STRIPLINE BEAM POSITION MONITORS FOR “ELBE”

P.Evtushenko, A.Büchner, H.Büttig, P.Michel, R.Schurig, B.Wustmann, FZR, Germany
K. Jordan TJNAF, USA

Abstract

At the Forschungszentrum Rossendorf (FZR), the superconducting electron linear accelerator ELBE is under construction. It will deliver an electron beam with an energy of up to 40 MeV at an average beam current of up to 1mA. The accelerator uses standing wave DESY type RF cavities operating at 1.3 GHz. A non-destructive system for the measurement of the beam position at about 30 locations is needed. To obtain the required resolution of 100 μm, a system of stripline beam position monitors (BPM) is under design.

1 INTRODUCTION

There are some different applications of the electron beam of the ELBE accelerator. It will be used for experiments in radiation physics, nuclear physics and neutron physics. It also will be the driver for the infra red free electron laser (FEL). Obviously an accelerator needs a system for the beam position measurements. Also the position of the electron beam has to be controlled at the target in any experiment and inside the undulator of the FEL. In the case of the ELBE accelerator, the required resolution of the beam position measurements is about 100 μm. We decided to use stripline BPM, since it is well known that with the BPM one can easily achieve the resolution.

2 MECHANICAL DESIGN OF THE BPM

2.1 3λ/4 version of the ELBE BPM

Two versions of the BPMs were designed. The BPM of the JLab FEL machine was the prototype for our first BPMs. The BPM is electron beam welded and it has four SMA feedthroughs which are also welded to the BPM. The transmission line which is formed by the strip and external pipe of the BPM has on impedance of 50 Ω. The length of the strip is an important item for BPM sensitivity and for the calibration of the whole BPM system. Usually the length is optimized so that the BPM has maximum sensitivity at the fundamental frequency of the accelerator, which leads to a strip length $(\lambda/4)\times(2n+1)$, where n is 0,1,2,… That means 57 mm, 173 mm and so on at 1.3 GHz. But because of the calibration procedure which we want to use the length of the strip of the BPM is 144 mm, instead of 173 mm.

2.2 Calibration of the BPM system

For the calibration and verification of the BPM system we will use the procedure familiar with the JLab BPM system [1]. Before we explain the idea of the calibration we want to note, that during machining and welding of the BPM the X plane electrodes can be a little shifted in the X direction, but not in the Y direction. The procedure of the calibration is the following, if we want to calibrate, for instance, the Y plane of a BPM, we can inject a 1.3 GHz signal to the X plane electrode of the BPM. In this case the position which will be displayed in the corresponding BPM software is a result of two facts. First is the difference between the mechanical and electrical center of the BPM and second is that electrical chains of the two opposite channels can have slightly different gain and offset. All these facts can be taken in to account in the calibration. There is one more important item in the calibration. To enable such a method of calibration the S_{21} from the X channel to a Y electrode has to be big enough. To increase the S_{21} the strip length was reduced from 173 mm to 144 mm. Important is that such calibration can be done when the BPM detectors are already installed on the beam line.

2.3 Compact version of the BPM

During the manufacturing of the first BPMs we faced some technological problems. For instance, some feedthroughs

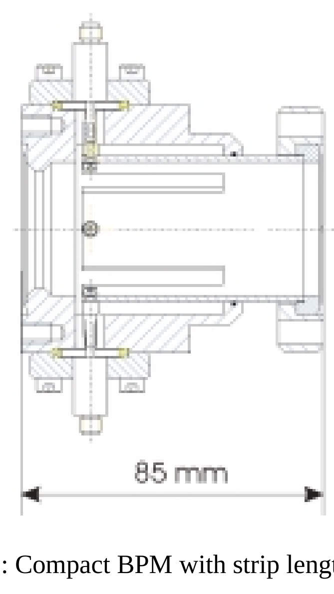

Figure 1: Compact BPM with strip length 40 mm

were broken under welding of the BPM or during the baking of the beam line. Sometimes it was not possible to put the BPM at the desirable position on the beam line because of its length. All these reasons pushed us to design another BPM. The main idea was to reduce the strip length from 3λ/4 to λ/4. The cutaway view of the compact BPM is in figure 1. On the BPM another kind of the SMA feedthrough is used. The feedthroughs are not welded to the BPM but sealed to it with the CF flanges. This make possible changing the feedthrough on the BPM without removing it from the beam line. The BPM is done with the help of hard soldering, but not with electron beam welding, which makes it significantly cheaper. The strip length is 40 mm, this enable the calibration described above. The total length of the BPM is 85 mm.

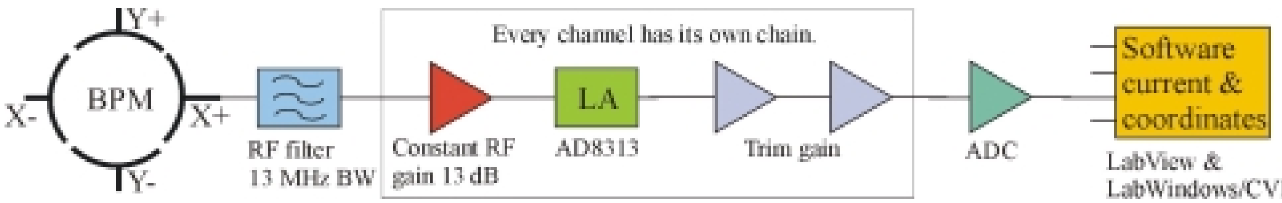

Figure 2: Principle scheme of the BPM electronics

3 THE BPM ELECTRONICS

The BPM electronics is based on the logarithmic amplifier AD8313 from Analog Devices [2], which is a direct RF to DC converter rated up to 2.5 GHz. This fact give us the possibility building the BPM electronics without mixing down the RF signal of the BPM. Thus the electronics operate at the fundamental frequency of the accelerator, which is 1.3 GHz, and have a rise time of about 10 µs. The BPM signal goes through the bypass filter with 13 MHz bandwidth. Then it is amplified with constant RF gain 13 dB to be matched to the extra linear range of the AD8313. The range goes from –65 dBm up to –5 dBm. The output of the logarithmic amplifier is matched to the ADC working range with the trim gain. One digit of the ADC corresponds to 8 µm beam displacement.

4 MEASUREMENTS ON THE WIRE TEST BENCH

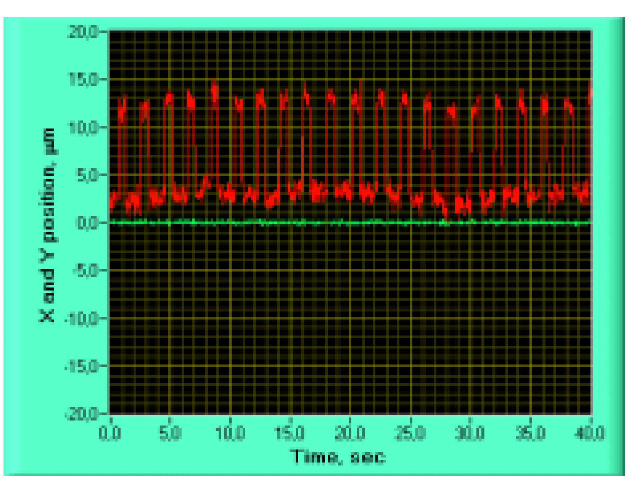

Figure 3: One result from the wire test bench.

All new BPMs and the BPM electronic units are tested on the "wire test bench”. The BPM is mounted on the linear motor stage, which can move the BPM in steps of 2.5 mm. A well aligned wire is stretched through the BPM. All this equipment is mounted on the optical table to prevent wire oscillations. The wire is driven by an RF generator at 1.3 GHz and excites TEM waves in the BPM thus simulating the electron beam. One of the tests we perform with the wire is a modulation of the wire position with a very small amplitude. Decreasing the amplitude of the modulation we can see the minimum of the wire (beam) displacement which we can detect with the BPM and electronics. The result of one of the tests is shown in figure 3. During the test, the position of the wire was modulated with an amplitude of 10µm. Another test concerned the linearity of the BPM. This way we proved that the BPMs are linear enough in the required range of ±5mm.

5 MEASUREMENTS ON THE ELBE INJECTOR

Finally, the real BPM resolution has to be measured with the beam. Up to now we were able to make such measurements with the ELBE injector with the 250 keV electron beam and current of up to 1 mA. To estimate the BPM resolution, the beam position was measured with a 5 µs rate over several milliseconds. The average position of the beam was calculated, as well as the standard deviation of the beam position distribution. The standard deviation is naturally the accuracy of the position measurements in the case when the measurement time has the same order of magnitude as the sampling time which is 5 µs in our case. In fact the minimum of the macro pulse length of the accelerator has to be 100 µs. That means that with the help of the averaging we have accuracy even better than the measured standard deviation.

Results of the measurements at different currents are presented below.

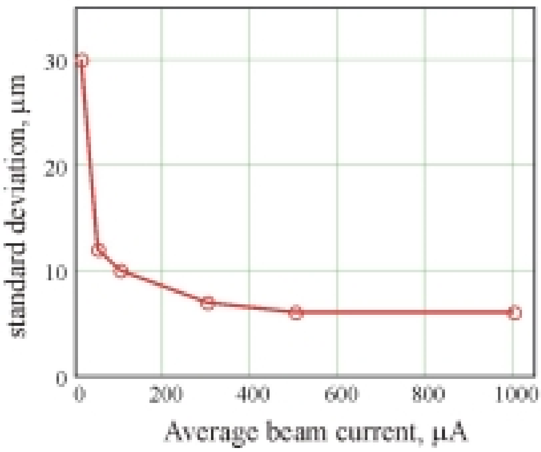

Figure 4:Standard deviation of the position measurements.

6 BUNCH LENGTH MINIMIZATION IN THE INJECTOR

For proper operation of the accelerator it is very important to minimize the length of the bunch entering the RF cavity. The injector of the ELBE accelerator consists of the pulsed thermionic electron gun and two buncher cavities. The gun is producing pulses with a repetition rate of 13 MHz or 260 MHz with a length of about 500 ps. The bunchers are used to compress the bunch so that its length is about 10 ps at the entrance of the first RF cavity. The first subharmonic buncher operates at 260 MHz and second fundamental buncher operates at 1.3 GHz. To make the correct bunch compression we must set the right phase and gradient of both bunchers. Thus we have to be able to measure the bunch length in the range from 500 ps down to 10 ps. One of the BPMs is installed upstream of the accelerating module. Since the spectrum of a beam depends on the bunch length, measurements in the frequency domain can give information about the bunch length. The idea is used successfully on the accelerator. To do this we just need to connect the BPM output directly to the spectrum analyzer and to maximize the signal amplitude by changing the power and phase of the bunchers. During the test phase of the injector we did the cross check measurements of the bunch length with the help of the kicker cavity. Measurements done with the kicker cavity and with the BPM are in good agreement. In figures 5 and 6 there are results of the measurements of the BPM signal at 1.3 GHz as a function of the subharmonic buncher power and phase. Thus we can see that optimal power and phase are 500 W and 5° respectively.

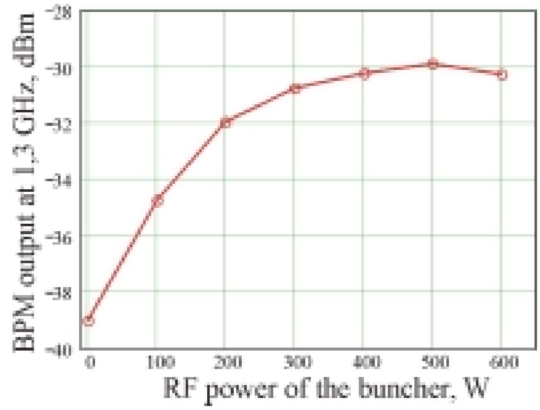

Figure 5:The BPM signal vs. the buncher power.

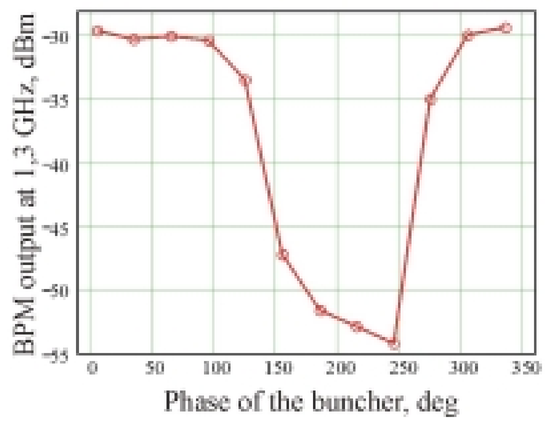

Figure 6:The BPM signal vs. the buncher phase.

REFERENCES

[1] T. Powers et al., "Design, Commissioning and Operational Results of Wide Dynamic Range BPM Switched Electrode Electronics", BIW'96, Chicago, May 1996.

[2] http://www.analog.com/