BEAM POSITION MONITORS INSIDE THE FEL-UNDULATOR AT THE TESLA TEST FACILITY LINAC

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Abstract

Beam-based alignment is essential for the operation of a SASE-FEL at the TESLA Test Facility Linac. It requires the transverse beam position to be measured at several points inside and between the undulator modules with a resolution of better than 5 μm. Between the undulator modules cylindrical cavities will be used, excited in the TM$_{110}$-mode by an off-center beam. The amplitude of this mode is detected in a homodyne receiver by mixing the cavity output and a 12 GHz reference signal. For monitors inside the undulator modules the realization of two different concepts is under way. The first one is a button-type monitor using very small feedthroughs. The second one is a structure consisting of four ridged waveguides oppositely arranged around the chamber, where the averaged position of a single bunch train will be measured in a narrowband X-band receiver. The fabrication and test of prototypes is under way. This paper summarizes the designs and some preliminary results.

1 INTRODUCTION

The construction of a free-electron laser (FEL) is under way at DESY yielding a coherent, very bright beam of photons with wavelengths tunable between 6 and 20 nm [2]. The electron beam of high intensity to drive the undulator will be delivered by the TESLA Test Facility Linac (TTFL) [1]; some parameters are listed in Table 1.

Bunch train length	800 μs
Number of bunches	max. 7200
Repetition rate	10 Hz
Bunch charge	1 nC
Bunch length (FWHM) Phase I / II	250 μm / 50 μm

Table 1: Parameters for the FEL, at the end of the TTFL

The operation of this FEL is based on the the self-amplified spontaneous emission mechanism (SASE). Inside the undulator the electron beam performs a snake-like motion due to the alternating magnetic field of the dipoles. Synchrotron radiation is emitted because of this motion, a density modulation takes place and the electron beam is micro-bunched. In order to focus the beam along the undulator beamline, a FODO structure is superimposed.

The position of the electron beam might vary, mainly because of field imperfections in the dipole and quadrupole magnets. Since the overlap between the electron beam and the photon beam is essential for the operation of the FEL, the position of the electron beam has to be measured and corrected along the undulator beamline. Beam position monitors (BPM) are to be installed within and between the modules, and steering coils are located inside each undulator module. In Phase I the 15 m long undulator consists of three identical modules and the bunch length is a factor of 5 larger than it will be for Phase II. The beam pipe having a radius of 5 mm will be made of aluminium.

2 BETWEEN UNDULATOR MODULES

The transverse beam position has to be measured with a resolution of about 1 μm between two undulator modules. These monitors have to fit in a block of stainless steel, housing two wire scanners (see Fig. 1). Circular cavities excited in the first dipole-mode by an off-axis beam were chosen because of the desired resolution and the transverse space available. The amplitude of this TM$_{110}$-mode yields a signal proportional to beam displacement and bunch charge, its phase relative to an external reference gives the sign of the displacement. The signal amplitude is much higher than the signal given by other monitors and is a linear function of the beam displacement. Both TM$_{110}$-polarizations have to be measured to obtain the displacements in x and y.

2.1 Cavity Design and Signals

For a cavity without beam pipes, the voltage of the TM$_{110}$ excited by a single bunch of charge q at a position δx can be estimated using the following relation:

$$V_{110}(\delta x) = \delta x \cdot q \cdot \frac{l}{{R_{\text{res}}}^3} \cdot {T_{tr}}^2 \cdot \frac{J_1^{\text{max}}}{J_0^2(a_{11})} \frac{a_{11}}{2\pi\varepsilon_0} \qquad (1)$$

a_{11} is the first root of J_1, T$_{\text{tr}}$ the transit time factor. Since the resolution is proportional to the cavity size, a resonant frequency (TM$_{110}$-mode) of 12 GHz was chosen, limited by the beam pipe diameter. In the preliminary design of the block which has to be inserted between two modules (Fig. 1) one clearly sees the two cavities and their coupling to WR-90 waveguides. Table 2 summarizes some important parameters. The temperature of all cavities made of aluminium will be stabilized. The dimensions of the coupling iris to the waveguide were designed following a method described in [4], resulting in a coupling factor of about 2.5.

Since the field maximum of the common modes is on the cavity axis, they will be excited much stronger than the

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Cavity radius R_{res} / length l	14.6 mm / 8.4 mm
Loss factor k_{110}	0.2 V/pC
Unloaded and loaded Q_{110}	about 6000 / 1000
Frequency f_{110}	12.0 GHz

Table 2: Design parameters for the cavity monitor

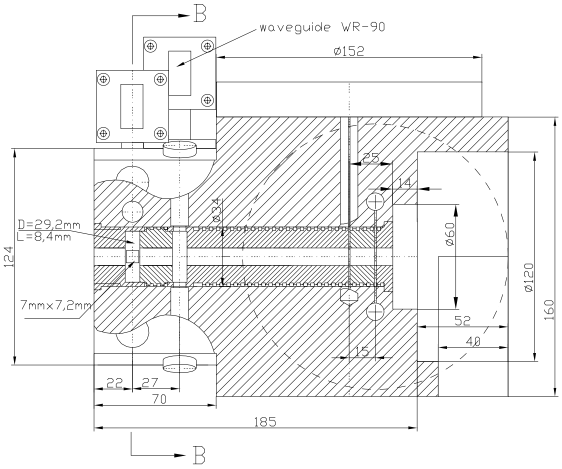

Figure 1: Block to be inserted between two modules

TM_{110} by a beam near the axis. Due to their finite Q, all modes have field components even at the TM_{110}-mode frequency. The excitation of the dominant TM_{010}-mode with respect to the one of the TM_{110}-mode and their spectral densities can be estimated following [3]. Two opposite cavity signals will be combined in a hybrid to reach the desired resolution. A frequency sensitive common-mode rejection of about 73 dB is necessary to detect this displacement [5].

2.2 *Electronics*

The TM_{110}-amplitude is detected in a homodyne receiver by mixing the cavity output and a reference signal down to DC in two stages [6]. First the 12 GHz-signals from the BPM and a reference cavity will be converted down to 1.517 GHz, using a reference signal from a common oscillator. In the second stage these signals will be mixed down to DC, using components developed for the TTFL-monitors [5]. The beam position can be calculated from the resulting I- and Q-signals, digitized by 12-bit ADCs. Near the electrical center of the cavity the resolution is also limited by the thermal noise of the electronics.

3 INSIDE UNDULATOR MODULES

The block to be inserted into an undulator module and containing the beam pipe will be made of aluminium having a rectangular profile (12 mm in height). A first prototype section of about 4 m length will be equipped with an alternating arrangement of 10 correction coils and monitors. The requirements on the monitors are listed below:

- A resolution of less than 5 μm around the center is necessary to realize the overlap between the electron and the photon beam.
- All mechanical parts of the pickup have to fit inside the undulator gap of 12 mm; the magnets allow only a horizontal access.
- The effect on the impedance of the vacuum chamber has to be minimized (large number of BPM).

The realization of two different monitor concepts is under way. Both types are described in the following.

3.1 *Broadband Electrostatic Pickup*

3.1.1 Design and First Tests

The pickup mechanics of this BPM concept is intended to be "as simple as possible". It seems feasible to use it with the longer bunches of Phase I, and it might be operated even with shorter bunches (Phase II, see Table 1).

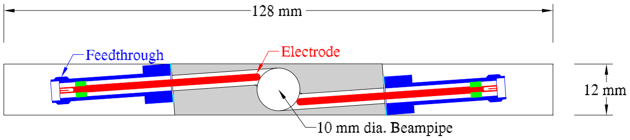

Figure 2: Cross-section of the electrostatic pickup.

Figure 2 shows a sketch of this "degenerated button" pickup. Because of the small beam pipe diameter the center-pin (.8 mm radius) of a coaxial vacuum feedthrough is used as an electrostatic "button"-electrode. It couples to the electromagnetic field of the electron beam; the level of the induced signal depends on the beam intensity and the transverse beam position. Four symmetrically arranged electrodes are used to measure the beam position with respect to the center of the beam pipe. Due to the space limitations, we had to split them longitudinally by 41 mm $\equiv$ 3/2 of the betatron wavelength. Each couple of two opposite electrodes is rotated by 30^0 from the horizontal plane, so the horizontal and vertical position characteristics of the BPM differ. 50 Ω coaxial cables will be used for the signal transmission from the electrodes to the readout-electronics, where the levels of all four signals are detected to compute the horizontal and vertical beam displacement.

The vacuum feedthroughs used are commercial SMA types from KAMAN Corp. having an increased center-pin length and modified for flange-mounting. Each pin-end is shaped spherically in order to reduce the local electric field strength (protection of sparks, induced by the fields of very short electron bunches).

First tests were made by measuring a simplified 'electrical' model (brass, silver/gold plated) with the network-analyzer. Figure 3 shows the transfer characteristics between this simulated 'beam' - a rod placed in the beam pipe center, giving a coaxial system with a 50 Ω characteristic impedance - and one pickup electrode (output). The useful frequency response range is $4 \ldots 12$ GHz: at 4 Ghz

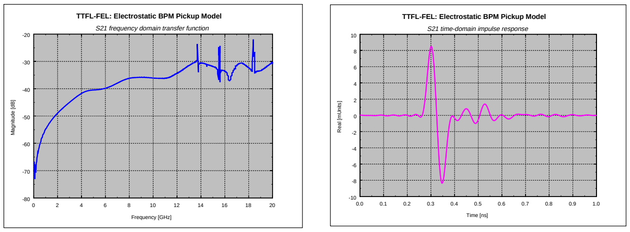

Figure 3: Measurements on the electrostatic pickup model.

the highpass-like roll-off frequency was found, and above 13 Ghz unwanted, but weak resonances were observed. A differentiated signal appears as a time-domain impulse response. Taking into account the 20% reduced feedthrough pin-diameter of the model, the beam-to-electrode coupling estimated from these measurements is about 1%.

3.1.2 Signal Detection

The electronics will be realized as a single broadband channel, aquiring the levels of the four electrode signals in consecutive time steps of 25 ns. Therefore, three of the four pickup signals will be delayed by 25 ns, 50 ns and 75 ns, and all of them will be combined in one transmission line. The signal processing includes low-pass filtering which has to be effective at very high frequencies, probably realized with help of lossy coaxial cables and attenuators.

3.2 Waveguide Monitors

3.2.1 Design

Because of the required compact size and extremely short bunches in Phase II, microwave concepts were used for the realization of a second pick-up structure. In this case the magnetic field of the electron beam couples to a waveguide through a slot in the beam pipe. Four coupling slots and waveguides are positioned 90 degrees apart in azimuth, similar to standard electrode-type monitors. The coupling factor of each slot is about 1% at 12 GHz according to MAFIA-calculations. Rigded waveguides of a special shape were designed to reduce their size and to realize the coupling. At the end of each waveguide, a coaxial adapter with a vacuum feedthrough is flange-mounted. Its cross-section is shown in Fig. 4. The fabrication of a prototype is under way (see Fig. 5).

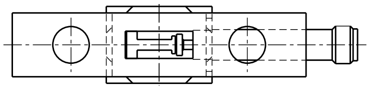

Figure 4: Cross-section of the coaxial adapter including the waveguide (center) and the feedthrough (to the right)

3.2.2 Electronics

The $\frac{\Delta}{\Sigma}$-signal of two opposite waveguides yields the normalized beam position, similar to the formalism used for electrode monitors. A narrowband receiver will be used to detect the rf-signals of all individual waveguides. The filtered 12 GHz-signal will be amplified in a low-noise amplifier (LNA) and down-converted to 1.9 GHz. In the second stage this signal will be further down-converted, to about 50 MHz, and the $\frac{\Delta}{\Sigma}$-ratio of two channels will be detected using the amplitude-to-phase conversion scheme.

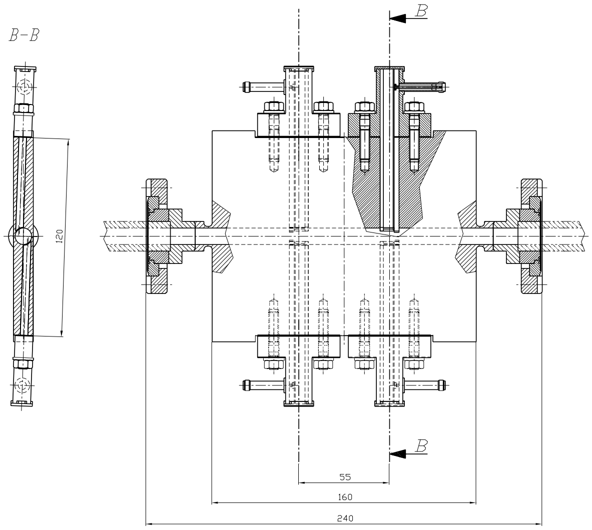

Figure 5: Prototype-Design of the waveguide monitor

In the near future prototypes of both monitors will be tested at the CLIC Test Facility at CERN [7], where the bunchlength is close to the one planned for Phase I.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

[1] *TESLA TEST FACILITY LINAC - Design Report*, edited by D.A. Edwards, DESY Hamburg, TESLA-Note 95-01, March 1995

[2] *A VUV Free Electron Laser at the TESLA Test Facility Linac - Conceptual Design Report*, DESY Hamburg, TESLA-FEL 95-03, 1995

[3] W. Schnell, “Common-mode rejection in resonant microwave position monitors for linear colliders”, CLIC Note 70, 1988

[4] N. M. Kroll, D. Yu, “Computer Determination of the External Q and Resonant Frequency of Waveguide Loaded Cavities“, in *Particle Accelerators*, 1990, Vol.34, pp.231-250

[5] R. Lorenz et.al., “First Operating Experiences of Beam Position Monitors in the TTF Linac“, this Conference

[6] R. Lorenz et.al., “Study of Orbit Feedback Systems for the TESLA Linear Collider“, this Conference

[7] H.H. Braun et.al., “Results from the CLIC Test Facility“, in Conference Proc. of the EPAC94, London, 1994, pp.42-46