INSTRUMENTATION FOR MACHINE PROTECTION AT FERMI@ELETTRA

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Abstract

FERMI@Elettra is a linac-driven free-electron laser currently under commissioning at Sincrotrone Trieste, Italy. In order to protect the facility's permanent undulator magnets from radiation-induced demagnetization, beam losses and radiation doses are monitored closely by an active machine protection system. The paper focuses on the design and performance of its main diagnostic subsystems: Beam loss position monitors based on the detection of Cherenkov light in quartz fibers with multi-pixel photon counters, conventional ionization chambers with a new frontend electronics package, and solid-state RADFET dosimeters providing an online measurement of the absorbed dose in the undulator magnets.

INTRODUCTION

FERMI@Elettra is a fourth generation light source currently under commissioning at Sincrotrone Trieste. As illustrated in Fig. 1, the main components of the accelerator are a photocathode RF gun, 16 accelerating S-band sections, an X-band structure for phase space linearization, two magnetic chicanes for bunch compression, and two separate undulator sections with 7 and 10 undulators, respectively. The linac design foresees the extraction of electron bunches with a maximum charge of 1 nC at a rate of 50 Hz and the acceleration to a final energy of 1.2 GeV [1].

The maximum power carried by the beam amounts to about 60 W. While this hardly poses a direct threat to beamline components, considerable amounts of radiation can be released when a part of the electron beam strikes the vacuum chamber. Elevated radiation doses are especially undesirable in the undulator sections where they can lead to a partial demagnetization of the permanent magnets with a detrimental effect on the free-electron laser process.

To avoid beam-induced damage, Fermi is protected by an active machine protection system that inhibits the extraction of charge in the photoinjector when necessary [2]. Several diagnostic systems have been developed specifically with the focus on machine protection. In the following, we give a brief overview of these systems and make some remarks on the operational experience gathered so far.

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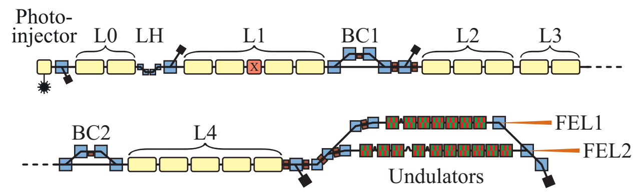

Figure 1: Overview of the FERMI@Elettra accelerator. Accelerating S-band structures are shown in yellow, main dipole magnets in blue, collimators in dark brown, undulators in red/green.

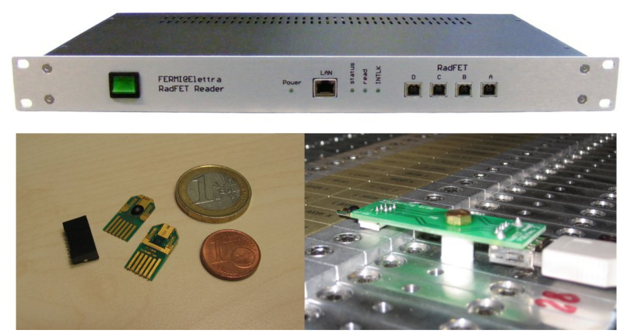

Figure 2: Photos of the RADFET dosimetry system. Top: Reader unit. Left: Single RADFET dosimeters. Right: Dosimeter installed on undulator support.

RADFET DOSIMETERS

The dose deposition in the sensitive undulator magnets is monitored by four compact integrating MOSFET dosimeters per undulator. These *RADFETs* (see e.g. [3]) of the type RFT-300-CC10G1 are produced by REM Oxford Ltd., have an oxide thickness of 300 nm, and allow the measurement of doses up to about 10 kGy without the application of a bias voltage during irradiation.

The dosimeters are mounted on the undulator support structure with the help of a small printed circuit board as depicted in Fig. 2. They are read out by a custom microprocessor-controlled reader unit that periodically drives the RADFETs with a constant current of 490 μA. The voltage needed to drive this current is digitized with a 24-bit ADC. Each unit has four channels and communicates via an ethernet interface.

At the moment, the dosimeters have a purely diagnostic function and no direct connection to the machine protection system is foreseen. However, the reader is equipped

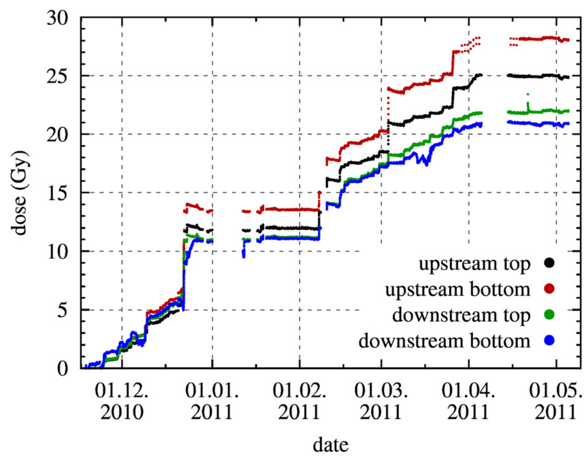

Figure 3: Doses registered by the RADFET dosimeters mounted on the first undulator of the FEL1 beam line.

with an interlock output that can be freely controlled by the microcontroller code. The implementation of alarms based on measured dose rates is therefore easily possible.

The response of the RADFETs to radiation doses from 1 Gy to 10 kGy has been extensively studied with 6 MeV bremsstrahlung and with Co-60 sources. The results of this calibration effort will be published separately. Figure 3 shows the doses read by the RADFETs on the first undulator of the FEL1 beamline over the past 6 months of operation. The maximum dose registered so far is about 50 Gy on undulator 3.

IONIZATION CHAMBERS

Nineteen ionization chambers will be used as beam loss monitors along the undulator beam lines and allow a shot-by-shot measurement of the radiation dose rate.

Each ionization chamber consists of three plane electrodes mounted inside an aluminum enclosure containing a gas volume of 1.3 l (Fig. 4). A high voltage of up to 1000 V is applied between the two outer electrodes and a central, grounded one. Additional guard electrodes reduce leakage currents and increase the homogeneity of the electric field. The chamber has a gas inlet and an outlet to allow the operation with a constant gas flux. However, the application as beam loss monitor for Fermi does not require maximum measurement precision. The chambers are therefore used in air, allowing for sensitivity changes of few percent due to variations in atmospheric pressure and humidity.

Each ionization chamber has a separate frontend electronics package (Fig. 4). It is based on the readout electronics described in [4], featuring a microcontroller and a 20-bit ADC. Besides amplifying, integrating, and digitizing current pulses from the ionization chamber, the frontend also generates the necessary high voltage. Readout of data and control of all device funtions is possible via a standard Ethernet interface. The frontend also compares the digitized signal with a set of programmable thresholds and, if necessary, signalizes alarms on two independent digital outputs

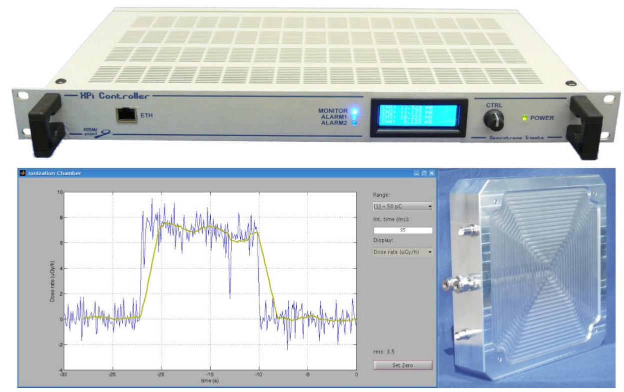

Figure 4: Photos of the ionization chamber BLM system. Top: Frontend unit. Left: Plot of low dose rate response. Right: Single ionization chamber.

connected to the machine protection system.

With air filling at standard atmospheric pressure, the sensitivity of the chamber in terms of generated charge per absorbed dose amounts to

$$S \approx 1.31 \cdot 1.2\,\frac{\mathrm{g}}{\mathrm{l}} \cdot \frac{e}{34\,\mathrm{eV}} \approx 46\,\frac{\mu\mathrm{C}}{\mathrm{Gy}},$$

using the average energy of 34 eV for creating an electron-ion pair in air. A rough control measurement with a Co-60 sources has confirmed this value within 15%. With the first installed chamber, the electronics shows a noise floor of less than 0.4 µGy/h (rms) or 4 µGy/h (peak-to-peak) at the maximum voltage of 1000 V (Fig. 4).

CHERENKOV FIBERS

Two Cherenkov beam loss position monitors [5, 6] are currently installed along the FEL-1 electron beam line, and two more are pending installation on the FEL-2 line. Each monitor consists of a long optical fiber, a frontend for the detection of Cherenkov light generated by charged particles traversing the fiber, and a test pulser.

Custom quartz fibers with high OH content are used to obtain sufficient radiation hardness. The fiber core has a diameter of 300 µm. It is surrounded by a step-index silica cladding, a polyimide buffer, and a protective nylon jacket of 330, 370, and 850 µm diameter, respectively. Two fibers per undulator line are placed in parallel grooves on the surface of the undulator vacuum chambers as shown in Fig. 5. Each fiber has a total length of 100 m.

The modular frontend uses Hamamatsu S10362-11-050U multi-pixel photon counters (MPPC, [7]) for the detection of the Cherenkov light. Each MPPC contains an array of 400 reversely biased avalanche photodiodes. These photodiodes work in Geiger mode, i.e. they produce a breakdown discharge current when they detect a photon. The signal output from the MPPC is the sum of the outputs of all photodiodes. In order to maintain a constant detector gain, the bias voltage is adjusted in dependence of the MPPC temperature.

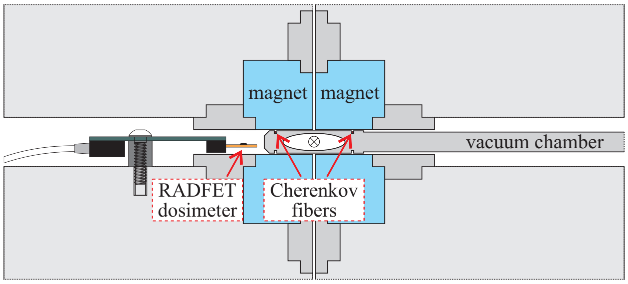

Figure 5: Cross section of a FEL-1 undulator with closed gap. The positions of the two Cherenkov fibers and of a RADFET dosimeter are indicated.

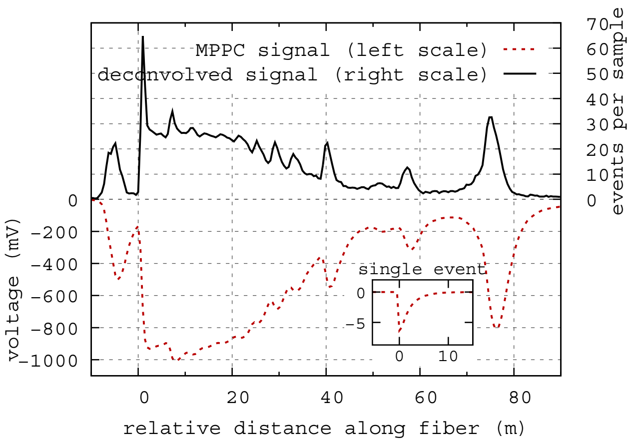

Figure 6: Deconvolution of a beam loss signal trace. The lower half of the plot shows the MPPC signal versus the relative distance along the fiber. The upper half of the plot shows the deconvoluted signal.

The arrival time of light pulses with respect to the bunch trigger is a measure of the longitudinal position of the beam losses. To make use of this, the MPPC signal is sampled by a fast 12-bit ADC with 250 Msamples/s, resulting in a longitudinal resolution of about 50 cm.

The pulse shape for a single photodiode breakdown event can easily be measured. Therefore, it can also be used to deconvolute the MPPC signal, yielding a much clearer picture of the beam loss situation (Fig. 6). In addition, this procedure allows to determine the absolute number of photodiode breakdowns.

To ensure the integrity of the fiber and of the readout chain, a LED-based test pulser at the far end of the fiber injects 100 ns long light pulses after the passage of the bunch. If these pulses are not detected by the frontend, the monitor is considered defective.

CONCLUSION

FERMI@Elettra is an accelerator with relatively low average current. Nonetheless, substantial amounts of radiation can be released when its electron beam is lost in an uncontrolled fashion. Especially due to the high requirements on the magnetic field precision of the undulators, it is mandatory to monitor and control beam losses tightly. The need for suitable diagnostic systems has led to the development of three systems that may also be of interest for other applications.

The RADFET dosimetry system offers a simple, low-cost solution for integrating online dosimetry in the range of up to few kGy. It provides the operators with minute-by-minute updated information on the deposited dose in the undulator magnets and eliminates the need for manually exchanging and reading chemical dosimeters.

The new electronics package for ionization chambers integrates a high-precision charge integrating readout with the generation of a high voltage of up to 1 kV. In combination with a simple ionization chamber design, it allows us to reliably measure dose rates down to few µGy/h.

Finally, the Cherenkov fiber based beam loss position monitors have become an essential tool for the operation of Fermi. They allow to identify both the magnitude and the position of beam losses along the undulator beamline. The use of MPPCs has allowed to integrate the complete detection and signal conditioning chain for an arbitrary number of channels into a single, compact frontend system.

ACKNOWLEDGEMENTS

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