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Electron Beam Diagnostics for TTF II

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This paper presents an overview of the electron beam diagnostics for the upgrade of the TELSA Test Facility (TTF II). Beside of a program for testing components, especially superconducting accelerating structures, for the linear collider project TESLA, TTF II will serve as SASE FEL 4th generation synchrotron radiation user facility.

1. INTRODUCTION

In phase II of the TESLA Test Facility (TTF II) the electron beam energy will be increased – by use of 6 TESLA cryo-modules – from 250 GeV/c (TTF I) up to 1 GeV/c (Fig. 1.).

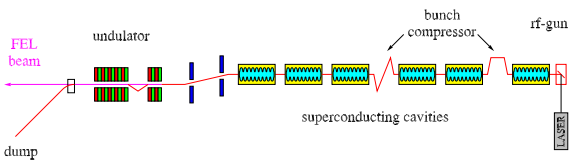

Figure 1: Schematic overview of TTF II.

Table 1
Parameters of the TTF II electron beam.

max. beam energy	=	1 GeV
max. rep. rate f_{rep}	=	10 Hz
macro pulse length t_{pulse}	=	800 μs
bunch spacing $\Delta\, t_b$	=	110 ns or 1 μs
N_e per bunch	=	0.1...4 nC
bunch length σ_z	=	50 μm
norm. emmittance ϵ_{norm}	=	2 mm mrad

*This work is carried out in the framework of the TESLA collaboration and therefore represents also the contribution of many coworkers within the collaboration, who cannot be mentioned here.

While still acting as test accelerator for the development of the superconducting L-band (1.3 GHz) cavity technology for the TESLA linear collider [1], emphasis is now put on driving the 30 m long SASE FEL to wavelength as short as 6 nm. In order to act as SASE-based 4th generation synchrotron radiation user facility [2],[3] a set of new reliable, precise instruments are required to ensure the required quality, stability and control of electron and photon beams [4]. Table 1 gives an overview of the electron beam parameters.

In order to control orbit and charge stability required for stable and reproducible FEL operation, the "basic" beam instrumentation – *charge* and *position* of the electron beam – needs single bunch resolution, i.e. each of the up 7200 electron bunches within the macropulse has to be measured individually to control drifts or slopes within the macropulse, originating from sources like beam loading or wake fields. This yields an integration or measurement time of < 110 ns.

Also the measurements of the *beam profiles* (transverse and longitudinal) are challenging. Low emittance and strong bunch compression require a resolution < 20 μm for the transverse profile and subpicosecond techniques to measure bunch-lengths on the order of 100 fs.

2. LINAC INSTRUMENTATION

2.1. Bunch Charge

Apart of **Faraday cups** in the gun region, the single bunch charge measurements in TTF II rely on broadband **toroids** (bandwidth: 10 kHz...$>$ 50 MHz). In

contrast to most current transformers, the ferrite core of this type, developed at DESY, is made out of two half rings, allowing to complete the assembly after the vacuum parts including the ceramic gap are already mounted.
A prototype toroid, already tested in TTF I, has demonstrated the single bunch capability for 9 MHz bunch rep. rate. The toroid signals are not only used for bunch charge monitoring, but also in connection with the realtime protection system.

2.2. Beam Position

Different types of BPM pickup's are used throughout the TTF II linac [5]:

Cavity BPM's A *re-entrant* cavity BPM will be tested as alternative to the 1.5 GHz *dipole mode* cavity monitors, used so far inside all the cryomodules. Recent studies show high cryogenic losses for using the dipole mode BPM in the TESLA linear collider. The strong damping by external loads in case of the re-entrant BPM minimizes this effect and it's broadband characteristic offers an improved single bunch capability.

Stripline BPM's are foreseen in most of the "warm" parts of TTF II. They will be located inside the quadrupole magnets, not only to save space, but also for alignment purposes. Using an automatic procedure on a wire test bench, the magnetic axis of the quadrupole can be aligned to the electric axis of the stripline pickup to an absolute error $< 20\ \mu$m [6].

Button BPM's equipped with commercial feedthrough electrodes are considered at space critical locations, like the injector and the bunch compressors. To cover the whole aperture of the wide, flat vacuum chamber in the dispersive section of the bunch compressor, an array of 4+4 button electrodes will be installed.

In order to simplify operation and maintenance an updated version of the TTF I undulator BPM *read-out electronics* will be used for most pickup stations, i.e. all stripline and button type BPM's. The signal processing is based on the *AM/PM principle*, which delivers a bunch charge independent beam position analog signal for every passing bunch [7].

The cavity BPM's (re-entrant, as well as dipole mode) require special treatment with dedicated readout techniques.

2.3. Beam Emittance and Energy Spread

The *transverse beam profile* will be measured with *OTR screens* and *wire-scanners*. The *beam emittance* is deduced by either quadrupole scanning methods or beam size measurements at four consecutive locations along the FODO lattice.

OTR screens TTF II will be equipped with approximately 25 screen monitors, which are distributed along the accelerator. Most of them uses a 300 μm thick silicon wafer OTR target (without coating). For machine commissioning, i.e. low intensity beams some dedicated stations will be equipped with YAG crystals. The imaging system consists out of single achromatic lenses. Different image scales and variable attenuation will be handled by sliding lenses and filters remote controlled into the optical path. A resolution of 20 μm is expected for these systems.

Wire-scanners A modified version of the CERN-LEP wire-scanner [8] will also be used for transverse beam profile monitoring. Mounted under 45^0 with respect to the horizontal plane and using a V-like wire schema allows x and y profile measurements with a single scanner.

2.4. Bunch Length

In order to operate the SASE FEL successfully high current densities in the electron bunches are mandatory. Therefore the bunches have to be compressed down to a length of 50 μm or below ($\equiv$ 160 fs). Monitoring the *bunch length* with conventional methods, i.e. observing radiation produced by the beam bunches with a streak camera, is only possible at the early stages of compression. Several methods have been developed to monitor the ultimate bunch length at TTF II:

Longitudinal phase space tomography is based on phase scans in the accelerating structures in combination with transverse beam images in dispersive sections to reconstruct the longitudinal phase space [9].

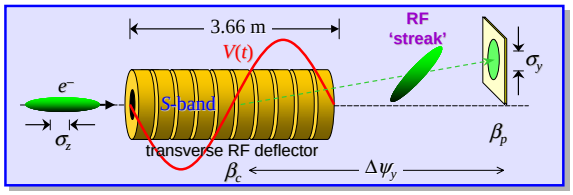

Figure 2: Deflecting S-band cavity for bunch length measurements (courtesy of P. Emma).

Interferometric methods uses coherent far infrared (FIR) transition or diffraction radiation with an interferometer. The coherent FIR radiation, produced by the sub-picosecond bunches, is accessed by using a screen, an aperture or just at a discontinuity of the vacuum chamber. In the following interferometer this radiation is used to measure the autocorrelation signal [10],[11].

Electro optical sampling (EOS) measure directly the electromagnetic field of the bunch by changing the optical properties of a crystal. The changes are probed by means of ultrashort laser pulses. The electron bunch is sampled by scanning the delay of the laser pulses with respect to the bunch, which results in a longitudinal image of the bunch [12].

Transverse mode cavity The bunches are deflected ("streak") directly in the transverse rf-fields of a S-band dipole mode cavity structure (similar to the streak camera principle, see Fig. 2). In this way the longitudinal plane is transformed into a transverse image, which can be detected with a screen downstream the cavity [13].

2.5. Beam Phase

In order to achieve stable SASE operation, the stability of beam energy and longitudinal beam profile have to be accomplished. Phase "jumps" in the accelerating structures yield both, an energy variation and due to the use of magnetic bunching to a change in the longitudinal beam profile.

A set of **phase monitors** will be installed behind the gun and between each of the accelerating sections. The pickup consists out of an impedance matched ring electrode, supplying a differentiated broadband pulse signal when passed by an electron bunch. A *beam phase signal* can be derived by I/Q mixing a filtered 1.3 GHz component with signal of the 1.3 GHz master oscillator. *Time-of-flight (TOF)* measurements can be realized by precise measurement of the time difference of the signals from two phase monitors.

3. UNDULATOR DIAGNOSTICS

3.1. Diagnostic Block

The undulator of TTF II [14] is divided in six 4.5 m long sections. The position and transverse profile of the electron beam are monitored in seven *diagnostic blocks* (see Fig. 3), which are located between these sections:

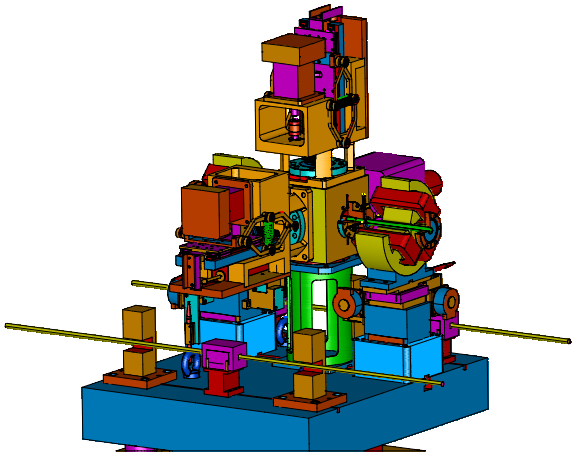

Figure 3: The diagnostic block keeps two wire-scanners and a beam position monitor.

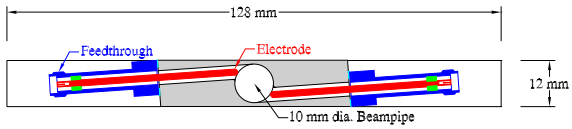

Figure 4: Cross-section of the BPM pickup eletrodes mounted inside the undulator.

Wire-scanner For the transverse beam profile a new type of *wire-scanner* with an unidirectional drive unit has been developed. Individual units of this new type are foreseen for scanning horizontal and vertical plane.

Beam position monitor (BPM) A removable unit holds 4 symmetric arranged *electrostatic electrodes*, which are similar to the well-known "button"-BPM's. These BPM electrodes are the same as those inside the undulator, but here they can be arranged in the horizontal and vertical plane.

3.2. Undulator BPM's

In contrast to TTF I, the undulator will be operated without internal strong focussing, relaxing the need for BPM's inside the undulator. Only two additional electrostatic "button" BPM's will be integrated in the vacuum chamber of each undulator section. These BPM's (Fig. 4) are identical to those used successfully in TTF I [15],[16].

4. ACKNOWLEDGEMENT

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REFERENCES

1. TESLA Collaboration, "TESLA Design Report", TESLA Report 2001-011 (2001)
2. M. Körfer, et. al., "The TTF-FEL Status and its Future as a Soft X-ray User Facility", Proc. of the 23rd FEL Conf., Darmstadt (2001), Germany, to be publ.
3. B. Faatz, et. al., "The SASE FEL at the TESLA Test Facility as User Facility", these procedings
4. D. Nölle, "The Diagnostic System of TTF II", Proc. of the EPAC 2002, Paris (2002), France, pp.242-44
5. C. Magne, M. Wendt, "Beam Position Monitors for the TESLA Accelerator Complex", TESLA Report 2000-41 (2000)
6. F. Brinker, et. al., "Precision Alignment of BPM's with Quadrupole Magnets", Proc. of the 18th Int. Linac Conf. LINAC 96, Geneva (1996), Switzerland, pp.502-4
7. M. Wendt, "BPM Read-Out Electronics based on the Broadband AM/PM Normalization Schema", Proc. of the DIPAC 2001, Grenoble (2001), France, pp.63-65
8. J. Camas, et. al., "High Resolution Measurements of the Lepton Beam Transverse Distribution Proc. of the PAC 93, Washington D.C. (1993), U.S.A., pp.2504-6
9. M. Hüning, "Investigation of the Longitudinal Charge Distribution in Very Short Electron Bunches", Proc. of the DIPAC 2001, Grenoble (2001), France, pp.56-60
10. M. Geitz, "Investigation of the Transverse and Longitudinal Beam Parameters at the TESLA Test Facility Linac", DESY Thesis 1999-033 (1999)
11. J. Menzel, et. al., "Experimental Investigations on Coherent Diffraction, Synchrotron and Transition Radiation", these procedings
12. M. Brunken, et. al., "Electro-Optic Experiments at the TESLA Test Facility", Proc. of the 23rd FEL Conf., Darmstadt (2001), Germany, to be publ.
13. R. Akre, et. al., "A Transverse RF Deflecting Structure for Bunch Length and Phase Space Proc. of the PAC 01, New York (2001), U.S.A., pp.2353-55
14. B. Faatz, et. al., "Undulator System for the VUV-FEL at the TESLA Test Facility – Phase 2", these procedings
15. R. Lorenz, et. al., "Beam Position Monitors inside the TESLA Test Facility Linac", Proc. of the Particle Accelerator Conf. PAC 97, Vancouver (1997), Canada, pp.2134-36
16. P. Castro, et. al., "Orbit Analysis at the TTF Linac using Model Independent Methods", Proc. of the EPAC 2002, Paris (2002), France, pp.2134-36