BEAM PROFILE MEASUREMENT WITH OPTICAL FIBER SENSORS AT FLASH

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Abstract

The system is intended to determine the beam profile at the DESY-FLASH undulator section as well as measuring beam losses with high spatial resolution. The measurement setup is based on wire scanners, optical fibers which are symmetrically mounted around the beam line over the full length (30 m) of the undulator section, a signal conditioning unit and a data acquisition system. The optical fibers are used as beam loss sensors, and depending on the software configuration, the setup is working either as a beam loss position monitor [1] or as a beam profile measuring system.

INTRODUCTION

Modern linear accelerators for Free Electron Laser operation (FEL) require highly sophisticated techniques to monitor the beam profile, beam tails or HALO and beam losses.

This paper describes a system developed for the free electron laser facility FLASH at DESY, Hamburg (Germany) [2]. The permanent magnets of the undulators are radiation sensitive components and must be protected. Continuous control of the radiation exposure at the undulators not only protects the permanent magnets from degradation but also verifies the efficiency of the collimators in front of the undulator section. During accelerator commissioning as well as routine operation the real time response of the beam loss monitor system enable the operators to a direct adjustment of machine parameters. Complementing the established beam diagnostic systems, the time resolved measurement provides information about the spatial distribution of particle losses.

Beam profile measurement can be achieved by using the existing beam loss position measurement system (BLPM), upgraded with hardware modules to enregister the current wire scanner position and using extended software.

CHERENKOV RADIATION

Cherenkov light is generated when the speed of a charged particle exceeds that of light in a dielectric medium through which it passes [3-4]. The threshold velocity v_{thr} for the generation of Cherenkov light is a function of the refractive index n of the medium given by $v_{thr}=c/n(\lambda)$ depending on the wavelength λ. For a refractive index of 1.5 the threshold of the kinetic energy for an electron to cause Cherenkov light is 175 keV. The light is emitted in a cone in forward direction with an opening angle depending on the energy of the particle. The number of photons that are emitted per unit wavelength and per unit length is proportional to $1/\lambda^2$. The light is emitted predominantly in the ultra violet region. The Cherenkov light is produced instantaneously while the particle passes through the medium in contrast to other luminescence effects where characteristic time constants increase the response time.

Cherenkov light inside the optical fiber as a result of beam losses e.g. caused by wire scanner operation, allows the measurement of the spatial distribution of the scattered beam and furthermore the determination of beam profile.

OPTICAL FIBERS

The detection system needs a radiation resistant optical fiber extending the working periods without relevant changes of fiber properties. The most radiation resistant commercial fibers for visible light and light of shorter wavelength are multi-mode step-index fibers with pure silica core of high OH-content. To increase the signal to noise ratio the fiber was shielded by black Nylon buffer against ambient light, which results in a total fiber diameter of about 800 µm. The light output of the sensor fiber increase linear with the diameter, but a larger diameter reduces the bandwidth and limits thus the local resolution. The spectrum of the output light depends strongly on the spectral attenuation of the fiber. According with theoretical predictions the maximum intensity was measured in the wavelength range around 550 nm, after travelling through a fiber length of 35 m.

EXPERIMENTAL SETUP

The optical fibers are installed in the undulator section of FLASH. This part of the accelerator consists of a 30 m long undulator, comprising six single permanent magnet segments. These units are separated by a wire scanner system combined with a quadrupole doublet and vacuum pumps. As yet, the wire scanners [5] are used for measuring the transversal beam profile, in conjunction with standard scintillation sensors.

The new beam profile measurement system consists of the following components: 4 optical fiber sensors, each of them with a length of 40 m, which are installed in equidistant radial arrangement along the FLASH undulator section in narrow slots very close to the beam line. The optical fibers are both, sensor as well as guiding medium to lead the generated Cherenkov light pulses to the photomultiplier tubes (PMT). The analog output signals of the PMT are conditioned and amplified using a Signal Conditioning Unit (SCU) which is installed near the undulator section in the tunnel. The SCU is connected via a RF-cable to the data control and monitoring unit outside the tunnel (fig. 1).

To accomplish beam profile measurement it is necessary to obtain precise information about the wire scanner position, while passing the beam. This is realized by counting the pulses which are steering the WS stepper motor, preconditioned that the WS start position is well defined; further information see [5].

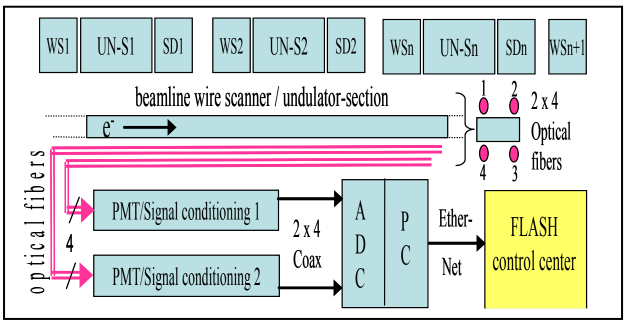

Figure 1: Schematic outline of the beam profile / beam loss position monitoring system. In the upper position are shown the undulator segments (UN-S1), the wire scanners (WS1) and the scintillation detectors.

The implemented photomultipliers (PMT) are tested, to obtain the gain characteristic of each device. Thus enables to set the gain control voltage of each individual PMT in the way that the PMT output signals are directly comparable. Remote PMT gain control is done by means of Ethernet controlled DACs, which are installed inside the signal conditioning units. Dedicated software was developed to use this measurement system either in BLPM mode or in beam profile measurement mode. The software written in LabVIEW enables the monitoring of the current beam losses, shown in the left section of the control panel (fig. 2). At the right side the beam profile is displayed. All relevant parameters, e.g. scan size, number of samples, used wire scanner, PMT gain, are tuneable on the fly.

BEAM PROFILE MEASUREMENT

Two measurement systems, each with four fibers sensors are synchronously used; one is working with high PMT gain and the other system with predefined lower gain. The high gain set up is used to measure the beam tail or beam HALO. To protect the PMTs against very high levels of input signal (Cherenkov radiation), the PMT gain is reduced to prefixed values if the incoming light exceeds a specified level. The second system is working with an appropriate lower PMT sensitivity, to show the results in a continuous graph (fig. 3,4).

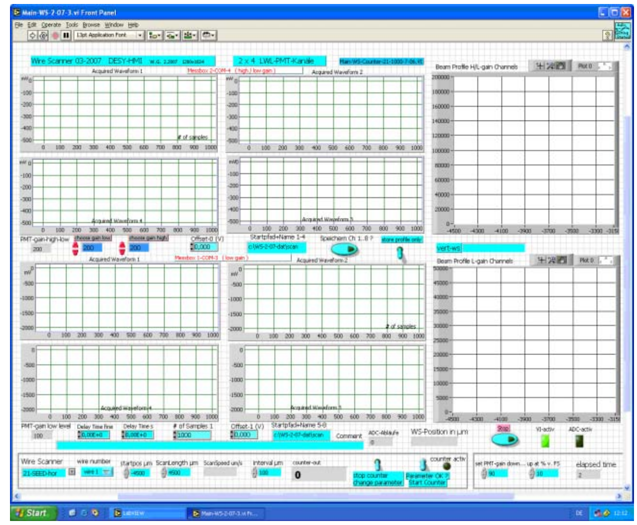

Figure 2: LabVIEW control panel of the beam profile measurement system.

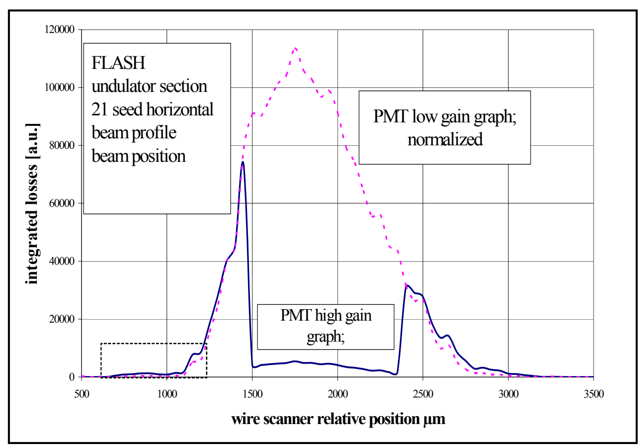

Figure 3: Beam profile measured with two independent measurement systems, with different gain, showing the beam position and beam size.

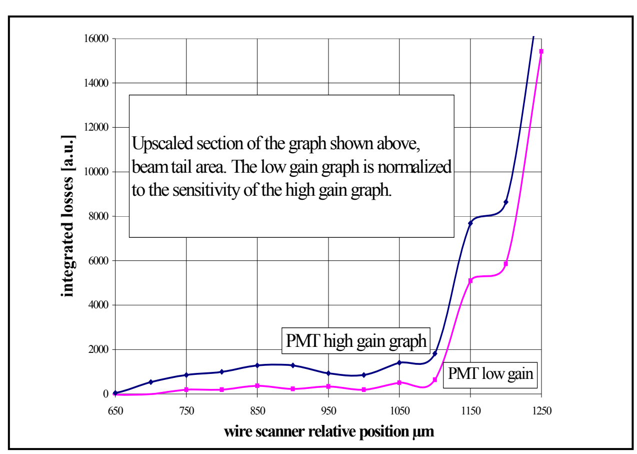

Figure 4: Expanded section of a beam tail in figure 3. The beam profile was generated with the wire scanner 21 Seed horizontal.

A measuring cycle starts, when the used wire scanner reaches a predefined position. The measuring interval (e.g. 100 µm) is defined by a prefixed number of micro steps of the wire scanner. At each interval increment, the generated Cherenkov light in the fiber sensors - which is proportional to the intensity of bremsstrahlung - is measured. As an improvement, the loss shower is not only measured at a singular location but over the entire length of the undulator section. Accomplishing an x-y-scan leads to a two dimensional profile of the beam. The synchronisation with the beam trigger allows the characterization of each bunch. The data are visualized in real time and stored in a log file for extended evaluation. The high sensitivity of the system allows an accurate monitoring of the beam profile as well as beam tails or HALO measurement.

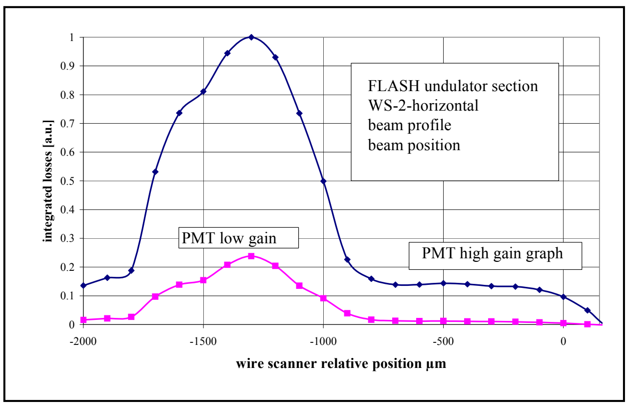

Figure 5: Beam profile measurement with very low light intensities, thus the high gain section is not shutting down the sensitivity. On the right side an extended beam tail profile was obtained.

At FLASH, the standard wire scanner is positioned upstream of the szintillation target. The distance between scanner and scintillation target is about 4.75 m. Due to geometrical constraints the scintillators are partially shielded by the undulator block. This decreases their geometric acceptance angle.

The existing BLPM system with optical fibers allows as well the reconstruction of the transverse beam profile. The loss traces generated at successive wire positions are measured and recorded. In detail :

Time of flight in the beam line, light travel time in the optical fibers and the undulator length of 30 m results in a measuring time (data aquisition time) of about 240 ns. Reaching a prefixed position of the wire scanner and started by the system trigger, with adequate post/pre-trigger timing, all PMT output signals are digitized , with a sample rate of 1 ns. The result is a group of four data files, representing the loss signals in each optical fiber. Integrating the values of each file in the group and summing up these data, provides one data point of the beam profile graph, with respect to one distinct wire scanner position. This happens synchronouously for the high gain PMT system and the low gain system, and continues until the wire scanner leaves the predifined measuring area.

The result represents the radiation response (bremsstrahlung) for a predefined number of successive wire scanner positions and allows a more precise determination of beam profiles, especially of the weak signals generated by the tail of the beam. The reconstructed transverse beam profile generated with the BLPM system is shown in figure 3 and 5. The results are in good agreement with the measured beam profiles of the standard measurement system used in the undulators.

CONCLUSION

A real time monitor system measuring the spatial distribution of electron losses at FLASH undulators was presented. This system was used as a beam loss position monitor system [1] and in addition as a beam profile measurement system. The system has been operated successfully during the FLASH commissioning and routine operation runs. The advantages of the presented beam profile measurement with fiber sensors are as follows:

- accurate monitoring of the beam profile as well as beam tails or HALO
- Obtaining of beam losses over the entire length of the undulators
- Real time verification of mismatch active components e.g. RF, collimators, magnets

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