Electron Beam Loss Monitors for HERA

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Abstract

A serious beam current limitation character-
ised by very short lifetimes of the electron
beam was first observed in HERA in 1992.
Beam Loss Monitors (BLMs) were installed
around the entire ring to locate the regions
and diagnose the causes of the beam losses.
For this task, the PIN-diode BLMs used at the
HERA proton ring were moved temporarily to
the electron ring at the end of 1992. The
successful results led to the construction of a
dedicated BLM-system for the electron ring
which was installed at the end of 1993.
This paper includes a description of the meas-
urements the with this new electron BLM-sys-
tem and a comparison with simulation results.

1. INTRODUCTION

HERA consists of two storage rings, a super-
conducting ring designed to store 163 mA
protons at 820 GeV/c and a normal conduct-
ing ring designed to store 58 mA electrons at
30 GeV/c. The proton ring is equipped with
262 PIN-photodiode beam loss monitors
(BLMs) which are used to prevent beam loss
induced quenches of the superconducting
magnets [1,2]. The monitor consists of two
PIN-photodiodes (2.75 x 2.75 mm^2) mounted
face to face and used as semiconductor count-
ers. The coincidence counting readout tech-
nique make the BLMs insensitive to synchro-
tron radiation while they are sensitive to
charged particles [3]. Therefore this type of
BLM can be used at high energy electron ac-
celerators, too.
A beam current limitation at the HERA elec-
tron ring characterised by very short lifetimes
was observed in 1992 . Below 3 mA the life-
time was stable in the order of several hours
at 26.7 GeV/c. Above this current the lifetime
was observed to drop suddenly by about one
order of magnitude. At the end of the 1992
collision run the proton BLMs were moved to
the electron ring and mounted on the inside of
the vacuum chamber. Using these monitors
the position of a heavy localised beam loss
was clearly identified. After the removal of
two adjacent vacuum chambers a higher cur-
rent with a stable lifetime was reached, but
lifetime problems were still present. While
the BLMs are important at the proton ring,

214 similar PIN-BLMs were installed in 1993
to study the problems in detail. The PIN -
photodiodes have an active surface of 0.75 x
2 cm^2 and an additional lead shield. The
measurements and a comparison with simula-
tions are discussed in the following.

2. THE LOSS MECHANISM

Electrons loose energy ΔE due to inelastic
scattering (Bremsstrahlung) mainly on the
nuclei of the residual gas molecules. The
deviation of the electron orbit from the nomi-
nal orbit depends on the dispersion function in
the accelerator and on ΔE. The electrons may
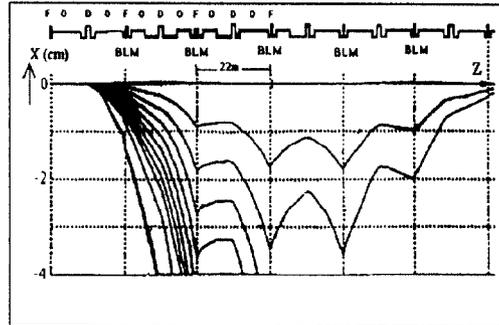be lost at one of the next dispersion maxima
(Fig. 1).

Figure 1: Path of electrons with an energy
loss of $\Delta E/E$ = -1% to -10% though a FODO
structure. x is the horizontal displacement of
the electrons. The pipe wall starts at x = ±4
cm.

Therefore these maxima are the most
sensitive positions for measurements of beam
losses (in HERAe: horizontal focusing
quadrupoles in the arcs). The lifetime of a
stored electron beam is normally limited by
the average vacuum pressure in the beam
pipe. Under special conditions, micro
particles can be trapped by the electron beam,
resulting in a decrease of lifetime and an
increase of beam losses at these maximum
[4].

3. MEASUREMENTS

A measurement of the vacuum distribution in
the ring can be made based on the average
rate of the BLMs. Tests with small nitrogen
inserts in the vacuum system indicate that the

count rate of the BLMs is proportional to the measured vacuum pressure in the ring over a few orders of magnitude (see Tab. 1).

Position	Pressure	BLM-rate
OL287	1.00E-06	5.40E+03
NR428	8.00E-09	9.70E+01
OR545	1.00E-10	5.00E+00

Tab. 1: Vacuum pressure versus BLM-rates at some exemplary positions in HERA at a low synchrotron radiation level (12 GeV/c).

An example with limited lifetime shows Fig. 2a, a reversible (at 22:00) and an irreversible drop in the lifetime (at 23:00). Fig. 2b, c show the rates of selected BLMs measured at the same time.
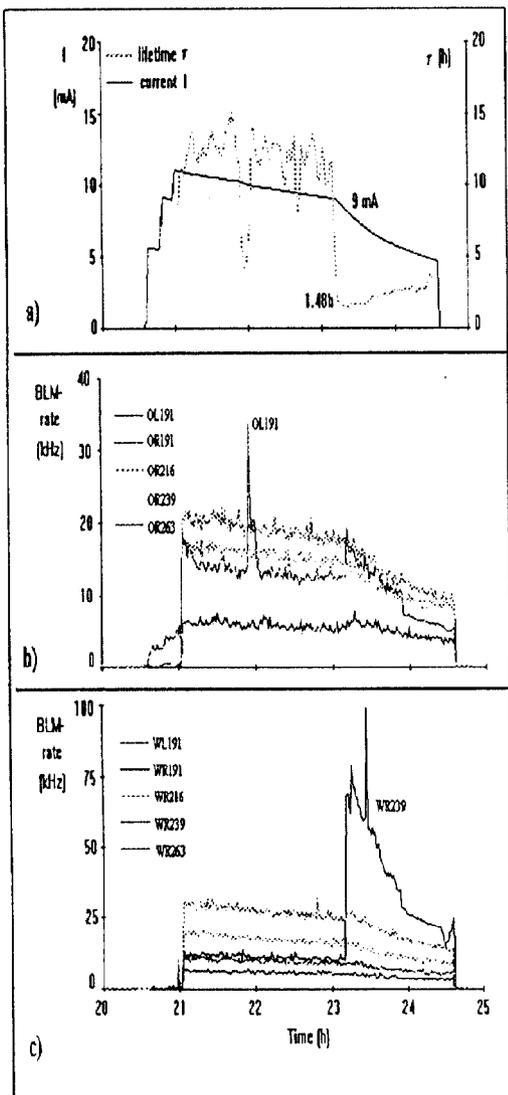

Figure 2: a) Electron beam current and lifetime versus time, b,c) response of selected BLMs in the east and in the west areas of HERA.

At long lifetimes at 26.7 GeV/c, the BLMs have a background rate of about 10 kHz coming from synchrotron radiation. During the reversible drop in the lifetime the count rate of the BLM located at the section east (OL191) is increased while the other monitors are not affected. During the irreversible drop the count rate of a single monitor (WR239) dramatically increases, with no effects in nearby monitors, indicating very localised problems in the ring. These problems were seen to recur in the same locations. A therapy to cure these problems was to reduce the high voltage of the integrated ion pumps near these positions. After these studies a maximum current of 30 mA at 26.7 GeV/c with a lifetime of several hours was reached.

4. SIMULATIONS

In the following we present the calculation of the efficiency of the detection of electrons lost in the arc. We assume that the beam loss of Fig. 2 comes from a local pressure bump at a certain position in the HERA arc. The electrons undergo inelastic scattering on the trapped ions and loose energy. From Fig. 1 one can see that the electrons with $\Delta E > 2$ % hit the beam pipe wall within the next 20m around the adjacent BLM. An electron which hits the wall creates an electromagnetic shower. We have used the EGS4 Monte-Carlo program to calculate the distribution of charged particles leaving the beam pipe. Fig. 3 shows the distribution of these particles with an energy $E \geq E_{min}$ (E_{min} = minimum ionising) created by 26.7 GeV/c electrons. Most of the shower particles are distributed over about 14 cm. Therefore the BLM viewed a part of 14cm/20 m (=0.7%) of the lost electrons. Within these 14 cm, the PIN - photodiodes are crossed by about 0.29 charged particles per lost electron. The efficiency ε of the BLM is determine to 0.3 counts per MIP (minimum ionising particle) (Ref. 5). This results in a mean count rate of:

$$6.1 \cdot 10^{-4} \text{ counts/lost electron.}$$

From Fig. 2 one can see that all of the electrons at the irreversible lifetime drop are lost around one BLM. The lifetime dropped to $\tau = 1.48$ h at I = 9 mA corresponding to a lost rate of $1.4 \cdot 10^8$ electrons/s. This gives an expected count rate of

$$3.1 \cdot 10^{-4} \cdot 1.4 \cdot 10^8 = 91 \text{ kHz.}$$

The measured increase of the count rate is 69.2 kHz which is consistent with the calculated value. More detailed calculations
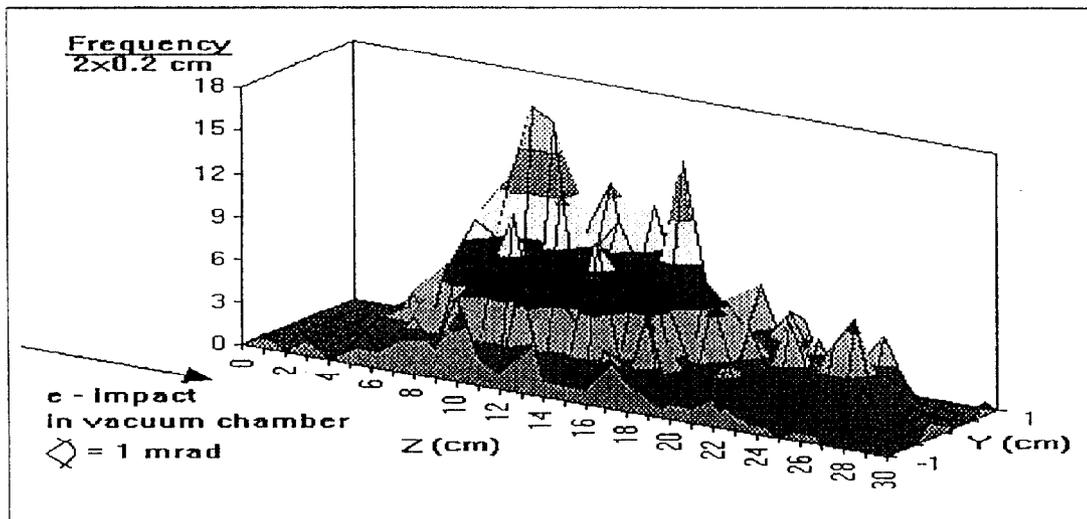
Figure 3: Shower leakage distribution (charged particles) on the side of the beam pipe surface. Z is the direction of the electron beam. The loss occurs at (z,y) = (0,0). The wall thickness is 1 cm copper and 0.5 cm lead. The simulation is based on 202 primary electrons.

are in preparation (Ref. 6). A lifetime measurement of the electron beam with the BLMs similar to the proton beam is possible after calibrating each BLM

5. CONCLUSIONS

The PIN photodiodes BLMs at HERA were originally designed to measure the beam losses at the proton ring in the presence of strong synchrotron radiation and with a very high dynamic range (10^9). These tasks are utilised at the electron ring, where these type of BLM provides a sufficient signal to background ratio which will not be reached by other types of BLMs (Ref. 7 and 8). Even with very high synchrotron radiation background (26.7 GeV/c) the BLMs are sufficient to detect strong local losses which reduce the normal lifetime of the beam by about one order of magnitude. Similar results were obtained in the synchrotron radiation source DORIS III (Ref. 9). The response of the BLM system to losses is well understood at the HERA proton ring as well as at the electron ring. The Monitors are small, cheap, easy to handle and radiation resistant. The development of a smaller SMD version of the BLM is in progress.

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