DESIGN OF OTR BEAM PROFILE MONITORS FOR THE TESLA TEST FACILITY, PHASE 2 (TTF2)

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Abstract

The TESLA Test Facility is being extended to an electron beam energy of 1 GeV to drive a new Free Electron Laser facility. 24 beam profile monitors based on optical transition radiation (OTR) will be used along the linac. Their design is a challenging task, since the system has to measure transverse electron beam sizes from millimeter scale down to 50 μm with a high resolution. This paper describes the design of the beam imaging system, the readout system as well as the mechanical construction.

INTRODUCTION

The TESLA Test Facility (TTF), Phase 1 [1] operated at DESY until November 2002 to perform various tests and experiments related to the TESLA linear collider project [2] as well as to serve as a Free Electron Laser [3, 4]. Presently TTF is being extended to a new Free Electron Laser facility (TTF2-FEL) [5]. In the first stage, five accelerating modules having eight 9-cell superconducting TESLA cavities each are installed, later two more modules can be added. Electron beam energies up to 1 GeV can be achieved. A sketch of the TTF2 linac is shown in Fig. 1.

The requirements for beam profile diagnostics are demanding. Beam profile monitors have to measure transverse electron beam sizes from millimeter scale down to 50 μm (sigma) with a high resolution. These monitors will be based on the use the visible part of the transition radiation spectrum, i.e. the optical transition radiation (OTR), providing a fast single shot measurement with a linear response. OTR was already used at TTF1 for beam transport optimization and beam characterization [6]. However, in order to meet the more strict requirements of TTF2, several improvements to the old monitor system have been made. The OTR beam profile monitor system is realized, as at TTF1, mainly by INFN-LNF and INFN-Roma 2, in collaboration with DESY.

OTR MONITORS AT TTF2

Totally 27 beam profile monitors will be installed along the TTF2 Linac (Fig. 1). Most of them (24) are equipped with an OTR screen, three monitors in the RF-gun section have Ce:YAG screens. Eight of the OTR monitors are combined with a wire scanner.

Profile monitors have multiple tasks. They provide online beam images and profiles to optimize the beam transport through the linac. They are also used for the characterization of the beam: measurements of the transverse beam shape and size, emittance measurements using both the quadrupole scan and the four screen methods, as well as energy spread measurements in dispersive sections. The resolution of the monitor has to be sufficient to measure beam sizes down to 50 μm. In addition the system has to be robust, remote controlled, and have a possibility to change the magnification of the imaging optics and the attenuation of the OTR signal. Furthermore, because TTF2-FEL will serve as a user facility, reliability is an important aspect.

OTR monitors are based on measuring backward optical transition radiation emitted by a screen inserted into the beam with an angle of 45° with respect to the beam direction. A sketch of the monitor is shown in Fig. 2, and the different components are described below. OTR monitors in the bunch compressors have a special design, and they are not discussed in this paper.

VACUUM CHAMBER AND MOVER

A standard OTR vacuum chamber is a 7-way cross having three view ports. Fused silica (DUV-200) is used at the OTR output window because of its radiation hardness and good transmittance at the visible wavelengths. The opposite port is used for alignment purposes and has a normal glass window. The third view port is a small glass window at 45° with respect to the beam direction allowing to illuminate the screen from the front.

Eight of the monitors are combined with a wire scanner providing complementary measurements of the beam profile. Both devices are mounted into the same vacuum chamber. Ideally the screen and the wire should be in the same longitudinal position, but in order to avoid an accidental collision between them, they are separated in the beam direction by 25 mm. In order to have space to the wire scanner actuator, the opposite view port is lacking in these chambers.

An OTR screen is inserted into the beam by a stepper motor actuator. This mover is similar to the movers used at TTF1, but some mechanical parts are redesigned to improve its stability. The moving range is 100 mm, and the absolute screen position is read out by a potentiometer. For compatibility reasons, the motor driver is the same as used for other stepper motors at TTF2.

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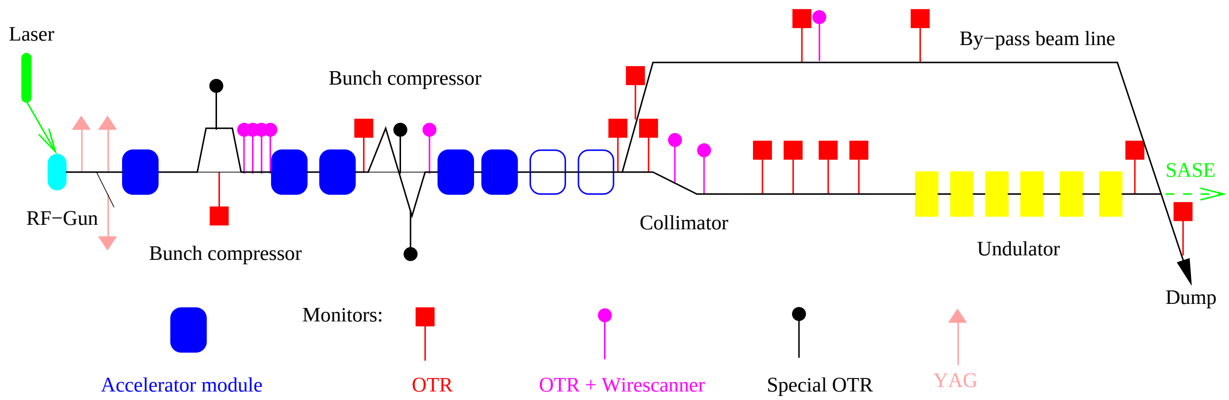

Figure 1: Schematic overview of the TTF2 linac (not to scale). Beam direction is from left to right, the total length is about 250 m. Different beam profile monitors along the linac are indicated.

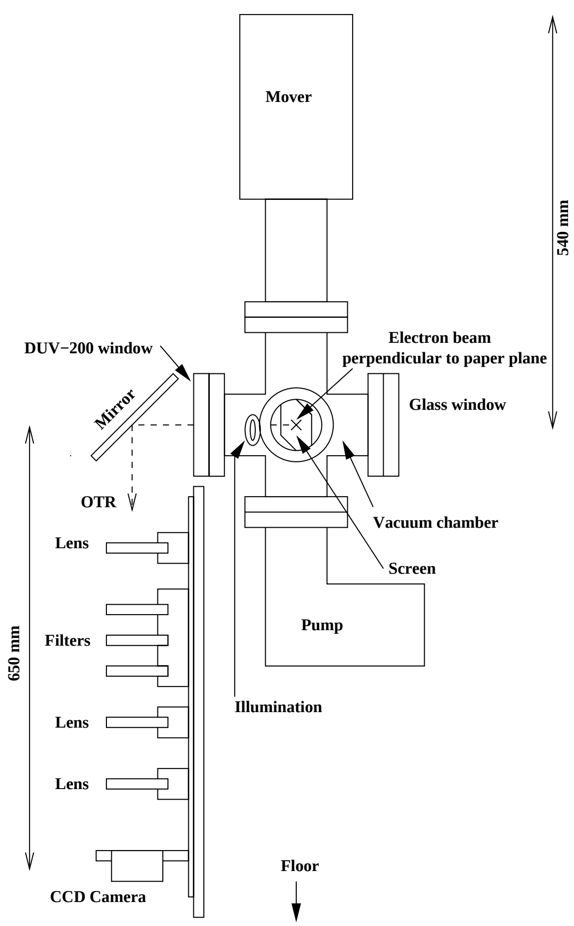

Figure 2: Sketch of a standard TTF2 OTR monitor (not to scale).

SCREENS

At TTF1, kapton foils with an aluminium coating were used as OTR screens. These screens showed cracks in the Al coating after some time of use. Our understanding is that the beam heats the screen and due to different thermal expansion, the Al coating cracks. One silicon screen with an aluminium coating was used as well. No visible damage is seen on this screen.

At TTF2, due to smaller beam sizes, the charge density on the screen will be even higher than at TTF1. Even if the number of electron bunches per macropulse will be limited to only a few, the charge density on the screen may be sufficient to destroy it even by a single shot. Therefore the screen material has to be carefully selected. So far, two materials, silicon and aluminium, have been studied. Other possibilities are tungsten, titanium and beryllium. According to EGS4 simulations [7] with a round gaussian beam distribution of σ = 50 μm, a silicon screen stays below its stress limit, when the charge per macropulse is less than about 110 nC. For aluminium the corresponding value is about 10 nC. The light emission efficiency of these two materials has been measured at TTF1: The number of photons detected by the same standard CCD camera was about four times less for polished silicon than for aluminium.

Because of the significant difference in the light emission, it has been decided to mount two screens in all the monitors: a 350 μm thick polished silicon screen and a silicon screen with a 40 nm aluminium coating. The size of both screens is 30 mm x 30 mm, and they are mounted on a common screen holder made of stainless steel. Between the two screens, on the same plane, are marks to adjust and calibrate the imaging optics.

OPTICAL SET-UP

A sketch of the optical system used to image the OTR light to the CCD camera is shown in Fig. 2. This system consists of a mirror deflecting the OTR light downwards, three achromatic doublets, three neutral density filters, and a CCD camera. The components are mounted on two rails on a stainless steel plate. The plate will be fixed to the support structure of the linac. The optical system is protected against the stray light, and the CCD camera is shielded with lead to reduce radiation damage.

Both, lenses and filters can be remotely moved transversally in or out of the optical axis. Only one lens is inserted at any time. Focal lengths of the lenses are 250 mm, 200 mm and 160 mm providing nominal magnifications of 1, 0.38 and 0.25, respectively. The filters have transmission of 10 %, 25 % and 40 %, and any combinations of them can be used. The camera is a digital CCD camera (Basler A301f) with a firewire interface (IEEE1394). The sensor size of the camera is 658 x 494 pixels with a pixel dimension of 9.9 μm x 9.9 μm.

The initial adjustment of the optical set-up is done on an optical table. The optical axis is defined with a help of a He-Ne laser and small diaphragms. The correct position of the lenses is searched by automatically measuring the contrast on a calibration target. When the correct position of the lenses and the camera is found, their position is fixed. On the beam line, the distance of the whole system from the screen is adjusted with the help of the marks on the screen holder. The same marks are used to calibrate the magnification.

The resolution of the optical system was studied by measuring the Modulation Transfer Function (MTF). The resolution can be improved significantly by using a diaphragm reducing geometrical aberrations. In order to define the limiting resolution of the system, an edge profile of a black rectangle on the calibration target was taken. A gaussian point spread function (PSF) convoluted with a step function was fitted to the measured profile. From the fit the gaussian width (σ) of the PSF can be determined. A value of σ = 10 μm was obtained with a diaphragm of a diameter of 20 mm (magnification of 1). Without a diaphragm, the corresponding value was σ = 30 μm.

The highest resolution is required when the beam size is expected to be small. This is the case at the high beam energies, in the case of TTF2 after the full acceleration, when the beam energy is of the order of 1 GeV. At high energies OTR is well collimated and therefore the intensity cut by a diaphragm is small. Thus this technique can be used to improve the resolution in the high energy section of TTF2.

READ OUT-SYSTEM

The beam images are captured by digital CCD cameras. All the cameras are connected to a computer running control and acquisition software. This computer acts as a image server controlling the cameras and providing live beam pictures for monitoring, on-line beam profiles and beam widths, as well as high-resolution images for measurements, and low-resolution images for documentation. It also takes care of the communication with the TTF2 control system. A more complete description of the image server is in Ref. [8].

Digital IEEE1394 (firewire) cameras have been chosen, because they offer, at a cost comparable to their analog counterparts, several advantages, like full frame resolution, remote gain and shutter control and a triggered acquisition mode. A further advantage is a simpler cabling topology, because only a firewire link and a trigger are required, no videomultiplexer nor frame grabber is needed. On the other hand, there is no experience with a large digital camera system. The connection of almost 30 cameras distributed along the linac can be complicated, because the maximum length of standard firewire connections is only about 5 m. One possibility is to use glass fiber optical links and optical repeaters for long distance connections and hubs to connect locally the cameras via firewire links. Another solution is to replace the optical repeaters by compact PC104 computers connected to the image server via a local ethernet. In this solution each computer controls a limited number of cameras. The final solution for TTF2 is still under investigation.

STATUS AND OUTLOOK

All the vacuum components of the beam profile monitors are ready and the mounting of the OTR chambers in the linac will start this summer. The prototype phase of the optical set-up is successfully finished, and the first optical setups will be installed and commissioned soon. The test of the digital camera system continues and the decision of the final solution for the connection scheme will made within a few months. The complete OTR beam profile monitor system is expected to be in operation early 2004.

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