PROTOTYPE RESULTS WITH A COMPLETE BEAM LOSS MONITOR SYSTEM OPTIMIZED FOR SYNCHROTRON LIGHT SOURCES

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Abstract

Beam loss monitors in synchrotron light sources are finding an increasing utility in particular with the trend of numerous light sources pushing to lower emittances and thus higher intra-beam scattering, while operating in top-up injection modes and employing in-vacuum undulators in their rings. The development of an optimized electron BeamLoss Monitor aims at fulfilling, in one single system, all possible functionalities and applications like both the measurement of fast-time-resolved losses at injection and the possibility of ultra-sensitive detection of low & slow electron loss level variations. This optimized beam loss monitor system comprises both the acquisition electronics and up to four sensor head per unit. The sensor heads themselves, that can be configured for different sizes or volumes, are based on the detection of the electromagnetic shower resulting from an electron loss through the use of either Cherenkov radiator or gamma scintillator and a photomultiplier tube, all assembled in a single compact housing ready for installation.

DETECTION PRINCIPLE

The loss of a high energetic electron (i.e. its irreversible departure from the core of the beam) means that initially it will hit the vacuum chamber wall which then starts the creation of a so-called electro-magnetic shower: the initially created particles (electrons & positrons and γ-particles) will themselves create more particles but over a decreasing value of energy. The exact characteristics of this shower like the shape, length, number & type of particles, energy contents etc. depends much on the other obstacles (most often metallic) that the (developing) shower will encounter on its path: in a typical accelerator environment this series of obstacles comprises the vacuum chamber wall, vacuum flanges & pumps, magnet bodies, pipes, cables trays, girders, all kinds of supports and installed systems (valves, insertion devices, cavities) etc. This electro-magnetic shower is generally directed in a forward direction, i.e. in the same direction as that of the initially lost electron. However, each individual electron loss creates its own particular shower which can also have side or even back-scattered effects. Typical beam losses (in a unit of time) imply a significant number of electrons lost at the same location, and it is the sum of all these resulting showers that allows today to simulate and calculate a typical geometric distribution of that electro-magnetic shower (Figure 1).

This shower contains essentially two different types of particles that can be detected: particles with mass (electrons, positrons) and the γ-particles. Both types can be detected by the use of a suitable scintillator or radiator that converts the passage of such high energetic particle into a visible light photon. The detection of a mass-particle can be done with a specific radiator that converts its passage into so-called Cherenkov light, while for the detection of the γ-particles various optimized and highly efficient scintillator materials are available. The choice of the type of detector material depends on various considerations. In both cases, a visible photon is created that now needs itself to be detected, i.e. converted into an electrical signal and then to be recorded.

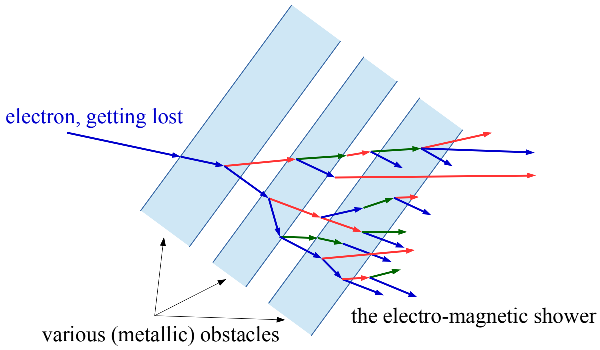

Figure 1: The electro magnetic shower.

The Photo-Multiplier Tube (PMT) will detect the visible light photon at its photo-cathode, and the emitted electron will be amplified inside this PMT and an electric current impulse will be created at its anode. And this anode's output signal will be transported over a cable to the electronics signal acquisition system. The PMT's photo-cathode is optically coupled to the scintillator (or radiator) via its input window. The size (area) of the photo-cathode and that of the scintillator (typically a cylindrical rod) are to be roughly matched so that a large part of the light generated inside this rod is effectively getting to the area of the photo-cathode. Typically diameters of 10 to 25 mm are of practical use.

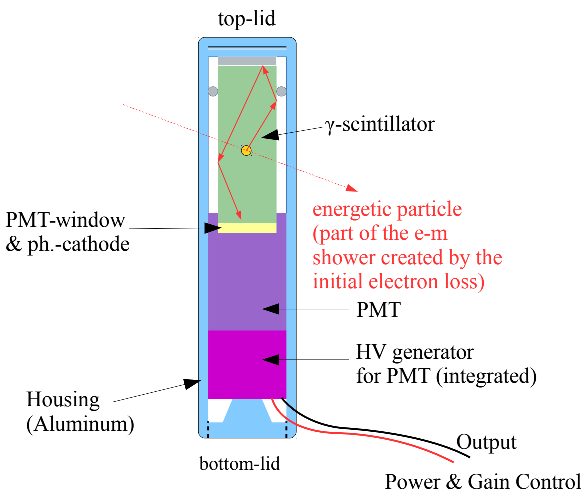

Figure 2: Scheme of the detector.

The scintillator rod and the PMT are housed together in a dedicated single, light weight, aluminum tube structure. This housing maintains the PMT and the rod in a stable and optimum position (for the optical coupling) and has two lids at either end. It is conceived such to make possible an easy, simple and reliable assembly of the components while providing light-tight shielding against ambient light and suitable cable passages. Also an optional possibility to verify or calibrate the detector head with a LED exists.

FIRST PROTOTYPE TESTS

System Installation

The detector shown in Figure 2 was developed at the ESRF and is of medium size with a 25 mm diameter rod. It is able to detect – in combination with a highly sensitive PMT – the signal generated by a single 6 GeV electron loss. The detector is put in a Lead shielding to prevent scattered X-rays (from synchrotron radiation) to contribute to the signal. Therefore only the real electron beam loss signal will be detected. This signal is carried by the γ-rays in the electro-magnetic shower, itself created by a lost electron that hit the vacuum chamber wall. To cover for a variety of potential electron losses the most suitable place of installation is on the internal side of the dipole magnet, since the probability of an electron crashing here at the inside of the dipole's vacuum chamber is higher than elsewhere. However, it should not be installed too close to X-ray crotch absorbers to avoid the effect of back-scattered particles that could originate from here (Figure 3).

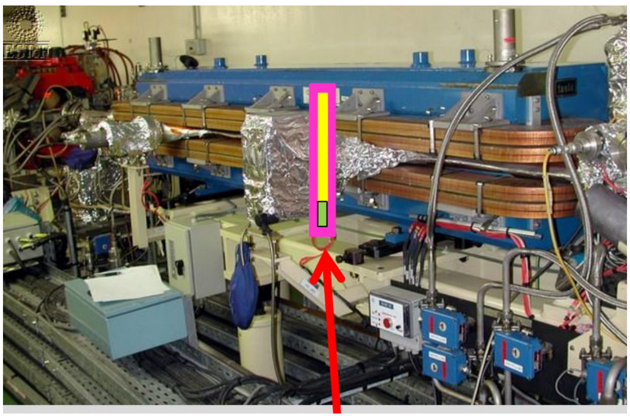

Figure 3: Detector installation.

Acquisition Electronics

The prototype electronics is available at ESRF since 2011. It is based on a Libera instrument that was customized to provide 50 Ω and High-Z (10 kΩ) input impedance. Four input channels support connection to four detectors. Acquired data is available from TANGO Control System and Matlab. Raw data (at ADC sampling frequency) acquisition can be synchronized with injection or other event in the accelerator via the electrical trigger signal. The total buffer size (raw data) is 16384 samples which corresponds to ~40 turns in the ESRF Storage Ring.

Tests at ESRF

Figure 4 shows the losses at two injections. One plot is inversed in the vertical axis for more illustrative presentation. Results indicate the losses (amount, appearance, frequency) vary from injection to injection. These big losses typically come with injection from Booster to Storage Ring. The input channels were set to 50 Ω input impedance. where the high bandwidth (about DC to 8 MHz) offers detailed information with 8 ns time-resolution [1].

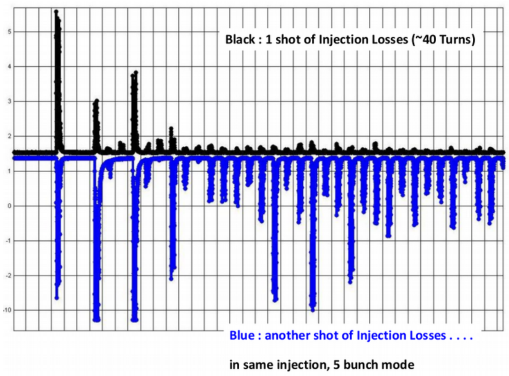

Figure 4: Two injection shots, showing different losses in first tens of turns.

Measurements from Figure 4 were done at 5-bunch fill pattern. Raw data can be further zoomed-in to show losses on a bunch-to-bunch basis. Results are shown in Figure 5.

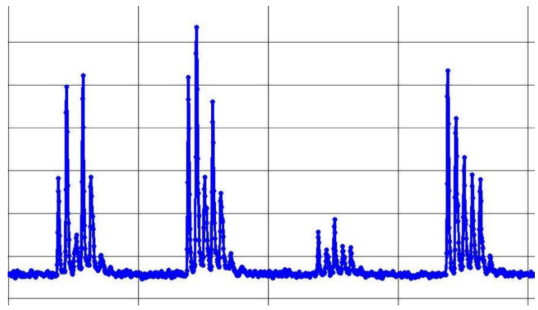

Figure 5: Sub-turn losses.

Monitoring of fast losses is one of the typical operation modes for the PMT where electric pulses are not counted but rather integrated. This differentiates the Libera beam loss monitor prototype from other beam loss monitoring systems.

SECOND PROTOTYPE TESTS

In circular machine (Storage Rings) the (local) losses can be very small in intensity but of varying levels due to small fluctuations of the conditions in the Ring (e.g. vacuum quality, or the change of the transverse aperture like with In-Vacuum Undulators) or of the beam characteristics (affecting e.g. the Touschek losses). By operating the acquisition electronics at Hi-Z impedance and with integration over longer time-scales (milliseconds – seconds) these small variations can be precisely measured. The first prototype electronics offered the input impedance 10 kΩ. This was not sufficient enough – compared to a simple (very slow) digitizer with 1 MΩ input impedance. For the second set of tests, Red Pitaya was used with input impedance 1 MΩ. It was tested in the test stand using the detector with a LED. This way, the single-photon detection ability was confirmed.

Tests at Taiwan Photon Source

Same detector and a Red Pitaya device were used for measurements at Taiwan Photon Source. The detector was fitted to the vacuum chamber just after the injection point from the Booster to Storage Ring (Figure 6). The Storage Ring was operating at ~50 mA in Top-up mode. Injections were done with 3 Hz repetition rate. The scintillator was exposed to beam losses with no Lead shielding to gain sensitivity.

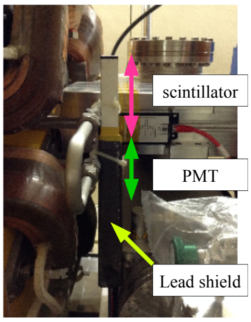

Figure 6: The detector was fitted to the Storage Ring vacuum chamber.

Signal acquisition from the detector was not synchronized with injections due to lack of trigger input on Red Pitaya. However, nice data was read using 50 Ω termination and slightly higher gain setting (+0.7 V) on the PMT. The data did not reveal the details of sub-turn losses like at ESRF but indicated this will be possible with the final electronics (auto/manual triggering, several measurement range options).

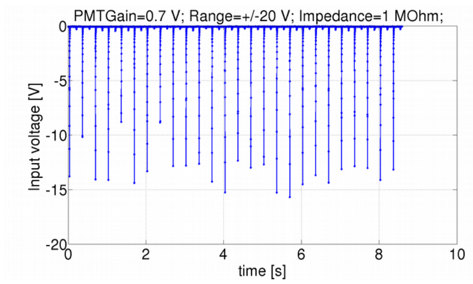

Figure 7: Injection-to-injection losses. Time constant is about 13 ms at 1 MΩ input impedance.

To prove the big losses are indeed present during injections, the input impedance was switched to 1 MΩ and measurement range increased to ±20 V. Red Pitaya contains the command-line utility that does ADC data acquisition with pre-defined averaging factor. This factor was set to highest value (65536) which extends the observation time from 131 µs (no averaging factor) to ~8.5 seconds (averaging factor 65536). Figure 7 shows the losses that result from injections. There are 26 glitches visible in about 8.5 s, meaning about 3 glitches / second (=injections). The time constant of the 1 MΩ input impedance is about 13 ms.

FINAL SYSTEM

The final system will include the detector and the electronics. The detector may be equipped with or without the Lead shielding, depending on which particles it should be sensitive to. The electronics will be built on the new Libera platform and will support signal acquisition from up to 4 detector. At the same time, it will provide the power supply and (independent) gain control voltage to the PMTs making the whole system easy to install and manage (Figure 8).

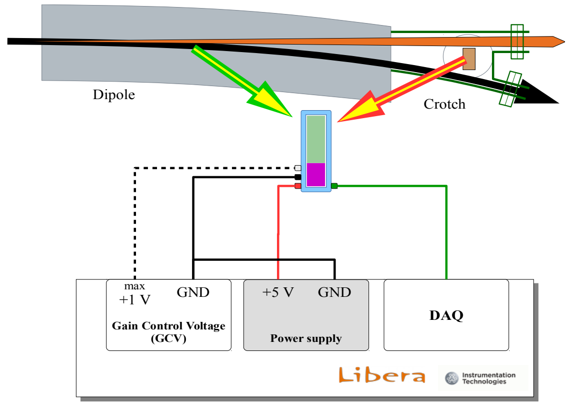

Figure 8: Proposed acquisition electronics including power supply and gain control for the PMT.

Besides the raw A/D data, the digital signal processing will provide the integrated and averaged data buffers with configurable integrating and averaging factors. The switchable input impedance (50 Ω / 1 MΩ) will make measurements of fast and slow losses available from a single instrument. The counting mode (which is more familiar to conventional beam loss monitors) will be implemented as well.

CONCLUSION

The proposed beam loss monitor system confirms its advantages for the Storage Rings by providing detection and measurement capabilities no system can do in one box. The system can handle all types of losses, from extremely weak loss levels up to fast and huge losses. It provides the user the quantitative data at fast time resolution.

ACKNOWLEDGEMENT

Acknowledgement goes primarily to the ESRF and Kees Scheidt in particular, for all developments (detector) and proposal on signal treatment for the electronics. Significant beam time was made available for tests in the ESRF Storage Ring confirming the proposed system indeed brings important improvements over the conventional system. Thanks go also to Kuotung Hsu for making beam tests available in the new Taiwan Photon Source Storage Ring.

REFERENCES

[1] K.B. Scheidt, “Fast Beam Losses”, Libera Workshop 2012 proceedings.