COMMISSIONING OF THE OTR BEAM PROFILE MONITOR SYSTEM AT THE TTF/VUV-FEL INJECTOR

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Abstract

The TESLA Test Facility (TTF) linac at DESY has been extended to an energy of 1 GeV to drive a new Free Electron Laser facility (VUV-FEL) with wavelengths from 100 nm to 6 nm. Beam profile monitors based on optical transition radiation (OTR) provide an essential beam diagnostics tool. The OTR diagnostic system is routinely used to optimize the beam transport and to measure the transverse beam size and shape with a resolution down to 10 μm. The imaging system, using digital CCD cameras connected to local controllers, provides the operators realtime beam images and tools for image analysis and measurements such as beam emittance. This paper presents the commissioning of the OTR diagnostic system. It provided a valuable tool for the first running period of the TTF/VUV-FEL injector in spring 2004.

INTRODUCTION

The TTF linac is being extended to a new free electron laser facility, the VUV-FEL. Based on the superconducting TESLA technology the beam is accelerated up to 1 GeV to drive a SASE FEL in the wavelength range from VUV to soft X-rays [1].

Compared to TTF phase 1, the VUV-FEL is built to be a user-facility, which implies strong requirements in term of reliability and remote control of subsystems. For this reason, the optical electron beam diagnostics was completely redesigned in respect to the phase 1.

The measurement of transverse electron beam shapes is based on optical transition radiation (OTR) providing a fast and single shot measurement with linear response.

A fundamental issue was on one hand the requirement to have an rms resolution below 50 μm to measure small beam sizes and on the other hand to have the flexibility to change the optical magnification of the imaging system. To improve the reliability the system is shielded from light, hands intrusion and radiation. Digital cameras were chosen to acquire the beam images. A distributed image acquisition system based on industrial computers collects the data and makes them available to the operator.

The OTR beam profile monitor is realized mainly by INFN (LNF Frascati and Roma 2) in collaboration with DESY.

The commissioning of the injector has been performed from middle of February to beginning of June 2004 [2], which included the commissioning of the first five stations of the OTR beam profile monitor system.

OTR BEAM PROFILE MONITOR

The OTR beam profile monitor is composed of several elements: a stepper motor actuator that inserts the OTR target into the electron beam line, an optical system to image the beam, an acquisition and processing system to deliver images and beam parameters to operators.

Vacuum components

Compared to TTF phase 1, an improved version of the stepper motor actuator with an improved mechanical stability is used to bring the target holder in the beam line. A calibration screen is embedded on the target holder. Most of the optical stations are equipped with two OTR radiators, a polished silicon wafer with and without aluminium coating. The aluminium coated radiator produces larger light intensity while the polished silicon radiator is suited for higher beam charge densities due to its higher melting point.

Optical system

The optical system consists of three lenses for three magnifications (1, 0.389, and 0.25) and three neutral density filters. Only one lens at a time is used, while it is possible to have more than one filter inserted to decrease the signal intensity. Every optical element is driven in and out of the optical axis with a DC motor. All motors are remotely controlled by means of CAN-BUS interface.

To improve the resolution of the optical system, a diaphragm is mounted in front of each lens. Their sizes are adapted to each lens in order to reduce the depth of field keeping the light intensity at the CCD large enough for camera sensitivity. One of the main requirements is the precision and the reproducibility in the positioning of the lenses into the optical axis. The system is mounted on a robust base and every element can be moved on two rods that guarantee the linearity of the movement. An end-switch disconnects the current to the motors 1 to 2 mm before the lens or filter holders touch the stopping block. Inertia brings the holder smoothly to the stops. They are well machined parts with small tolerances. We verified the precision and the reproducibility of the position and found that both are better than 10 μm.

A digital CCD camera is used to acquire the beam image. A black enclosure provides light shielding, while lead bricks protect the camera from radiation.

All systems have been aligned in Frascati and the lens positions have been carefully adjusted using computer codes that compute images of calibration standard in

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order to measure the resolution. The average rms resolution measured with 1:1 magnification is 11 μm.

More details on the system can be found on the reference [3].

Acquisition system

The use of digital CCD cameras has several advantages: the signal is digitized already in the camera without the use of a frame grabber. Since the outgoing signal is already digital, electronic and environmental noise have little effect on the image quality. In addition, the IEEE1394 link (Firewire) allows control of the camera remotely. A common problem of the Firewire link is the degradation of the signal with increased cable length. This limits its length to 10 meters. Since the stations are distributes in the TTF linac over more than 200 m, some kind of repeaters or hubs would be needed. We preferred to connect the digital cameras to "industrial" compact Personal Computers, up to 6 cameras each. They act as local controllers and are installed into the accelerator tunnel. They can be accessed from the image server in the control room through the network to read images and control the camera settings.

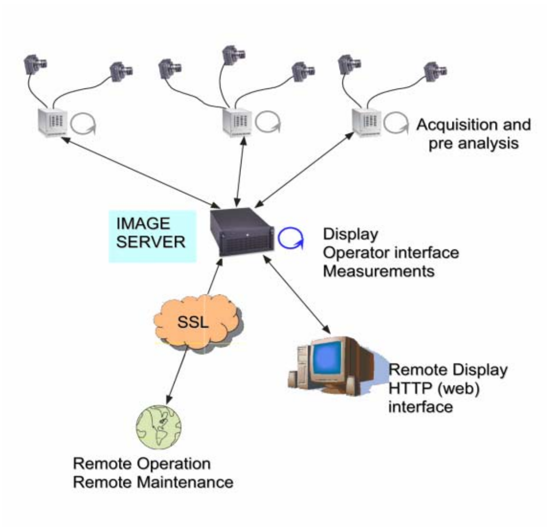

Figure 1: Topology of acquisition system.

With such a solution the topology of the whole system is simplified and also compatible with the specifications of the IEEE1394 link used to control the digital cameras. The image server provides display and control tools, high-level applications for image analysis and measurements and an interface for remote display (web server).

Display and measurement system

We have chosen Windows operating system for the image server because we use LabView tools for image acquisition and analysis and the support for different platforms is not yet available.

Beam images are displayed with on-line parameters, like projections, rms and FWHM sizes of the beam spot. Also a history of the beam parameters is available on the display screen.

A camera control panel allows operators to select a camera and to modify its parameters, such as gain, shutter time and brightness.

The beam image including some relevant parameters is also sent embedded in an html page and delivered to internet for a fast and easy access worldwide.

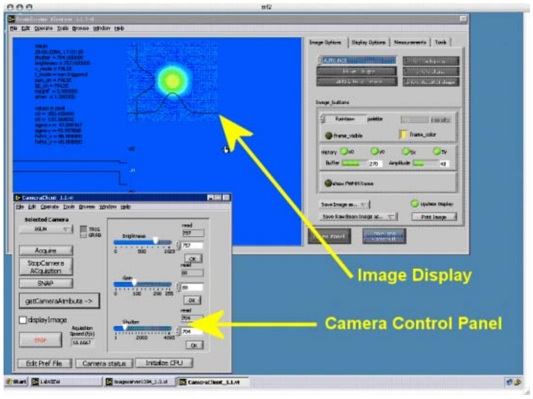

Figure 2: Appearance of the image display and camera control panel with a simulated beam.

OPERATING EXPERIENCE OF OTR MONITORS IN THE INJECTOR

The TTF and VUV-FEL injector is composed by an RF Gun followed by an accelerating module, the first bunch compressor, a matching section and a FODO lattice to be used for the emittance measurements with the 4 monitors method [4]. More detailed description of the injector is in [2].

There are totally 9 cameras in the injector area, but only 5 of them are equipped with the optical system described above. However, all cameras use the above described image acquisition system and are controlled by the local computers. The four optical systems in the FODO lattice have been aligned using a laser beam on the nominal electron beam axis. With beam, the alignment has been cross checked and only one system required a slight readjustment.

Measurements

The OTR beam profile monitors were daily used to measure several beam parameters: the transverse beam shape and size and the energy and the energy spread in the dispersive sections.

Particular attention was dedicated to the commissioning of the 4-screens emittance measurement. In the quasi-automated procedure the operator has to prepare the configuration of the optical system choosing the magnification and inserting or extracting the OTR screens. Also several others parameters have to be defined like number of images to average, background subtraction, and image filtering settings.

We developed for this measurement a LabView program that displays the images collected by the four screens, together with the live image to allow the operator to change camera gain or filter intensity to prevent pixel saturation.

Figure 3: Appearance of the 4 screens emittance measurement panel.

At the end of the acquisition procedure, images are filtered to remove noise. Background is subtracted to clean images from dark current and other residual light. An estimation of the Twiss parameters and the emittance is also performed on-line.

During the commissioning phase the main goal was to optimize the beam properties and its transport through the accelerating module. Systematic emittance measurements have been started, but could not been completed yet. Nevertheless it was possible to determine the working point of the injector in terms of transverse emittance.

Two methods have been used to determine the rms beam size. In the first method, the horizontal and vertical projections are fitted with a Gaussian shape. In the second, a cut of 10% of the total intensity was performed on the 2D image and after this the rms is calculated on the projections. Obviously, when the beam shape is very irregular the results of the two methods are quite different. For irregular beams the rms value is strongly dependent on the particular beam distribution.

For accurate emittance measurements, it is important to have a well matched FODO lattice such that the beam image on each screen is regular and has similar dimensions. During the first phase of the injector commissioning this was not always the case. Therefore, the results obtained so far have to be considered preliminary and still object to further analysis, giving however a clear indication that the normalized emittance at 100 MeV, with 1 nC charge, is below the value of 6 mm-mrad, which is required for the start-up lasing of the VUV-FEL at 30 nm.

Improvement

The only serious problem that we had during the commissioning of the system was related to the cameras. Sometimes a few cameras were hanging up making it impossible to reset them without disconnecting the firewire cable. We didn't encounter this problem before because we never ran such large number of cameras for so many hours in a noisy environment like the accelerator tunnel. To avoid beam down time due to the cable disconnection in the accelerator tunnel, we plan in the summer shut down to include the possibility to turn off remotely the cameras in our system.

REMOTE OPERATION AND MAINTENANCE

Remote operation has been tested from Frascati several times, and we succeeded to work remotely with the help of a DESY operator. We didn't encounter particular problems in the video conferencing and in transferring and displaying the beam images. We also succeeded to test and commissioning all our software remotely.

On a regular basis, maintenance and upgrading of the system has been done from Italy without any problem.

CONCLUSION

The OTR beam profile monitors in the TTF/VUV-FEL injector have been successfully commissioned. The system is used to measure beam shape and size, energy, energy spread and emittance. The optical system worked satisfactory, no failure has been observed. However, to solve the occasional hang of the cameras, a remote reset is in development and will be made available soon.

Acknowledgement

We want to point out, that R.Sorchetti has drafted the mechanical part of the optical system, and followed the realization. He participated in the installation of the systems as well as L.Caccioti, who designed the interface between the CAN-BUS and the optical system. We are also grateful to O.Giacinti that helped in cabling and mounting the systems. Without their work and help we couldn't done this job. We want also to remember the work on the CAN-BUS module and stepper motor drivers by J. Thomas and O.Hensler. Thanks also to the FEA group at DESY for their work on the trigger electronics.

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