FIRST OPERATIONAL RESULTS OF THE WAVEGUIDE BPM SYSTEM FOR THE TESLA TEST FACILITY FREE ELECTRON LASER

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Abstract

For the beam based alignment procedure at the TESLA Test Facility Free Electron Laser (TTF FEL) a high precision beam position monitor (BPM) system has been developed and tested. The operation principle of the BPM is based on waveguides coupling through small slots to the beam field. Tests in laboratory as well as under beam conditions have proven the functionality of the design. Ten BPMs will be in operation for the next run of the TTF FEL starting in July 2000. This papers describes the system design and first measurements under beam at the TTF FEL.

1 INTRODUCTION

The Free Electron Laser (FEL) at the TESLA Test Facility (TTF) [1] is based on the so-called SASE (Self Amplified Spontaneous Emission) principle [2] in which the spontaneous undulator radiation is strongly enhanced due to the interaction between the radiation field and the electron beam in the undulator. The SASE process imposes strong requirements not only on the electron beam quality but also on the overlap between the electron beam and photon field during the passage of the electron beam through the undulator. Simulations showed that the mean variation between photon path and electron trajectory must be kept under a level of $\Delta x = 10$ μm in order to reach saturation in the undulator [3]. This requirement can only be fulfilled with a beam based alignment (BBA) procedure based on dispersion free steering for the electron beam [4]. Since this procedure needs relative orbit measurements with very high precision at several points along the undulator beamline a beam position monitor system coping with the system related limitations was developed for this purpose [5]. Simulations of the BBA showed that the relative resolution of the BPMs should not exceed $\delta x = 2$ μm in order to keep the maximum deviation under the limit of $\Delta x = 10$ μm [6].

2 DESIGN CONSTRAINTS

As mentioned above the SASE process imposes strong requirements on the electron beam quality, especially on the phase space density of the electron bunches. In consequence only a non–destructive measurement technique is possible. Furthermore the BPM has to be an integral part of the undulator vacuum chamber in order to satisfy the requirements [7]

3 OPERATION PRINCIPLE

The operation principle of the waveguide BPM is based on the coupling to the electromagnetic field co–propagating with the electron beam providing a high resolution and non–destructive position measurement. A fractional part of the beam field is decoupled through four slots arranged symmetrically around the beam pipe. Special T-ridged waveguides were used to reduce the waveguide size and to enhance the coupling. Because of the limited space, each BPM unit is split into two symmetric pairs, separated by $3/2$ undulator wavelength in beam direction. At the end of each waveguide, a coaxial adapter is flange–mounted to the beam chamber. The cutoff frequency of the waveguide is at 9 GHz, the working frequency of the first element of the signal processing electronics at 12 GHz. Fig.1 shows a schematic sketch of one BPM unit.

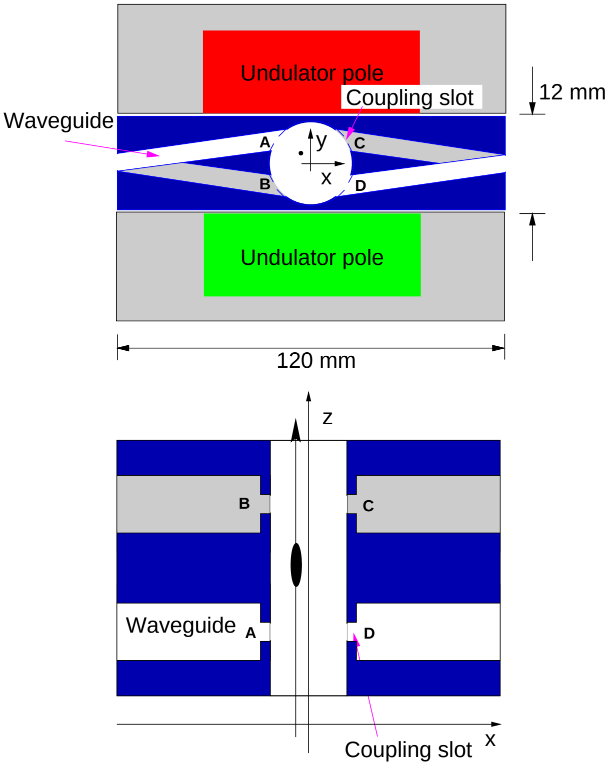

Figure 1: One BPM unit with four channels.

4 MEASUREMENTS

4.1 AT THE SBTF

For steering measurements at the SBTF (S-Band Test Facility) the signals coming from a prototype BPM were down–converted in one step from 12 GHz to DC using a mixer. The reference signal at 12 GHz with constant amplitude and phase stable to the beam was derived from the 4th harmonic of the accelerating frequency (2.99 GHz) visible in the spectrum induced in a stripline type BPM in the beamline of the SBTF. The BPM was moved transversely to the beam direction by a stepping motor and induced signals were detected with an oscilloscope. After that the beam position was determined by means of an algorithm developed for a beam based calibration technique [8]. In Fig.2 reconstructed beam positions are plotted versus set beam positions with the stepping motor. The BPM system is capable to measure beam positions to an offset of ±2 mm with high precision. During this measurement we were limited by the granularity of the internal ADC of the oscilloscope. For operation at the TTF FEL an ADC was developed for optimum pulse response with minimum distortion with a resolution of 14 bit.

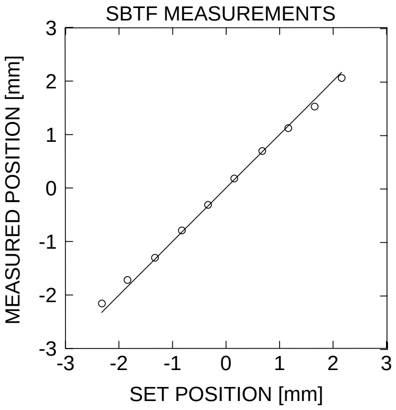

Figure 2: Results from prototype measurements at the SBTF. The solid lines indicates the ideal response.

4.2 AT THE TTF FEL

Down conversion as realized at the SBTF requires a reference signal at 12 GHz which is phase stable to the beam signal. Any jitter or oscillation in the reference signal will cause oscillations in the amplitude of the output signal strongly limiting the relative resolution of the BPM. With IQ–Mixing (or Quadrature IF Mixing) a technique is available which provides the opportunity to process signals at high frequencies without the necessity of a beam related reference signal. Therefore this technique has been used for a receiver of Waveguide BPM signals at the TTF FEL. In Fig.3 the receiver for one BPM channel is sketched. In total, 40 channels were build and installed and are now under tests with beam. The BPM signal is at first filtered at 12 GHz and then amplified by 11 dB before it is mixed down to 1 GHz by a local oscillator (LO) at 11 GHz. The main part of the electronics is the UHF stage which consists of two balanced mixers and two hybrids. The 1 GHz signal from the RF stage is introduced to two mixers in phase and the signal of the 2nd LO through a quadrature hybrid; the outputs at the intermediate frequency (IF) are in phase quadrature. This results in a coordinate system where the vector of the output signals with the two components $V_i(t)$ and $V_q(t)$ rotates with the IF frequency. The induced voltage for any BPM channel can then be calculated as $V_{CH} = \sqrt{V_i^2 + V_q^2}$. In Fig.4 measurements of this vector at different phases (for 200 orbits) for one BPM are plotted. As it can be seen, the signal is noisy resulting in a low signal to noise ratio V_A/σ_V limiting the relative resolution of the BPM to $\delta x = 100\mu m$. From the induced voltages beam positions for the 200 orbits were calculated. Fig.5 shows the results for the horizontal and vertical direction. Since the jitter of the electron beam was in the order of ± 20 μm [9] the main effect spoiling the resolution is noise created in the electronics. This is due to an improper choice of an element in the demodulation stage. This problem is encountered by a re-design of this part and will be tested during the next run of TTF FEL in July 2000.

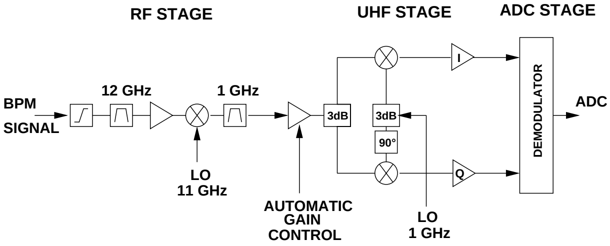

Figure 3: Signal processing electronics for one BPM channel.

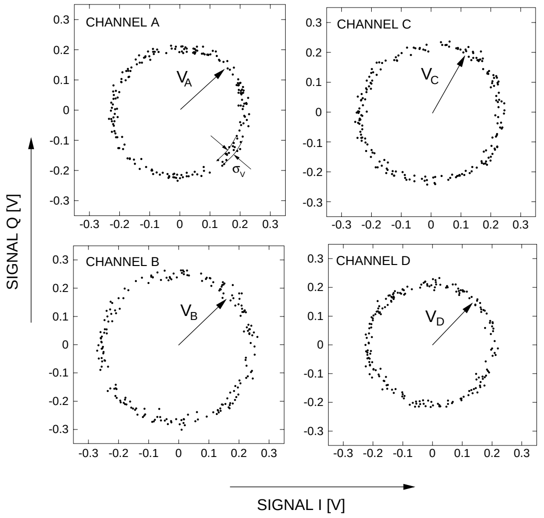

Figure 4: Polar plots of the V_i and V_q signals for all channels of one BPM.

The dynamic range of the electronics was also tested.

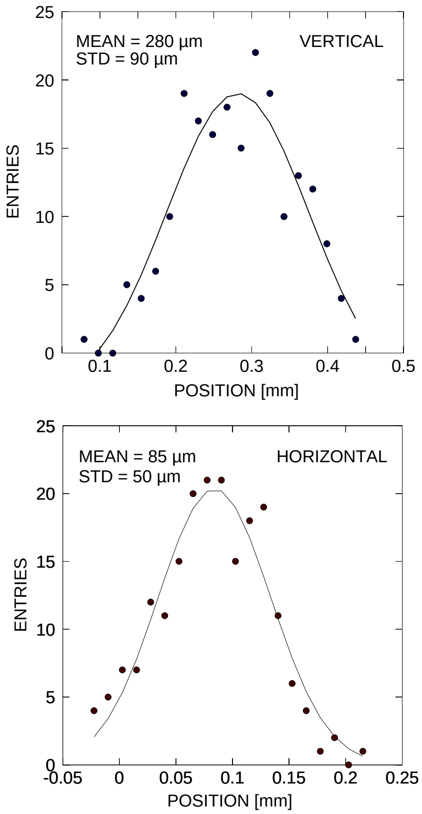

Figure 5: Measured positions for 200 orbits using a roughly centered beam with 0.7 nC bunch charge.

Fig.6 shows the sum of all channels of one BPM versus a reference measurement with a bunch charge monitor. The dynamic range of the BPM electronics meets the requirements for FEL operation, namely being linear for bunch charges in the range from 0.1 to 1.0 nC.

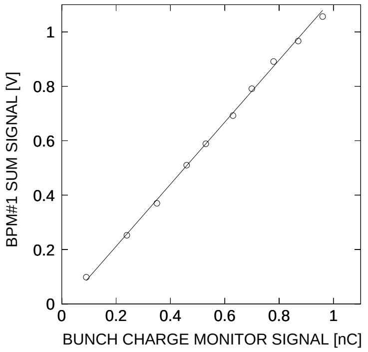

Figure 6: Sum signal of one BPM for different bunch charge levels.

5 FUTURE ISSUES

After the completion of the electronics for all BPM units calibration measurements will be accomplished in order to allow relative position measurements with a resolution in the order of $\delta x = 1\ \mu$m.

6 CONCLUSION

Measurements under beam conditions proved the functionality of the Waveguide BPM and the capability to measure relative beam offsets with high resolution in a region ±2 mm of the center of the beam pipe. For the electronics a re–design of the last element is necessary to maintain the high signal to noise ratio from the first elements of the electronics chain.

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REFERENCES

[1] J. Rossbach for the TESLA FEL Study Group, A VUV free electron laser at the TESLA test facility at DESY; Nucl. Instr. Meth., A375(1996)269

[2] A. M. Kondratenko, E. L. Saldin; Part. Accel. 10(1980)207

[3] S. Reiche, Numerical Studies for a Single Pass High Gain Free Electron Laser; PhD Thesis, University of Hamburg, 1999

[4] T. O. Raubenheimer, R. D. Ruth, A Dispersion Free Trajectory Correction for Linear Colliders; Nucl. Instr. Meth., A302(1991)61

[5] T. Kamps, Monitoring the Electron Beam Position at the TESLA Test Facility Free Electron Laser; PhD Thesis, Humboldt University of Berlin, 2000

[6] P. Castro, Orbit Correction by Dispersion Minimization in an Undulator with Superimposed PODO Lattice; Proc. of the EPAC98, Stockholm, Sweden, 1998

[7] R. Lorenz, T. Kamps, M. Wendt,Beam Position Measurement inside the FEL-Undulator at the TESLA Test Facility Linac; Proc. of the DIPAC97 Workshop, Frascati, Italy, 1997

[8] T. Kamps, Calibration of Waveguide Beam Position Monitors; Proc. of the FEL99 Conf., Hamburg, Germany, 1999

[9] M. Wendt, private communication, 2000