Concept of Electron Beam Diagnostic for the VUV SASE FEL at the TESLA Test Facility (TTF FEL) at DESY

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Abstract

The electron beam trajectory inside an undulator with integrated strong focusing quadrupoles is disturbed by any kind of magnetic or alignment errors of the guiding field. The electron and photon beam must overlap over the entire undulator length to achieve an optimum output of the TTF FEL [1]. Therefore it is necessary to measure and correct the electron beam trajectory. The orbit correction in the undulator is based on two principles of orbit measurement. The absolute position of the electron beam inside the undulator can be measured at 4 points of support with calibrated monitors. The second method of measuring the beam trajectory is a beam based alignment algorithm which uses relative orbit changes at 30 distributed beam position monitors along the undulator. A mismatching of the optic at the entrance of the undulator can be seen by measuring the beam size at different locations along the undulator.

1. Introduction

The TTF FEL uses an undulator with integrated strong focusing quadrupoles. The undulator consists of three undulator sections with integrated strong focusing quadrupoles. Each undulator section contains 10 quadrupole magnets building a FODO structure. At the entrance, the exit and in between the undulator sections diagnostic blocks are installed as shown in figure (1). Orbit deviations inside the undulator are introduced by unknown, random dipole kicks, due to the error in the planar undulator structure, and kicks due to misaligned quadrupoles. To correct the errors of the 30 quadrupoles, for each quadropole a steerer and a beam position monitor (BPM) are installed.

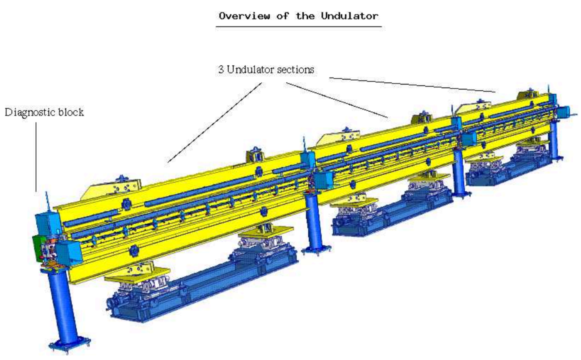

Fig. 1. Three undulator sections with four diagnostic blocks.

The diagnostic inside the undulator is necessary to align the electron beam within 10 μm rms deviation to a straight line. This ensures the overlap of the electron and photon beam over the entire undulator length to keep the gain reduction of the FEL smaller than 15 % in phase 1 of the TTF FEL project [1]. It is foreseen to use the undulator at electron beam energies between 200 and 500 MeV. Due to the fact that the magnet strength is fixed inside the undulator the optical functions inside the undulator change with the beam energy. To get a periodic beta function the optic is adapted to the beam energy at the entrance of the undulator. A mismatching of the optic at the entrance of the undulator can be detected by using four wire scanners along the undulator.

Table 1: TTF FEL Phase 1 in Numbers [1]	
Beam energy	200 to 500 MeV
Normalized emittance	2 πmm mrad
Average beam size inside the Undulator	0.08 mm
Charge per bunch	0.1 to 1 nC
Bunch repetition rate	1 MHz
Macropulse repetition rate	up to 10 Hz
Macropulse length	up to 800 μs
Chamber Diameter inside the Undulator	9.6 mm
Number of undulator sections	3
Undulator gap height	12 mm
Undulator section length	4.5 m
Undulator period length	27.3 mm
Gradient inside the undulator	12.5 T/m
Number of BPM's inside one section	10
Number of diagnostic blocks	4
Number of wire scanners	4 hor. and ver.
Number of cavity monitors	4 hor. and ver.

2. Different Type of Monitors for the Undulator

To measure the orbit deviations due to quadrupole errors two different methods can be used.

1. the absolute beam position in respect to the undulator axis can be measured at several points of support and then be corrected. This is done by calibrated wire scanners [2, 3, 4], which allow the electron beam position to be measured in the reference frame of the undulator.

2. In a second step a beam based alignment procedure is used to reduce the offset over the entire undulator [5, 6].

2.1. Absolute Beam Position Measurement

The absolute error of the electron beam orbit with respect to the undulator axis is measured by means of several wire scanners which are located before, after and between the undulator sections. The wire scanner uses a carbon or quartz wire of 7 μm diameter, which moves through the beam. The beam profile is obtained by measuring the bremsstrahlung emitted from electrons hitting the wire as a function of the wire position [2], [3].

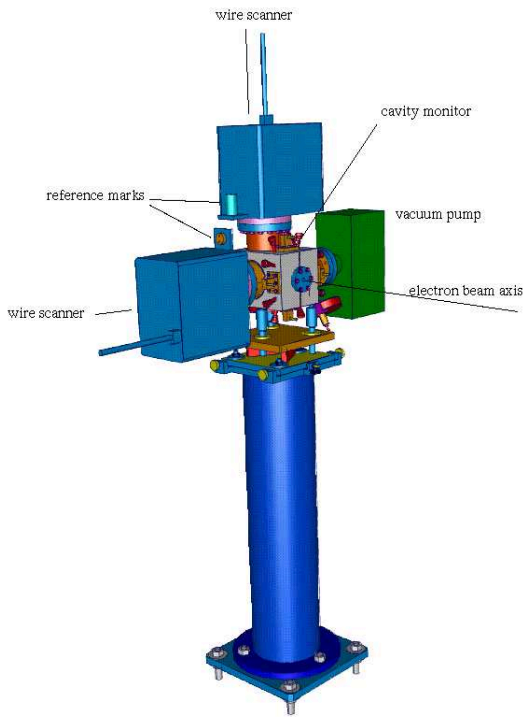

Fig. 2. Diagnostic block: Two wire scanners with reference marks are shown

The same wire scanner can be used as a slow or a fast wire scanners. Slow means that for each macropulse, consisting of 800 single bunches with 1 MHz repetition rate (see table 1), only one position inside the beam pipe is measured without moving the wire.
Fast means that during one macropulse the full beam profile and position is measured. In both cases the wire scanner cannot give the beam position with only one single electron bunch.

The wire scanners define a reference axis through the entire undulator with an absolute accuracy better than 15 μm. This is achieved by calibrating the wire position in respect to the reference mark on the wire scanner front plate (see figure 2). This is done before the installation of the complete assembly. The reference mark is then used to define the position of the wire in the undulator coordinate system after the installation of the complete undulator system.
The resolution of the beam position measurement with the wire scanner is of the order of 1 μm [3].
In a second step the wire scanners can be used

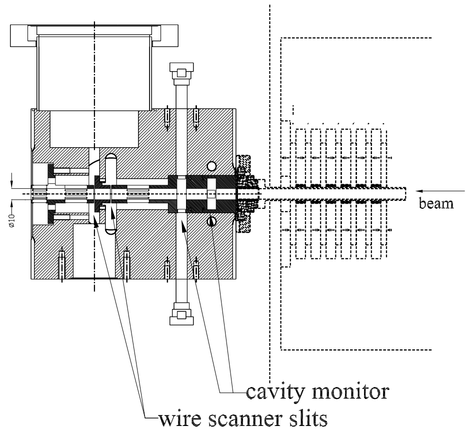

Fig. 3. Cut through the diagnostic block showing the end of an undulator section. The beam is coming from the right. On the left the slits in the beam pipe are visible which allow the wire to pass through the beam.

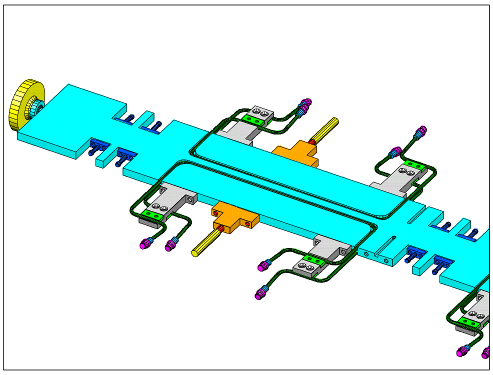

Fig. 4. Typical section of the undulator chamber [10]. Steerer windings and the 4 channels of the BPMs are visible.

to calibrate a cavity monitor [7] which is located in the same diagnostic block (see 3). The cavity monitor is a non-destructive device and allows the position of a single electron bunch to be measured. This is the reason why after calibration the cavity monitor will be the standard device for orbit measurements.
To allow this calibration both monitors are located in a so-called diagnostic block. Each diagnostic block contains a pair of wire scanners for horizontal and vertical beam profile and position measurement and a cavity monitor (figure 2). A cut through the diagnostic block is given in figure 3.

2.2. *Beam Based Alignment*

Figure 4 shows the undulator chamber [10] with integrated BPMs and correctors. For each quadrupole inside the undulator a corrector and BPM is integrated into the chamber. Two types of BPMs are used, both optimized for short electron bunches and both allowing a single bunch position measurement with an accuracy of 1 μm [8, 9]. This should allow the trajectory inside the undulator to be optimised to the desired rms value of less than 10 μm [5, 6].

3. Procedure to Align the Electron Beam

Different phases can be distinguished:

3.1. *Startup*

To get the electron beam through the undulator all BPM's can be used without any additional alignment or calibration. The accuracy due to mechanical and electrical tolerances of the monitors of a few hundred micro meters is sufficient.
To protect the undulator against radiation damage the startup will be done with only a few single bunches in the macropulse, a reduced macropulse repetion rate and a reduced charge per electon bunch (0.1 nC instead of 1 nC, see table 1). All types of monitors are able to work in this mode.

3.2. *Beam position in the Absolute Reference System*

The next step is to measure the electron beam position in the reference frame of the undulator with the wire scanners inside the diagnostic blocks. The electron trajectory is now fixed at 4 points with an accuracy better than 15 μm.

3.3. *Beam Based Alignment*

Using the BPM's and corrector coils inside the undulator sections (see 4, 5) it should be possible to achieve a straight orbit within the needed 10 μm [5, 6].

4. Measurement of Optical Mismatching

The beam optic before the undulator must be matched to the optic of the undulator to obtain a regular optic inside the undulator. Due to the

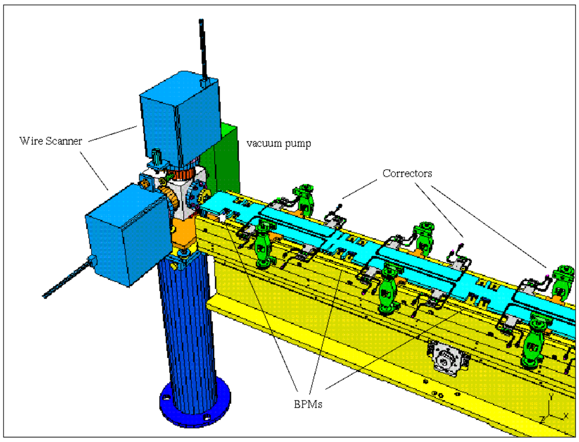

Fig. 5. Diagnostic block with part of the undulator chamber. The BPMs and correctors are visible.

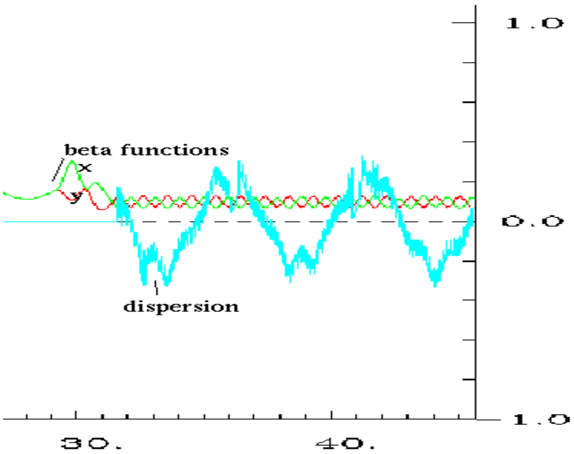

Fig. 6. The beta functions (β) and the horizontal dispersion ($D(s)$) are shown for a matched optic at a beam energy of 200 MeV. (x-axis: Longitudinal position in [m], undulator starts at 32 m.) The vertical dispersion is ≈ 0.
(y-axis: The beta function is shown as $(\sqrt{\frac{\beta}{m}} \cdot \frac{1}{10})$ and the horizontal dispersion is shown as $(\frac{-D(s)}{m} \cdot \frac{1}{10000})$.)

constant gradient of the quadrupoles the matching depends on the beam energy. Figure 6 shows a matched optic. A mismatching causes a beta beat which can be measured with help of the wire scanners. Figure 7 shows a mismatched optic.

5. Conclusion

The electron beam diagnostic will allow an easy start up of the FEL undulator. In a second step

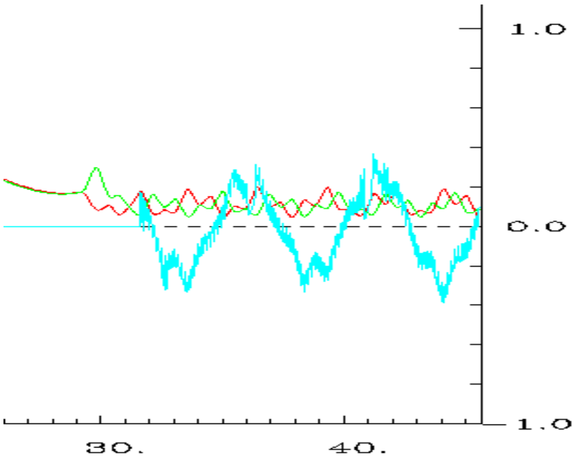

Fig. 7. The beta functions and horizontal dispersion are shown for a mismatched optic at a beam energy of 200 MeV. Same units as in figure 6 are used.

the necessary precision of the beam trajectory can be achieved by a precise measurement of the electron beam orbit in the reference frame of the undulator and with a beam based alignment procedure. The wire scanners check the correct matching of the beam optics to the undulator.

References

[1] A VUV Free Electron Laser at the TESLA Test Facility: Conceptual Design report, DESY Print TESLA-FEL 95-03, Hamburg, 1995

[2] K. Wittenburg, H. Schultz; DESY; A Proposal for using Wire Scanners at the LINAC Test Facilities; DESY-TESLA 94-15 (1994).

[3] G. Schmidt, S. Striganov, K. Wittenburg, Estimation of the TTF-FEL Wire Scanner Signal, Internal Report.

[4] With support from the Beam Instrumentation Group (BI), Cern.

[5] P. Castro; Orbit Correction by Dispersion Minimization in an Undulator with Superimposed FODO Lattice, Proc. 1998 EPAC, Stockholm

[6] K. Flöttmann, B. Faatz, E. Czuchry, J. Roßbach, Beam Based Alignment Procedure for an Undulator with Superimposed FODO Lattice, DESY Print TESLA-FEL 97-05, Hamburg 1997

[7] R. Lorenz, T. Kamps, M. Wendt, Beam Position Measurement inside the FEL Undulator at the Tesla Test Facility Linac, Proceedings of DIPAC 97, Frascati, Italy, p.73-75

[8] T. Kamps et al., *New Microwave Beam Position Monitors for the TESLA Test Facility FEL*, 8th Beam Instrumentation Workshop, SLAC, May 4 - 7, 1998

[9] M. Wendt, Coaxial line monitors, privat communication.

[10] The chamber is built in collaboration with the Experimental Facility Devision of the Advanced Photon Source (APS), Argonne.