EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — SL DIVISION

CERN SL-99-042 BI

COMPARATIVE TEST RESULTS OF VARIOUS BEAM LOSS MONITORS IN PREPARATION FOR LHC

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Different types of detectors have been tested in the SPS ring and secondary beam lines with a view to their possible use for this application.
This paper describes the measurements made with: microcalorimeters at cryogenic temperatures, PIN diodes, ionisation chambers, scintillators, and ACEMs.
Measurements made using proton beams showing their relative sensitivities, linearities in counting or analog mode and minimum detection level will be presented.

Presented at DIPAC
Chester – 16-18 May 1999

Geneva, Switzerland
August, 1999

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Beam loss detectors will play an important role in the protection of the superconducting LHC magnets.
Different types of detectors have been tested in the SPS ring and secondary beam lines with a view to their possible use for this application.

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1. INTRODUCTION

Beam loss monitors, BLM's, are commonly used on most of the CERN accelerators and transfer lines. They usually provide a relative diagnostic aimed to help the operators in their optimisation but also to protect the machine components against loss damages. For cryogening machines where excessive losses will induce magnet quenches their use is becoming mandatory.

For the LHC the "natural" losses level is such that the storage ring cannot be operated without transverse and longitudinal cleaning using collimators.

In the overall LHC project framework we have tested a few candidates [1] having in mind:

1.1 Criteria: First of all it is essential to have an estimate of the loss level, rate and distribution at the detector level. Then it is essential to question the requested time response and on the remnant dose at the monitor location.

1.2 Signal treatment: Two types are considered, the analog and the counting mode. In analog mode the BLM's signal is generally integrated or passed through filters. In counting mode the BLM's signal consists of pulses feeding a counter. Of course both the detector and its electronic must not saturate.

The LHC will be operated with 2835 bunches of 10^{11} protons each, separated by 25ns and distributed in 12 batches, with a revolution frequency of about 11KHz (10KHz for numerical applications).

With energies from 0.45 to 7 TeV, a magnet quench would occur for the following proton loss rates [2]:

Fast losses: $6{\cdot}10^9$p/(m.10ms), and $6{\cdot}10^7$p/(m.10ms) at 0.45 TeV and 7 TeV respectively.

Slow (or continuous) losses: 10^9p/(m.s) and $8{\cdot}10^6$p/(m.s) at 0.45 TeV and 7 TeV respectively.

Our comparative measurements were partially performed on the SPS machine but mostly on a SPS transfer line where a beam (with about 3cm diameter) of 10^4-10^7 protons at 120GeV/c, was extracted during 2.4s. This well monitored extraction line allows us to calibrate our measurements in view of LHC.

After a short description of the tested monitors we will give some guidelines for a preliminary choice of the monitors which could be retained. Data treatment or monitor controls as such will not be tackled in this paper.

2. DETECTORS

Our tests concerned: Scintillators with their PMT's, PIN Diodes, Ionisation monitors, ACEM's and Cryogenic microcalorimeters.

2.1 Scintillators

As is known, these devices emit light in which intensity is proportional to the energy lost by the particle passing through. The scintillator can be shaped in the most appropriate way (plates, cubes, rods,..). In the present case we make use of rectangular and rod shaped one's. Coupled to a Photo-Multiplier Tube (PMT), and associated with an appropriate electronics system, they allow large dynamic ranges in analog mode and in counting mode (up to 10^6 - 10^7). This BLM is very fast and bunch to bunch measurements can be achieved in both cases. Nowadays PMT sockets integrate high voltage power supply thus avoiding high voltage cables and the overall detector can be housed in a small volume (for our set-up l: 270mm, diam: 35 mm). The main drawback comes from the scintillator darkening when used in a high dose level environment. The gain of PMTs varies within a factor 10, a careful intercalibration of their sensitivities is necessary. Lastly this detector is expensive.

2.2 PIN-Diodes

Our experience is based on PIN Diode Beam Loss Monitor developed at DESY [3]. The system consists of two 10*10 = 100mm^2 area PIN diodes mounted face to face. The coincidence read out can measure a maximum count of 10 MHz with an intrinsic noise rate of less 1 Hz, which gives a dynamic range of more than 10^7.

This BLM is sensitive to MIPs with an efficiency >30%, is very fast, not very expensive, and the radiation resistance is rather modest. Experience made at PS, where relative high dose levels are of concern showed that the detector lifetime did exceed one year.

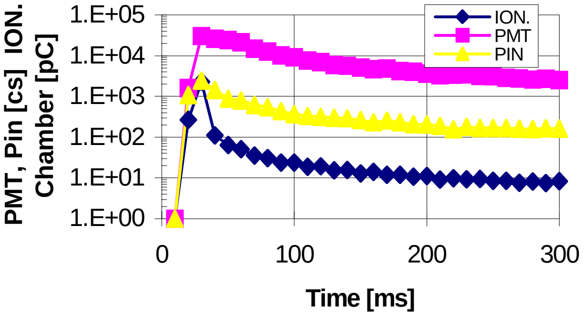

Figure 1: Losses on: PMT, Pin [counts], and Ion chamber [pC], during the first proton injection in the SPS ring.
It appears that the PMT and PIN are saturated.

We are now also considering smaller active area (0.5 – 10 mm^2) devices to get a higher bandwidth (more than 40MHz) and for other reasons, which will appear later. The diodes are commonly used in pulsed mode but analog mode has also been considered.

Pulse mode. Some estimates made for LHC [4] show that a 1cm^2 diode, placed a few meters from the proton impact, will deliver 1 pulse at 0.45 TeV for 1547 lost protons and 1 pulse at 7 TeV for 172 lost protons. These numbers are probabilistic since the shower simulation supposes that MIP passing through the active area follows a Poisson distribution.

As an example let us suppose that the 1cm^2 diode and its electronic can operate above 40 MHz (which is not the case), and that each bunch loses the same number of protons. For fast losses, inducing a quench at 0.45 TeV, the “theoretical” number of lost protons by one bunch every turn will be: $6\cdot10^9/(2835\cdot100) = 2.12\cdot10^4$ which is much larger than $1.54\cdot10^3$. The diode will saturate since it will deliver 1 pulse when 1547 or more protons are lost. In this range the detector will not be linear. A more detailed statistical analysis show that saturation occurs at a level which is about a factor 10 less (i.e. when more than $1.54\cdot10^2$ protons are lost per bunch and per turn at 0.45 TeV). Saturation effects are even more pronounced, at quench levels, when only part of the bunches (or batches) are of concern. For slow losses saturation should not be feared but care must be taken as accuracy is concerned.

A way to have less probability for such a drawback is to reduce the diode area. Anyway, saturation occurrences cannot be easily diagnosed by the operator. Of course such an effect exists for scintillators. An example is given by Fig. 1 comparing the pulse rate of a PIN-diode assembly and large area Scintillator for which saturation becomes evident (since then more than 1 particle is passing through the detector during its time response).

2.3 Ionization Based Monitors

We used two types of monitors:

a) The New SPS ionisation chamber with a multi-electrode layout (distance between the electrodes is about 5mm) to reduce the drift path and the recombination probability of the ions and electrons, and hence to improve the linearity. Two chambers are housed in the same body with equal volume about 300 cm^3 each.

Linked to two analog type electronics with different gains a very large dynamic range of 10^7 can easily obtained which allows simultaneously measurements with fast and slow losses.

These chambers, filled with air, are fast: the pulse rise time is about 1 µs, and the sensitivity is about $5*10^{-6}$ C/Gy [1Gray = 1Joule/kg].

This BLM is very sturdy, the radiation resistance is very good, and it is not expensive. The leakage current of BLM is less than 1 pA, with short cables between the chamber and the electronic $5*10^3$ particles can be detected (Fig. 2).

b) The ISR ion chamber made from a modified low attenuation air cored coaxial cable (l: 1m vol.: 200 cm^3) [5]. This BLM has about the same characteristics as the New SPS ionisation chamber. These two types of BLM are mainly used in analog mode and linked to very low bias current (<100 fA) amplifier or integrator can give high sensitivity, which allows very good measurements.

In the LHC the deposited energy per lost proton [4] is $6.2\cdot10^{-13}$Gy at 0.45 TeV and $3.8\cdot10^{-12}$Gy at 7 TeV. In the worst case, with slow losses at 7 TeV, the ionisation chamber will give about 150 pC/s large enough to make a good detection.

Comparative measurements made on SPS (Fig.1) clearly indicates the PIN-Diode and PMT saturation effect could not be traced without the use of ionisation chambers.

2.4 ACEM

The Aluminium Cathode Electron Multiplier is a photomultiplier where the photo-cathode is replaced by an aluminium foil. This foil works as a secondary electron emitter when irradiated. This detector has been intentionally developed at PS for the purpose of beam monitoring. The dimensions of the tube are 4 cm in diameter and 10 cm length. This BLM is very fast: rise time of signal <10ns, and by adjusting the HV the dynamic is more than 10^3, at high gain has sensitivity for MPI’s, and acquisition in counting mode may be done. With medium gain the Anode Dark Current is less than 100pA, low enough to make good measurements in analog mode. Bunch to bunch measurements can be achieved in analog and counting mode.

This commercial tube, although expensive, can operate in a radioactive environment.

Comparative measurements made with an ACEM and an ionisation chamber in analog mode show a very good linearity and a relative gain of 700 (Fig. 2).

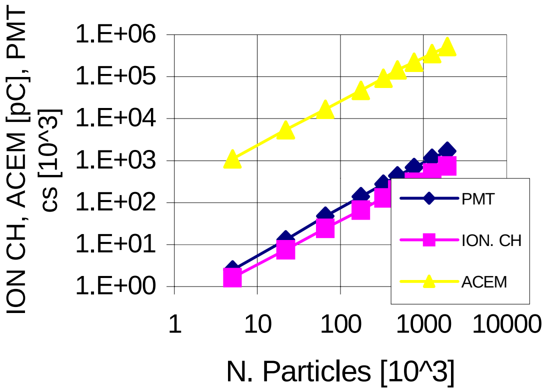

Figure 2: PMT output counts or, ACEM and Ion chamber [pC], versus number of particles crossing the detectors.

2.5 Cryogenic Microcalorimeter

This type of monitor, placed on the cryostat, has already been reported [6]. It uses the properties of carbon resistors which exhibit large values at low temperatures (R (T = 300°K) =100Ω, R (T = 1.8°K) =10^5Ω).

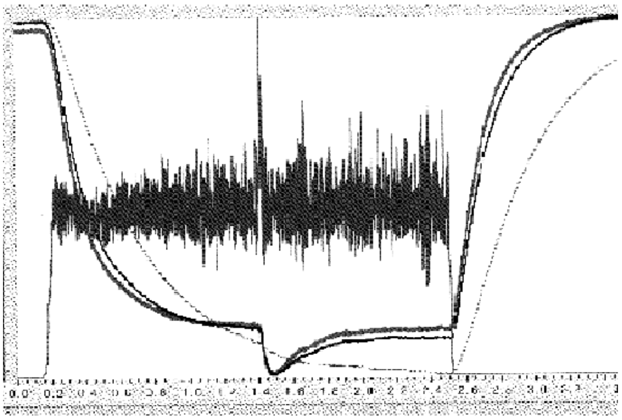

Figure 3: Cryogenic μ-cal. Voltage variation of different resistors as a result of particles crossing the monitor during slow extraction which spill is represented by the “rectangular” plot. Ordinate: arbitrary Units, Abscissa: Time [s].

The carbon resistor is encapsulated in a copper block through a small thermal resistance. The ensemble “block + resistor.” is coupled through a larger thermal resistance to the cryostat. The deposited energy [4], 3m away from the proton impact point on the vacuum chamber, is $53 \cdot 10^{-4}$ GeV/ $2cm^3$ at 0.45 TeV and $4 \cdot 10^{-2}$ GeV/$2cm^3$ at 7 TeV.

A reasonable temperature resolution is ΔT = 1m°K such that the corresponding lost proton resolution is equal to Np (0.45TeV)=10^6 and Np (7TeV)=10^5 which is acceptable for the upper LHC loss range.

The time response to losses is about 150ms, Fig. 3 shows a typical measurement made on the SPS transfer line. The “exponential” curves represent the time response of 3 different resistors. At about 1.4s an instantaneous extra-loss is induced which is detected by two of the fastest resistor. A higher sensitivity and faster response time could be obtained with sapphire replacing copper.

A variant is the use of liquid helium ionisation chambers.

3. CONCLUSIONS

According to our measurements a preliminary use of BLM’s could be as follows:

a) In the transfer lines, where the beam passes only once: ionisation chambers, used in analog mode,

b) In the cleaning zones (where magnets are hot) the relative high remnant dose level must be taken into account. One could therefore consider ACEM’s if individual bunch behaviour need to be analysed and ionisation chamber for slower processes,

c) For the ring cryogenic part, if individual bunch or batch losses must be analysed, PIN-Diodes of different sizes should be used. For slower processes (i.e. integration over 5-100 LHC turns) and more linearity the ion chamber should be also used, as well a long cable of length up to 15m would give valuable measurements for eventual helium leaks.

For special monitors where sensitivity, linearity and high speed are required the PMT will be the best detector.

The Cryogenic Microcalorimeter is probably too slow and has not enough sensitivity for all these applications.

Our monitor comparative tests were based on estimates for LHC obtained from simulations. Even if the actual losses would differ from simulations by one decade, the proposed choice will still remain valid. As shown the choice depends on the type of losses, the data treatment and the dose level at the locations where detectors are placed.

REFERENCES

[1] J. Bosser, G. Ferioli, Part I in PS/BD/Note 97-01 or SL/BI/Note 97-08; Part II in PS/BD/Note 98-03 or SL/BI/Note 98-027; + Private communications.

[2] J.B. Jeanneret, LHC Project Report 44.

[3] K. Wittenburg, NIM A 345 (1994) 226-229.

[4] T. Spickerman and K. Wittenburg LHC Project Note 124 + Private communication.

[5] Tech. Note ISR-OP/BH/cc/TN 76, ISR Performance report Run 1116, 26GeV.

[6] J. Bosser et al, LHC Project Note 71 (1996).