OPTICAL FIBER BEAM LOSS MONITOR FOR THE PHIL AND THOMX FACILITIES

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Abstract

Fiber beam loss monitor (FBLM) is an attractive solution to measure beam losses intensity and position in real time. It is a very useful tool, especially, for the commissioning and the beam alignment.

In this article we report on the development of the FBLM at PHIL (PHotoinIector at LAL, Orsay, France) as a prototype of the beam loss monitor for the ThomX machine, the compact Compton based X-ray source being in the construction phase in Orsay.

INTRODUCTION

ThomX is a project proposed by a colaboration of French institutions and one company to build an accelerator based compact X-ray source in Orsay (France) [1]. The main goal of the project is to deliver a stable and a high energy X-ray beam (up to 90 keV) with a flux of the orders of $10^{11} - 10^{13}$ photons per second generated by the Compton backscattering process. At present, the ThomX machine is under construction.

The ThomX accelerator facility is composed by the linac driven by 2998 MHz RF gun, a transfer line and a compact storage ring where the collisions between laser pulses and relativistic electron bunches result in the production of the X-rays. Low energy, compactness and lack of the operation experience make such type of the machine very difficult to operate and, especially, to commission. In this context, a reliable beam loss monitor able to locate the losses will be indispensable for the commissioning (tuning of the linac and the transfer line to optimize the injection, setting-up of the ring working point) and further operation of the machine.

Nowadays, the beam loss monitor technology based on the optical fibers is established. Hereafter, we will describe the FBLM installed at PHIL facility as a prototype for the ThomX machine. PHIL is a photoinjector driven by the 2998 MHz RF gun [2]. The beam line consists of the three solenoids, a pair of steerers and a dipole (see Fig. 1). Among the diagnostics tools are the ICTs, YAG screens, Cherenkov radiation monitor and a Faraday cup. Some of the ThomX and PHIL machine parameters are listed in Table 1.

Table 1: PHIL and ThomX Electron Beam and Machine Parameters

Description	PHIL	ThomX	Units
Beam energy	5	50 – 70	MeV
Bunch charge	< 1.5	1	nC
Bunch length (rms)	> 3.5	3.7 (injector) 30 (ring)	ps ps
Beam energy spread (rms)	< 2 – 3	< 1	%
Repetition frequency	5	50	Hz
Machine length	~ 5	~ 5 (injector) ~ 13 (transfer line) ~ 18 (ring)	m m m

BEAM LOSS DETECTION

The detection principle of the beam losses is based on the production of Cherenkov radiation in the optical fiber attached to the vacuum chamber by the electromagnetic shower generated when the main beam hits the vacuum chamber or any obstacle. The secondary charged particles produce Cherenkov radiation provided that the velocity of that particles are greater than the phase velocity of light in the fiber core material. Consequently, the Cherenkov light is converted to an electrical signal containing the information about the position and intensity of the beam losses.

A detailed description of the Cherenkov radiation process including production, photon yield, probability for the photon to be captured and guided by the fiber, photon detection, etc. has been extensively worked out in the framework of the Cherenkov fiber calorimetry [3].

Although the strength of the signal detected is proportional to the beam loss intensity, it is also dependent on the type and mass of the material within which the electromagnetic shower is developed. Various beam line elements and hardware will cause the signal variations since the fiber has to be pulled around such components. This, together with the absorption of the signal by the fiber as it transmits to the detector makes difficult to extract the exact amount of the beam loss and use the FBLM to measure the absolute intensity of the losses.

The calibration of the FBLM can be accomplished by several techniques [4]. The one, adopted by our scheme uses the beam loss signal produced by inserting a known device such as the vacuum valve, collimator, screen, etc. as the reference. Knowing the speed of light in the fiber, one can calibrate the oscilloscope display to the real distance along the accelerator. In our case, the speed of light in the fiber was measured to be 0.63 c (0.19 m/ns), where c is a speed of light in vacuum. The calibration gives that every meter along the accelerator is 8.6 ns on the oscilloscope.

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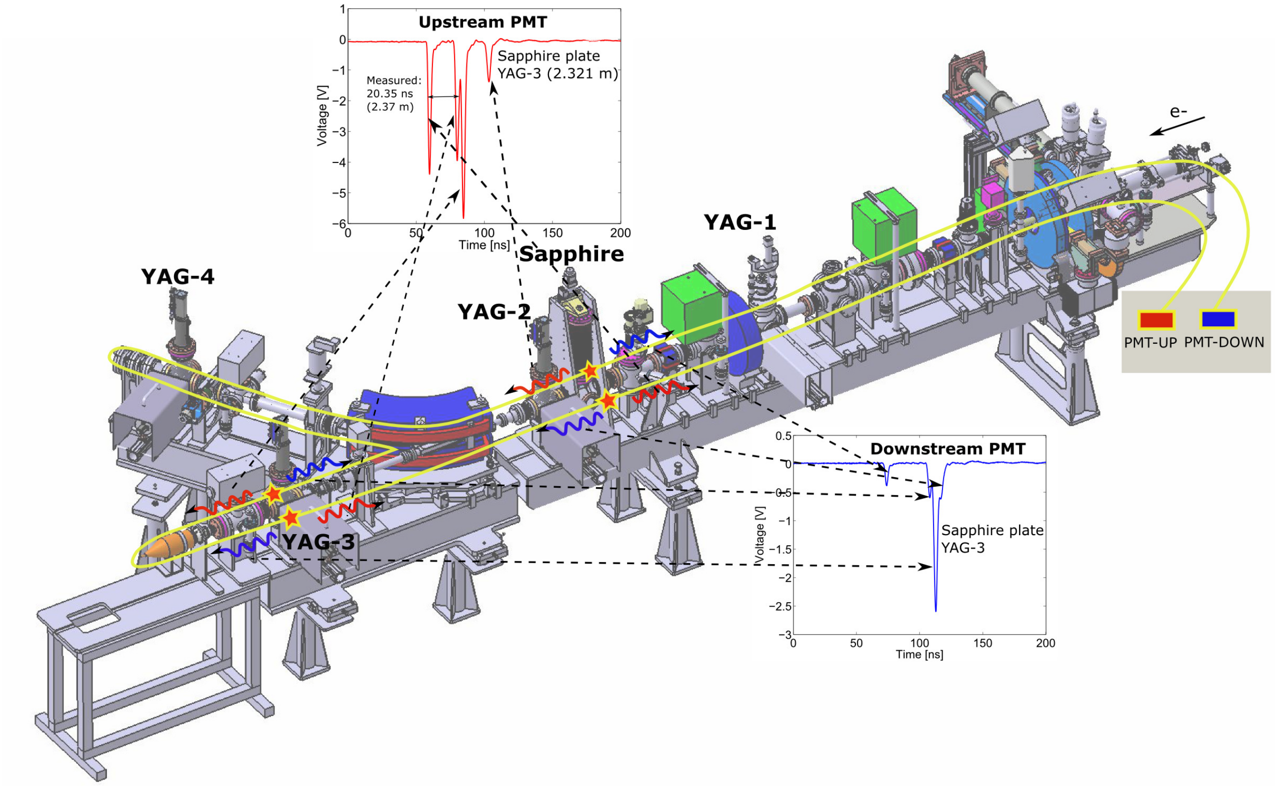

Figure 1: Scheme of the FBLM installed at PHIL. The red stars indicate the positions of the loss points at Sapphire plate and YAG-3 locations. In this case, two plots illustrate the typical beam losses measured by the upstream and downstream PMTs.

Therefore, by measuring the time between the reference and the unknown beam loss signal and dividing it by 8.6 ns/m one can determine the location in meters from the reference to the unknown beam loss point.

As mentioned before, in some locations due to the beam line elements the fiber covers a slightly longer path than the beam line. This results in the deterioration of the FBLM accuracy. Therefore, to reduce the errors in the absolute loss position measurements, it is required to have as many references as possible. Moreover, the fiber should be placed as close to the beam pipe as allowed by the geometry of the beam line components.

EXPERIMENTAL SET-UP

Fibers for the FBLM

The fiber installed at PHIL facility is made by the LEONI Fiber Optics GmbH. It belongs to the Hard Plastic Clad Silica (HPCS) fibers which combines fused silica glass core and polymer cladding consisting of a fluorinated acrylate. Numerical aperture of the HPCS fibers can go up to 0.49. This kind of the fibers are positioned as a cost-effective alternative to the silica/silica glass fibers. As far as radiation hardness is concerned, the fibers with plastic core/cladding suffer from radiation damages. Radiation damage of the optical fibers can be an issue because it will degrade the light propagation. Therefore, depending on the expected radiation level the fibers having silica glass core and cladding are preferable (e.g. AS600/660UVST, LEONI Fiber Optics).

The fibers used at PHIL have a 600 μm fused silica glass core, 630 μm of optical cladding made from polymer and 950 μm Tefzel® jacket. Since the jacket surrounding the fiber is transparent, the fibers have been covered with the heat shrinking tube. Attenuation of the fibers has been estimated to be several tenths of dB/meter at 405 nm. The cost of the HPCS fiber is about 4 euros per meter.

Detection System

In order to detect the Cherenkov light, the fiber has to be coupled with a photon detector. For this, two ends of the fiber have been connecterized by using the FC type connectors. The photon detectors employed are the photosensor modules H10721-01 manufactured by Hamamatsu Photonics containing the PMT and a built-in high-voltage power supply circuit. The sensitivity in the wide range 230-870 nm and a short rise time of about 0.6 ns result in a very fast loss signal allowing us to resolve the location of beam losses that are very close together (~7 cm).

The PMTs can be used to read out the signal from both fiber terminations. However, the better time resolution is obtained by using the signal from the PMT placed at the upstream end of the fiber. In this case, the Cherenkov light produced moves opposite to the beam direction and provides better information about the position of the beam losses since the peaks corresponding to the multiple loss point are more distant apart compared to the ones read out by the downstream PMT (see Fig. 1).

At PHIL, two PMTs are currently used to crosscheck the FBLM system and initially, to calibrate the speed of light in the fiber. In future, the downstream PMT could be replaced either by the reflector providing additional information to determine the exact location of the beam losses or by the LED to monitor from time to time the fiber efficiency.

Data Acquisition System

The FBLM signal is displayed and recorded by using a LeCroy WavePro 740Zi 40 Gs/s oscilloscope with 4 GHz bandwidth located near the detection system behind the PHIL. The acquisition is driven by the external trigger being the 5 Hz laser light signal measured by the photodiode. Remote control of the oscilloscope is used to adjust the display parameters at different beam loss regimes.

FBLM Installation at the PHIL Facility

The fiber with a length of 25 meters was installed alongside the vacuum chamber to cover continuously the total length of the photoinjector from both sides (see Fig. 1). The fiber ends are coupled to the PMTs mounted on the board and shielded by lead and black screens against the parasitic signals.

RESULTS

Four YAG screens and Sapphire plate have been used to calibrate and generate the beam losses at PHIL. Fig. 2 illustrates the beam loss profile from two successive beam loss points at the Sapphire plate and YAG-2 screen locations. Two peaks spaced by ~3 ns defines time resolution of the FBLM. However, more advanced approach can be taken to disentangle the pile-up and improve the FBLM resolution.

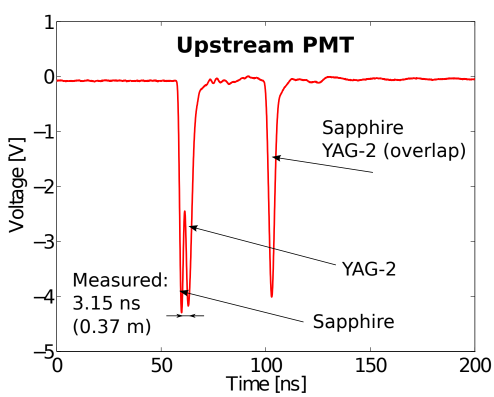

Figure 2: Beam loss signal (averaged) generated by the Sapphire plate and the YAG-2 screen spaced by 0.282 m.

Moreover, during the operation, it turned out that the FBLM can be served as a tool to characterise the dark current. Fig 3 shows the signal acquired during the dark current studies (RF photogun laser is OFF).

One can notice the whole RF pulse reconstructed by the beam loss signal. The detection limit of the system has been observed to be well below 1 pC that has also been confirmed by measuring the FBLM sensitivity hitting directly the fiber with the electron beam.

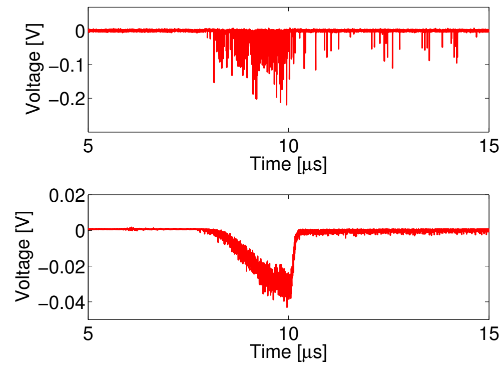

Figure 3: Beam loss signal generated by the dark current (60 MV/m). The RF pulse duration is 3 μs which is clearly visible on the waveform. Top: one acquired waveform. Bottom: averaging over several waveforms.

SUMMARY AND FUTURE PLANS

FBLM is a powerful tool in locating the beam losses with a good enough accuracy and evaluating changes in the beam operation along whole accelerator. The measured position accuracy allows resolving the beam losses occurring as close as 30 – 40 cm with the 25 m fiber along the vacuum chamber. Geometry of the fiber installation gives partial information about the loss spatial distribution. At PHIL, it can be very useful for machine tuning and during the user operations.

Real-time display system for the FBLM is now under development. It will be designed to provide a practical and simple interface to analyse the acquired waveforms and give the estimated location of the beam loss.

In the framework of the ThomX project, the optical fiber will be installed to monitor the losses along the linac, the transfer line and the ring. Auxiliary calibration procedure will be envisaged for the commissioning phase.

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