitations), one can calculate the lifetime of the beam from the measured loss rate by taking into account the calibration of the BLMs at each position. The summation of all "short" memories in terms of lost protons/time related to the actual total current in the ring can be converted directly into the lifetime of the beam. The lifetime determined from the current-decrease agrees with the loss-lifetime within a factor 2 over the whole momentum range and from very short lifetimes (<1 h) to more than 100 h. This indicates that the calibrations of the BLMs are correct within this factor if the assumption above is correct.
The determination of very high lifetimes (> 100 h) from the current monitor requires a very precise measurement of beam current differences. An integration time of a few minutes is adequate for a reliable measurement without strong fluctuations. The BLMs determine the lifetime in a few seconds because the total signal is large enough and a measurement of differences is not needed. The integration time is restricted by the readout-time for all 262 BLMs.

Summary

The technique of "counting" beam losses with two PIN-photodiodes offers a reliable, simple and cheap Beam-Loss-Monitor with a very high dynamic range. During two years of operation of 262 BLMs in HERA, only one monitor and one counter failed. The protection of the superconducting magnets from beam loss induced quenches is favourably achieved by this system. The BLMs calibrated in terms of lost protons/time provide a fast measurement of the lifetime of the beam up to several hundreds of hours. The monitors are insensitive to synchrotron radiation. Up to electron beam currents of 15 mA at 26.67 GeV/c no additional counts have been observed. Thus, these BLMs can be used at high energy electron accelerators, too. For lifetime studies at the HERA electron ring, the HERAp-BLMs were mounted temporarily on the inside of the electron beam pipe. They provide a clearly detectable signal indicating the position of lifetime limiting sections [11, 12]. It is planned to install in 1994 an equivalent BLM system in HERAe with about 250 monitors. Also the results of 8 BLMs installed in the synchrotron radiation source DORIS III (4.6 GeV/c) indicate their use for electron accelerators with a large amount of synchrotron radiation [13].

A Surface Mounted Device (SMD) - version of the BLMs will be available in the near future; reducing the dimensions of the monitor. These very handy devices can be used easily as beam loss monitors in accelerators where time and space distributed losses have to be determined.

Acknowledgements

The idea of counting the losses by PIN-diode coincidences was born in discussions with J. Bailey and K.H. Mess. The amplifier and the counting module were designed by M. Swars; some important details were added by K. Willmer. The SMD version of the monitor has been pushed by K. Unser. Mr. H. Schultz has spent lot of time in the HERA tunnel to guarantee a proper installation of the monitors at the two HERA rings. Additional thanks to K.H. Mess and P. Duval for very useful comments to this manuscript.

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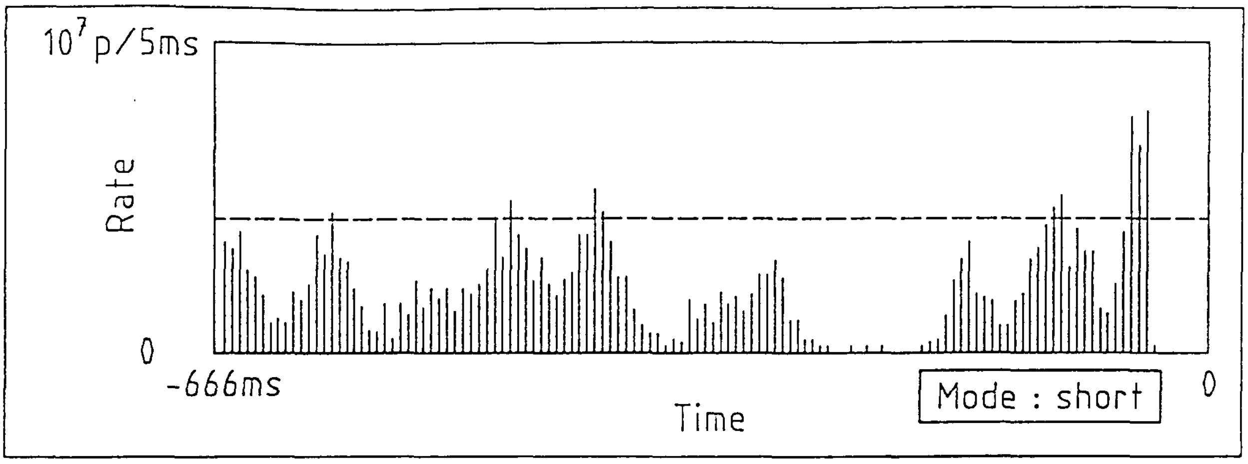
Fig. 1a



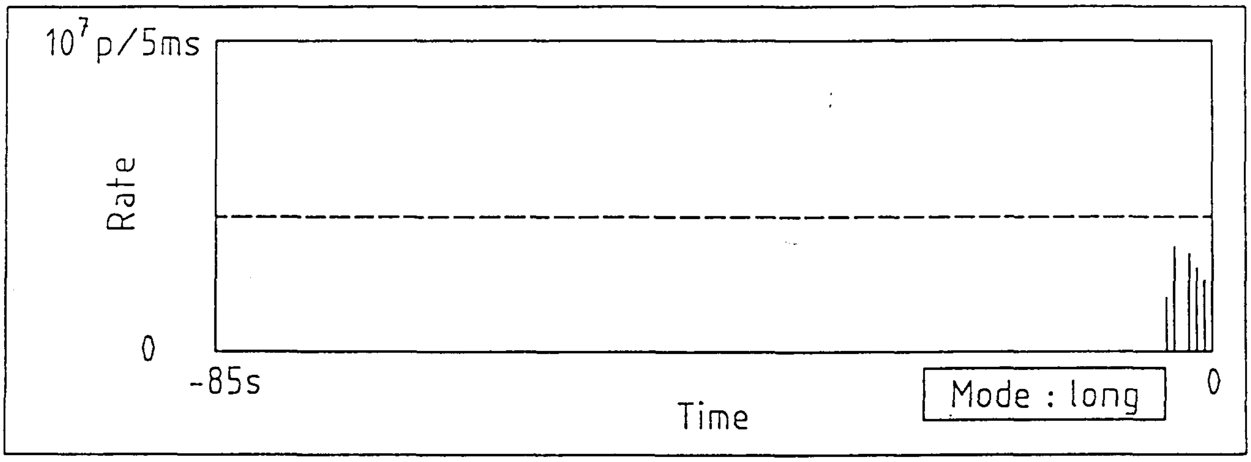
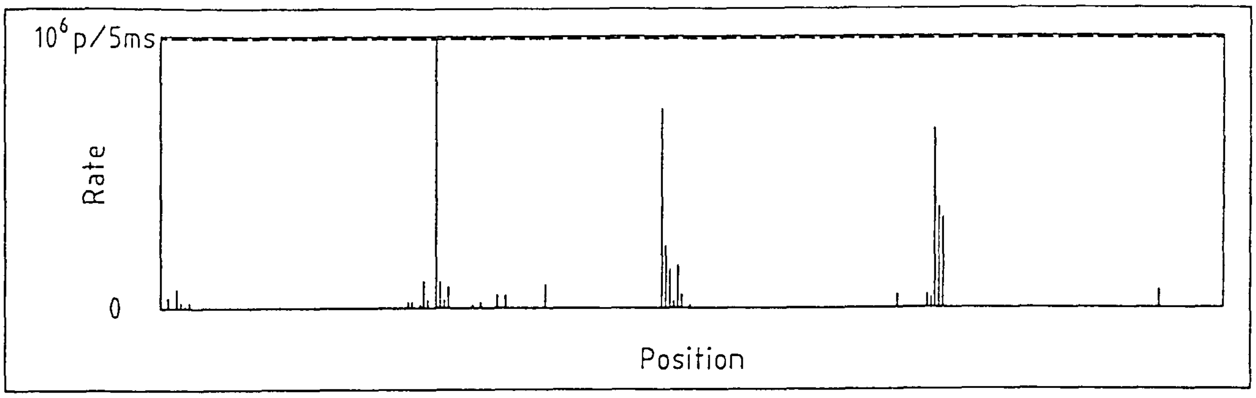


Fig. 1b

Fig. 1a: The loss rates measured by a BLM at position OR 32 at 820 GeV/c. The vertical scale is the number of lost protons. One line corresponds to a time bin of 5.2 ms. The last 666 ms before a fast beam abort (right end) initialised by the BLM system are shown. The dashed line indicates the threshold of this monitor at this beam energy (5 x 10^7 protons/5.2 ms).

Fig. 1b: The loss rates of the same monitor from the "long" memory. One line indicates the mean loss rate during 5.2 ms integrated over 666 ms. The last 6 lines show the loss behaviour during the last 4 seconds before the beam was aborted.

Fig. 2a



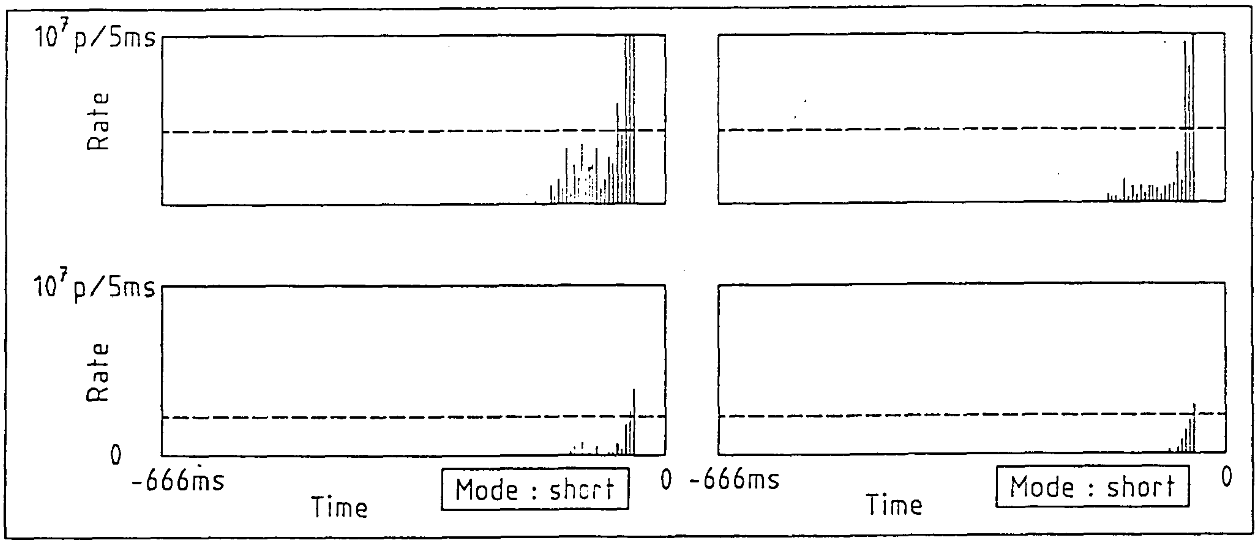


Fig. 2b

Fig. 2a: A display of the loss rates around the HERAp ring. Each line represents the loss rate of a BLM. A single BLM can be selected by a cursor and the mean loss rate of this monitor in the last 666 ms is displayed at "LOSS:".

Fig. 2b: The "short" memories of 4 selected BLMs from the same event. In this case, the losses increase quickly and reach the thresholds in less than 100 ms.

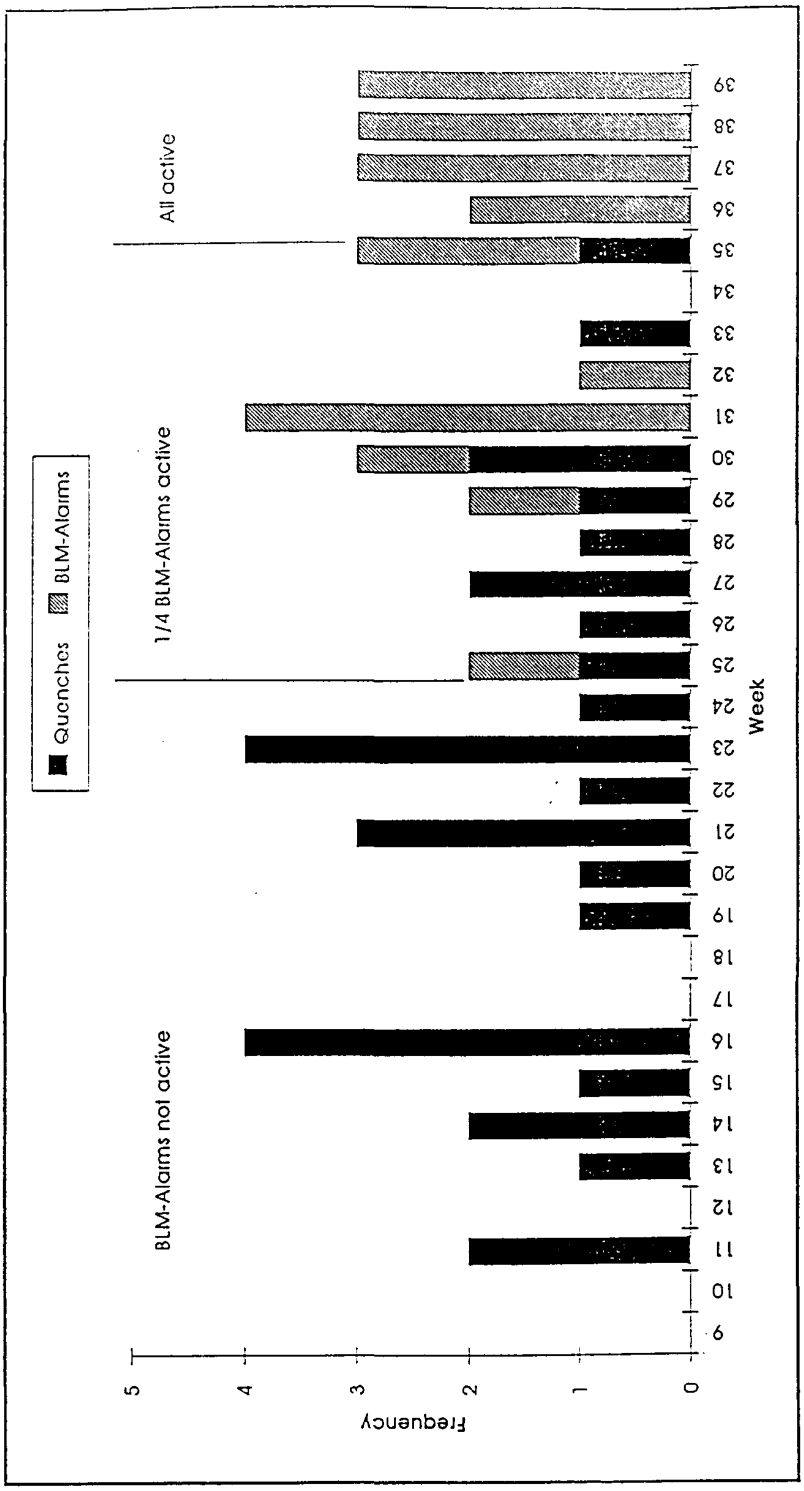


Fig. 3: Statistics of beam loss induced quenches and beam aborts due to BLM alarms in 1993. After week 26 HERA was running for luminosity routineously.