THE DIAGNOSTIC SYSTEM OF TTF II

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Abstract

The TESLA Test Facility (TTF) phase II will be the second LINAC at the DESY, based on TESLA accelerator technology[1]. The goal of this machine is twofold: Test and demonstrate the performance of the technology developed for the TESLA linear collider. Furthermore, the excellent beam quality allows to drive a SASE FEL to produce soft X-rays for a 4th Generation Light Source.

This paper presents the design of the diagnostic system for TTF II, and will give a brief overview over their variety and status.

1 INTRODUCTION

The TESLA Test Facility Phase II (TTF II) is a 1 GeV LINAC with 6 TESLA modules, able to drive a SASE FEL at wavelengths as short as 6 nm. In contrast to TTF I, it is constructed not only for tests of future collider technology, but also to serve as a driver for a SASE based 4th generation synchrotron radiation user facility.

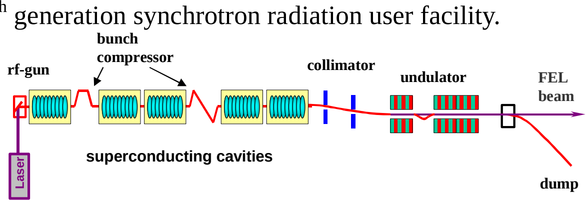

Figure 1: Schematic layout of TTF II

In contrast to storage rings and s-band based LINACs, the time structure of the electron beam at TTF is quite different. The beam consists of a macropulse with a maximum length of 800 µs with a rep. rate up to 10 Hz. Within the macropulse a bunch train is generated with bunch spacing between 110 ns and 1 µs. The charge will be between 0.1 and 4 nC with a bunch length about 50 µm. The normalized emittance will be 2π mm mrad [2].

These characteristics imply several challenges for the electron beam diagnostics:

- Single bunch resolution for position, charge and losses
- Measure and control fluctuations from macropulse to macropulse
- Interlock on poor transmission and losses with a reaction time of about 3 µs.
- Measurement of the transverse beam profile with a resolution of 20 µm or better.
- Measure sub-picosecond electron and radiation pulses.

2 ELECTRON BEAM DIAGNOSTICS

2.1 Beam Position

Several beam position monitor (BPM) types will be used [3]. Most of them will be Striplines, inside the quadrupole magnets. A special procedure will be used to align the axis of quadrupoles and striplines with respect to each other.

One cavity monitor is installed inside the module behind the last cavity together with superconducting quadrupoles and steerer magnets.

Reentrant cavity monitors have been used at TTF I at room temperature and at the 2 k level. The cold version is estimated to be an alternative to cavity monitors, because of the single bunch resolution capability and a rather low cyrogenic load. Therefore, a prototype will be installed in one of the modules.

Buttons are used mainly in the undulator section. In contrast to TTF I, the undulator will be operated without internal strong focussing, relaxing the need for BPMs in the undulator. The buttons will be installed in the diagnostic sections between the undulator modules as well as at the beginning and at the end of the undulator. In addition to the BPMs two additional button BPMs of the type already used for TTF I [4] will be integrated in the undulator vacuum chamber.

An arrays of button pickups are mounted in the flat wide vacuum chambers of the dispersive part of the TTF II bunch compressors, in order to get a reliable BPM reading over the whole aperture (Figure 2). Depending on beam energy and compression factor, the electron beam orbit varies within the chamber. The signal of the 4 electrodes closest to the orbit will be used to determine the beam position.

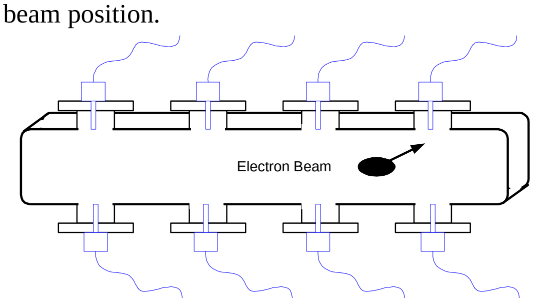

Figure 2: Schematic view of a button array for a beam pipe with high aspect ratio of the transverse dimensions typical for bunch compressors.

The same type of electronics will be used for all the BPM types, except the cavity BPM requires different processing.

2.2 Current/Charge

Apart of Faraday cups in the gun region, the charge will be measured by means of toroids. In contrast to other current transformers, the ferrite core of the DESY type is made of two half rings, so that it can be assembled after the installation of the ceramics. Another essential feature is the single pulse resolution even at the 9 MHz bunch rep. rate of TTF II. The signal measured with a prototype at TTF I is shown in **Figure 3**.

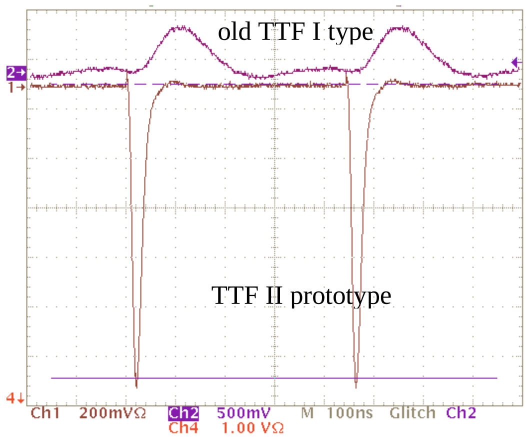

Figure 3: Signal of the prototype of the TTF II toroids together with the signal of TTF I type measured in TTF I with a bunch charge of 2.7 nC.

Toriods of this type are installed at the beginning and at the end of each warm section of the machine. The signal is not only used to measure the charge, but also to measure the transmission in the framework of a protection system.

2.3 Dark Current

For a machine with a time structure like TTF II and also TESLA the aspect of dark current is essential, as dark current could increase the radiation background in the machine, yielding additional cryogenic losses and radiation damage of sensitive components [5]. Even small charges per bucket can add to substantial fractions of the nominal current, because the dark current spreads over all rf buckets whereas only every 144^{th} bucked is filled by the photoinjector. One has to distinguish two contributions of the dark current.

At TTF I the dominating component is produced in the gun with similar properties like the nominal beam. Therefore, a significant fraction can be transported through the entire machine. This part of the dark current will be measured with reentrant cavity monitors, located in the injector and the collimator section. In TTF I this monitor has proven a resolution of less than 500 nA.

The second contribution of dark current is due to field emission in the superconducting cavities at high gradient. Since these electrons have a different energy and spatial distribution, most of the charge is dumped in the cavities itself, or shortly after passing the next magnets. In order to measure these dark currents, cavity monitors will be installed close to both ends of the two cavity strings ACC2-ACC3 and ACC4-ACC6. In order to reach a sensitivity of about 10 nA, the quality factor of such a cavity has to be high (≈1000). This implies a rather strong influence on the beam quality. To avoid problems during the FEL runs, the cavities are installed outside the vacuum using a ceramic gap. Thus they can be removed and the gap can be shortened.

2.4 Beam Phase, Phase Stability

Energy stability and the stability of the longitudinal beam profile are essential for stable SASE operation. Phase jumps of one of the accelerating cavities yields both, a change of mean energy and due to the use of magnetic bunching to a change of the longitudinal profile. In order to determine if and where such an event has happened in the machine, TTF II will use phase monitors together with an appropriate electronics to detect phase jumps of 0.5° and less. The monitors will be located directly after the gun and after each section including magnetic deflections. It consists of an impedance matched ring electrode integrated into a thick flange. Mixing the broadband signal from this monitor with the 1.3 GHz master oscillator and down converting it using the I/Q scheme, the resulting phase signal is directly related to the beam phase.

2.4 Beam Profile, Emittance, Energy Spread

The beam profile will be measured by means of OTR screens and wire-scanners. In order to measure the emittance, either quadrupole scanning methods or measurements of the beam size at 4 consecutive positions in a FODO lattice will be used.

About 25 screen stations will be distributed along the machine. Each can take combinations of different screens. In most cases only an OTR target will be present, made of 300 µm thick Silicon wafers without coating. At some places along the machine also YAG crystals will be used to detect low charge beams, e.g. during commissioning.

The imaging system will use single achromatic lenses. Different image scales (1:1, 1:2, 1:4) as well as variable attenuation are possible by sliding different lenses and filters remote controlled into the optical path. The resolution of the system is expected to be about 20 µm.

In addition to the screens a modified version of the CERN wire-scanners will be used [6]. The scanner will be mounted under 45° with respect to the horizontal plane. Using a V like wire scheme allows to measure x and y electron distribution with one scanner. In the diagnostic blocks between the undulator sections a new type of scanner with a unidirectional drive unit will be used. This new type will use different units for horizontal and vertical scans.

2.5 Bunch Length

In order to achieve the high current densities to operate the SASE FEL, the electron bunches of the LINAC have to be compressed to 160 fs level or less. Therefore, conventional methods, e.g. observing radiation produced by the beam with a streak camera, can be used only at the early stages of compression.

The following methods are proposed for TTF II and will be implemented:

- Longitudinal phase space tomography [7] uses phase scans of accelerating structures in combination with imaging of the beam in a dispersive section to reconstruct the longitudinal phase space.

- Interferometric methods using coherent far infrared (FIR) transition or diffraction radiation with an interferometer[8]. The coherent FIR radiation produced by sub-picosecond bunches can be accessed, using a screen, an aperture or just looking to a discontinuity of the vacuum chamber. The radiation is feed to an interferometer to measure the autocorrelation signal.
- Electro Optical Sampling (EOS) is using the electromagnetic fields of the bunch itself to change the optical properties of a crystal. This change is then probed by means of an ultrashort laser pulse. Scanning the delay of the laser with respect to the beam, the bunch length can be measured [9].
- A Transverse Mode Cavity will be used to[10]. Here the is streaked directly by using rf fields generated in a transverse mode cavity. Bunch length is transformed into a tranverse deflection, that can detected by using a screen downstream the rf cavity.

3 PROTECTION SYSTEMS

Superconducting high duty cycle LINACs like TTF II need protections systems to avoid damage of sensitive components caused by either radiation or heat deposition. Besides of a passive collimator system, there will be active 3 systems, acting on different time scales.

First there will be a measurement of the radiation dose with TLD crystals, providing information on a weekly basis. Furthermore, small coils of optical fibres will be installed close to the vacuum pipe along the undulator segments. The shower produced by particles lost in this region will degrade the transmission of light within the fibres. Monitoring the transmission of these elements allows to monitor the radiation losses on an hourly basis, i.e. fast enough to correlate the readings of the loss monitors with the actual machine operation [11].

The third system is an integral part of the fast acting beam inhibit system, collecting fast signals from all parts of the machine. In case of an interlock the laser is blocked and the beam pulse is stopped in less than 3 µs and the operation is continued in short mode only [12]. Within this system beam losses are detected by fast loss monitors, built from scintillators and photomulitpiers and distributed at sensitive parts of the machine so that redundancy of the signals is guaranteed. In addition a second fast but less sensitive system is checking the transmission of the machine, using pairs of toroids to monitor the transmission at different levels and time scales [13].

4 SYSTEMS FOR SASE OPTIMIZATION

In contrast to other synchrotron radiation sources for SASE LINACs FEL operation cannot be separated from the operation of the accelerator. Especially FEL intensity and radiation spectrum must be available to the operator like machine parameters as beam charge or position.

At TTF I several systems for the photon diagnostics have be tested, and will also be used for TTF II [14]. The so called MCP detector, using a thin gold wire reflecting a small fraction of the radiation onto a micro channel plate, has big advantage, that it can be calibrated and used over the whole intensity regime from the level of the spontaneous radiation to saturation [15]. It has been extensively used both for the optimisation of the SASE performance and also as an intensity signal for the users.

5 ACKNOWLEDEMENT

The author is indebted to all members of the TESLA collaboration [1] for their contribution to TTF I and their engagement in the construction of TTF II, especially INFN Frascati and CEA Saclay. Furthermore, the author would like to thank SLAC for the help with the transverse mode cavity.

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