BEAM LOSS MONITORS COMPARISON AT THE CERN PROTON SYNCHROTRON

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Abstract

CERN is planning the renovation and upgrade of the beam loss detection system for the Proton Synchrotron (PS). Improved performance in speed–to be able to monitor beam loss on a bunch-by-bunch basis–and in long-term stability–to reduce or avoid the need for periodic calibration–are aimed for. To select the most suitable technology, different detectors were benchmarked in the machine with respect to the same beam loss. The characteristics of the different detectors, the results of the measurement campaign and their suitability as future monitors for the PS are presented.

INTRODUCTION

The existing beam loss monitor (BLM) system of the CERN Proton Synchrotron (PS) is based on ACEM (Aluminium Cathode Electron Multiplier) detectors installed in the late 1980s [1]. The detectors are mounted on top of each of the 100 main magnets of the PS (see Fig. 1).

This type of detectors has to be re-calibrated every year [2], due to the ageing of photomultipliers which causes a degradation of the homogeneity of the response of the devices to the same loss. During the calibration, the detectors are removed from the tunnel and calibrated with a known radiation source. This operation involves the exposure of technicians to a radiation dose that could be avoided if monitors not requiring periodic calibration were to be installed. In addition the current acquisition electronics is very old and no longer maintainable. The renovation of the system therefore foresees both new monitors and new acquisition electronics. In addition to the standard measurement of integrated losses on the microsecond level, some fast detectors will be required for the study of bunch-by-bunch losses during critical locations such as injection and extraction. Several different monitors were therefore compared with a given common loss in order to study their time response and hence suitability as BLM detectors for the PS. The renovation of the system is planned in the near future, using new detectors for which the calibration is not required.

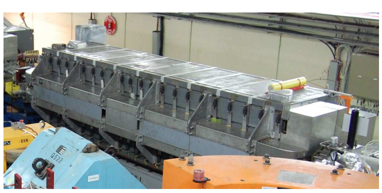

Figure 1: PS main magnet with a LHC-type BLM (yellow cylinder on top of the magnet) and an ACEM (orange cylinder in front of the magnet).

DETECTOR TYPES

A beam loss measurement campaign was done by using four different types of new monitors, and compared to the standard ACEM, each with the following characteristics (see also Table 1):

ACEM

The ACEM active part is composed by a glass vacuum tube with a thin aluminum sheet as a cathode and, next to the cathode, a 10-stage electron photomultiplier (CsSb). Secondary particles produced by the beam loss interacts with the cathode, where electrons are produced and directed toward the first stage of the photomultiplier, to reach a maximum multiplication factor 10^6. The ACEM BLM has a fast time response and a high sensitivity, but its small size provide a small solid angle coverage of the beam loss particle shower and the detectors saturate with large losses.

LHC Ionization Chambers or LHC-BLM

LHC ionization chambers are currently in use in the LHC as part of the machine protection system [3]. The detectors are ionization chambers with parallel aluminum electrode plates, forming a very large volume of about 1.5 liter filled with nitrogen gas at 1100 mbar. These detectors have a slow time response, about 89 μs, due to the drift time of the ions in the gas which is about 300 μs, whereas the electron have a drift time of only about 100 ns. Their sensitive volume provides a very large solid angle coverage. They do not require regular calibration.

LIC

LIC are ionisation chambers built as the LHC-type BLMs, but with a reduced volumes. For this reason, they are expected to saturate for higher losses, to be faster, but to cover a smaller solid angle. They do not require regular calibration. Two chambers were tested, one with a pressure of 0.1 bar, the second 0.01 bar.

SEM

A SEM (Secondary Emission Monitor) detector is composed by three electrodes, one signal electrode (middle) and two bias electrodes. When a particle goes through the signal electrode, it excites the conduction bands and inner shell electrons. The current created by the drifting electrons is measured between the signal and the bias electrodes. This kind of device saturates for losses much larger than the others, it has a high linearity and a fast time response. On the other hand, it has a low sensitivity (70 10^3 times less than and LHC-BLM) and typically it is used for measurement of very high losses, e.g. near collimators or dumps. It is has a reduced size and does not require regular calibration.

PEP-II

The active part of the PEP-II detector, a 1 cm^3 Fuse-silica Cherenkov crystal counter coupled to a small and rapid Hamamatsu PMT, is contained in a shielding box of 5 mm thick lead. Those detectors were used in the past in the PEP-II lepton collider [4], and more recently in the UA9 experiment [5]. There is no data available about the aging due to the radiation from protons and the linearity has to be tested for very large proton losses. The detector is pretty small, comparable to the ACEM and probably would require calibration due to the aging of the active volume due to radiation.

Table 1: Summary of BLMs Characteristics

Type	Response [ns]	Active area L x D [cm]	Voltage [kV]
ACEM	10	9 x 4	0.85
LHC-BLM	½ 3 10^5 / ½ 100	48 x 8.5	1.5
LIC	½ 3 10^5 / ½ 100	6 x 8.5	1.5
SEM	2	6 x 8.5	1.5
PEP-II	2	15 x 4	0.5

MEASUREMENT SETTING UP AND RESULTS

The different devices were installed on top of the main magnet just after the injection magnetic septum, near each other to acquire at the same time, with the same beam and the same losses, at least four detectors. Figure 2 shows a scheme of the monitors installation and Fig. 3 the installation in the PS tunnel.

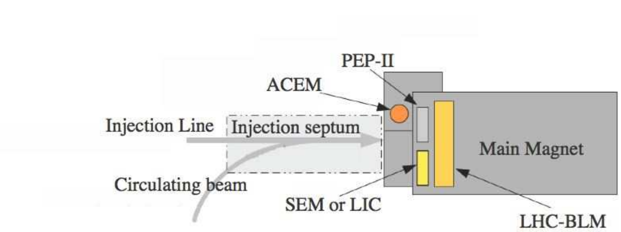

Figure 2: Sketch of BLMs installation in the PS injection.

Figure 3: Test BLMs installed on top of the main magnet. The dectectors are installed according to Fig. 2.

The measured losses are created by the interaction of the beam from the injection line and the blade of the injection septum. The detectors, connected directly to a 1 GHz oscilloscope, are triggered only for the first beam passage. Unfortunately, it is not possible to deduce from the device measurements the amount of beam which locally lost, since the intensity of the secondary particle shower reaching the detectors is not known. An upper limit of the beam loss can be deduced from the beam current transformers: a maximum of 5% losses all around the ring are usually observed during the injection process. Two different beams, both at the injection energy of 1.4 GeV, were measured (see Table 2).

Table 2: Summary of Beam Characteristics

Beam id.	Num. of bunches	Tot. Int. 10^{13}	Bunch length [ns]
TOF	1	0.85	≈ 234
CNGS	8	2.3	≈ 173

The beam loss data acquired by the BLMs are compared to the one obtained by a wall-current monitor (WCM), a fast pick-up used to determine the longitudinal structure of the beams. The WCM acquisition is limited to seven bunches, so the fall time of the detectors cannot be compared directly to the longitudinal structure. Figure 4 shows

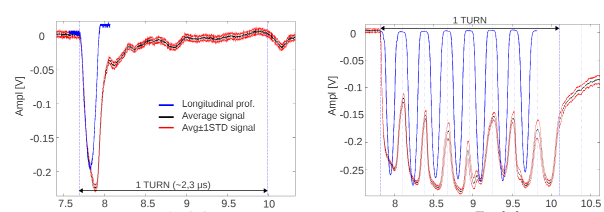

Figure 4: ACEM data for the TOF beam (left) and the CNGS beam (right). Red: BLM signal. Blue: WCM signal.

the signal of the PS-BLM standard ACEM detector compared to the bunches as measured by the WCM. The detector can clearly distinguish the single TOF bunch (left plot) and every single bunch of the CNGS beam (right), even if the signal does not reach zero between the bunches, sign of either saturation of the PMT or of remnant radiation in the detector.

Figure 5 shows the same measurement of the PEP-II as for the ACEM for the same beams: the detector can follow much better the bunch as seen from the WCM, and at every single bunch of the CNGS beam the detector signal goes clearly to zero. The device can also distinguish different losses within each bunch. Figure 6 shows a comparison of

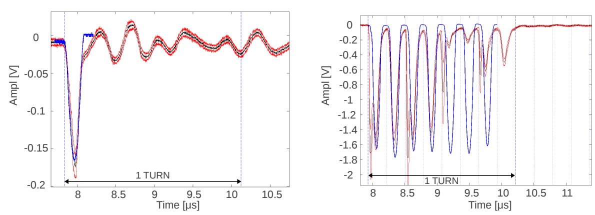

Figure 5: PEP-II data for the TOF beam (left) and the CNGS beam (right). Red: BLM signal. Blue: WCM signal.

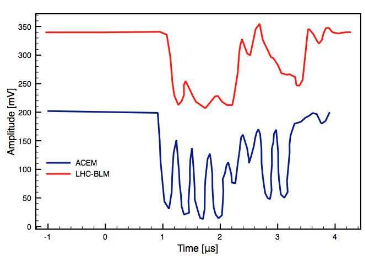

Figure 6: ACEM signal (blue) compared to the LHC-BLM (red) for the CNGS case. The vertical offset is introduced artificially to separate the two curves.

the data acquired for the CNGS beam between the ACEM and the LHC-BLM: as expected the LHC ionization chamber cannot distinguish between the bunches, being the drift time of the ions too long (½ 300 μs and ½ 100 ns) compared to the bunch spacing of only about 170 ns. Figure 7

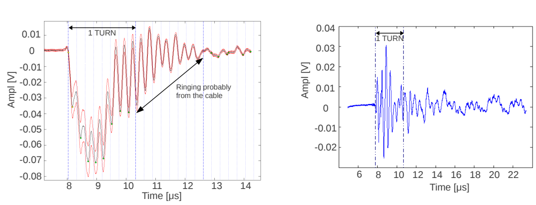

Figure 7: LIC signal (left) and SEM signal (right) measured with the CNGS beam.

present the signals of the LIC (left) and the SEM (right). In the case of the LIC, the signal continue to resonate, as indicated in the picture, even after the other detectors are not counting any longer. This could be an effect of non-adapted signal cable, meaning that in case this detector would be chosen for the system renovation, the existing ACEM cables should also replaced. The SEM, as expected, is not sensitive enough to detect any loss.

SUMMARY AND CONCLUSIONS

Five different type of beam loss detectors were exposed to the same beam losses to allow a direct comparison of their response. The PEP-II Fuse-silica Cherenkov crystal has a similar performance to the existing ACEM detectors, being able to distinguish losses from different bunches separated by about 280 ns. The LHC ionization chamber was too slow to provide the same information, with the electron drift time comparable to the time structure under test. The SEM detector did not provide any data in this test setup as the beam loss was too low to provide a measurable signal. Due to a cabling problem the LIC could not be fully exploited, but subsequent tests in the CERN-PSB and CNGS radiation facility have shown that their sensitivity is an order of magnitude lower than that of the LHC-ICs with a similar response time [6]. LHC ionization chambers or LICs should be well adapted to continually monitor the relatively low losses around the majority of the PS ring on the microsecond timescale, and would remove the need for annual BLM calibration. However, for locations were knowledge of the time structure of the losses is important for accelerator optimization needs faster detectors such as the PEP-II Cherenkov monitors or ACEMs would need to be added depending on the expected maximum loss to be measured. In this context diamond detectors are also under study as possible radiation hard fast BLM monitors.

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