EXPERIENCE WITH STRIPLINE BEAM POSITION MONITORS ON THE TESLA TEST FACILITY LINAC

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Abstract

Measurement and correction of beam position are very important for the optimization of beam characteristics and alignment in the Tesla Test Facility (TTF) linac. We describe and present measurements with beam of the performance of the stripline beam position monitors (BPMs) in operation and in order to determine the beam response.

1 INTRODUCTION

Beam position measurement and correction are essential in the TTF linac for collider applications and for the VUV FEL experiment [1]. Beam orbit correction algorithms use the knowledge of the machine lattice in the form of response matrix (element R_{12} in Transport [2] notation) in order to find a combination of corrector strengths which reduces the rms beam position offsets at the BPMs. These correction procedures involve several BPMs and corrector magnets, and require precise measurements of beam position and a good knowledge of the transport matrix.

A series of experiments has therefore been performed to determine the linearity region and range of the BPM response and its offset with respect to the magnetic centres of adjacent quadrupoles. Measurements of the response matrix are compared to the one calculated from known quadrupole gradients and measured beam energy. Results on BPM gains fitted to the measurements will be presented. Correlated beam position jitters, which affect trajectory and emittance measurements, have been measured. Here we will present only a choice of characteristic measurements. For a more exhaustive treatment see [3].

Several measurements have been performed both on TTF phase one and phase two layouts. Phase one had an injector with low charge per bunch (40 pC), high bunch repetition rate (216 MHz) and only one accelerating module (beam energy up to 120 MeV). Phase two has an injector with high bunch charge (1-8 nC), low rep. rate (1 MHz) and two accelerating modules (energy up to 250 MeV

In Fig. 4 is shown a sketch of the lattice layout of the TTF phase one in the high energy area after the accelerating module, with the location of the stripline BPMs. The focusing is provided by quadrupole doublets. There are also other types of BPMs on the TTF linac, both outside and inside the cryostats, which contain the accelerating modules. These additional BPMs are based on cavities and have a higher resolution than the stripline BPMs. Here we will limit our discussion to the stripline monitors, which were specified for a resolution of 0.1mm, considered sufficient for beam alignment in the low frequency TTF accelerating modules, having a large bore.

2 STRIPLINE BPMS

We will summarize briefly the characteristics of the stripline BPMs, which have been extensively described elsewhere [4, 5]. The stripline BPMs are 17 cm long and have a 3 cm bore radius. The readout electronics are based on the AM/PM circuit, which gives directly a normalized output proportional to beam displacement and independent of current. The response is linear within ±5mm and then deviates from linearity and saturates at about 1 cm. An output curve measured by scanning with a correcting magnet without any magnetic lenses between it and the BPM, is shown in Fig. 1.

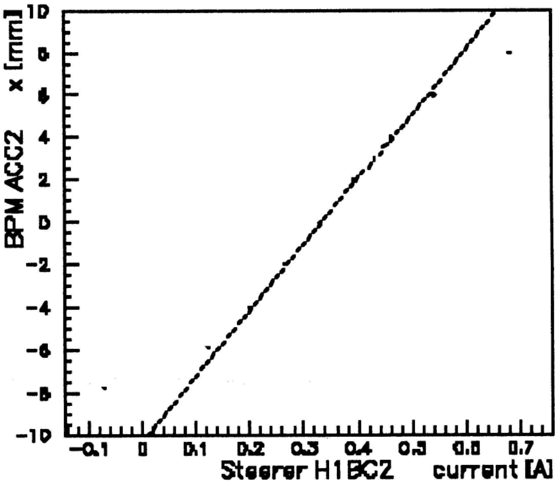

Figure 1: BPM reading versus corrector current.

The front end electronics had to be redesigned for the phase two, where the period between bunches is larger. The new design provides for single bunch response [6]. A typical output pulse is shown in Fig. 2. The acquisition system tracks the waveform until the middle of the flat top and then holds the corresponding value.

The electronics offset is set to zero using the beam induced signals. The voltage from one vertical (horizontal) electrode is split into equal branches and applied to the horizontal (vertical) ones. The overall output voltage is then set to zero by acting on a phase shifter in series with one of the inputs to the phase comparator of the AM/PM circuit.

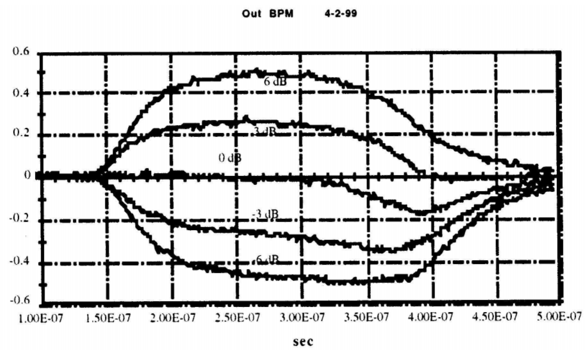

Figure 2: Typical output pulses from the fast BPM readout electronics for various beam positions, simulated by unbalancing the input signals.

The electronics for the phase one, having a slow response averaged over about 100µs, has shown low noise and good stability. The jitter was comparable with the resolution, 0.025 mm as determined by the least significant bit. Drifts in BPM gains over several days were less than 10%. The new fast electronics have a larger bandwidth and therefore a higher jitter, about 0.1mm.

3 Q-POLE MAGNETIC CENTER MEASUREMENT

A beam passing at a distance v from the center of a quadrupole with strength k receives a deflection α = kLy where L is the length of the quadrupole. A change of the quadrupole strength Δk leads to a change of deflection $\Delta\alpha$= (Δk)Ly , which is proportional to the beam offset at the quadrupole. The beam deflection at the quadrupole changes the beam trajectory at the downstream BPMs. Observing the position shift at the downstream BPM as a function of the position at the upstream BPM close to the quadrupole, one obtains a measurement of the position of the quadrupole magnetic centre with respect to the BPM magnetic centre. The horizontal and vertical corrector dipoles ahead of the upstream BPM are used to steer the beam at approximately the 0, ±2 mm, ±4 mm readings of the upstream BPM. In Fig. 3 are plotted the position measurements at the downstream BPM versus the beam positions measured at the BPM close to the quadrupole, for three values of the quadrupole current. The best fit of the dashed line (I=6 A) and the dotted line (I=10 A) coincide at Y = 0.13 mm.

Systematic errors on the determination of the quadrupole magnetic centre are due to the angle of the beam trajectory at the upstream BPM. For a BPM to Q-pole distance of 1 m and an angle of 0.1mrad the error is 0.1 mm.

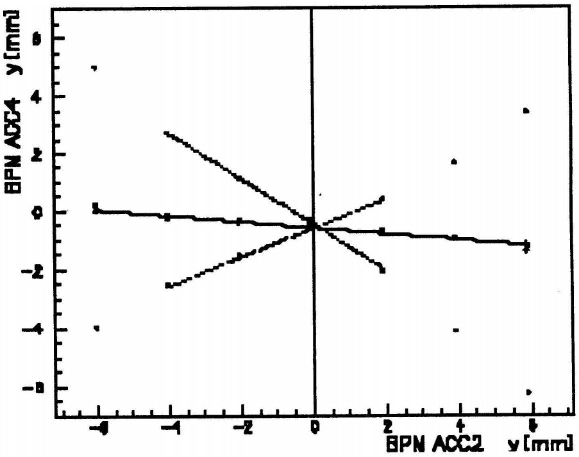

Figure 3: Measured beam position at BPM ACC4 versus measured beam position at the quadrupole doublet ACC2 set to 8 A (full line), 6 A (dashed line) and 10 A (dotted line).

4 RESPONSE MATRIX MEASUREMENTS

The shift of the beam transverse position at a given BPM due to a corrector field located upstream is given by the R_{12} element of the transport matrix. The so-called "response matrix", which is used for correcting beam trajectories, contains the R_{12} elements of the transport matrices between correctors and BPMs. In order to obtain detailed information on BPM gains, corrector magnets and quadrupole gradients, we compare the measured response matrix with the model response matrix.

The beam position shift Δx_{mn} measured with BPM m due to a change in the corrector magnet deflection n is given by.

$$\Delta x_{mn} = g_m \theta_n R_{12,mn}$$

where g_m is the gain of the BPM m. These parameters g_m and θ_n are varied to minimize the x^2 deviation between the model and measured response matrices

$$X^2 = \sum_{n,m} \frac{(R_{12,mn}(k_i).\theta_n g_m - \Delta x_{mn})^2}{\sigma_m^2}$$

where σ_m is the measured beam position error of BPM m averaged over 20 pulses . The fit parameters in R_{12} are the strengths k_i of both quadrupoles in the doublets. The beam energy is measured with a spectrometer magnet with a typical error of 3%.

The fit parameters g_m and θ_n are inversely correlated, therefore, depending on the initial values given to the fit parameters, a different set of results is obtained. We scale the gains $g_{m,}$ so that their mean value is equal to unity.

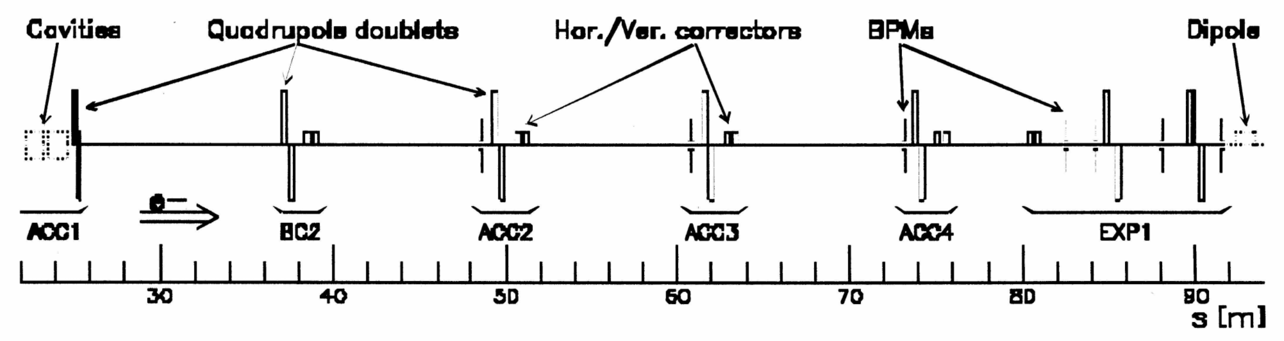

Figure 4: Magnetic layout of beam transport channel after the first accelerating section.

After scaling also the corrector strengths, the mean values of the θ_n obtained are only a few per cent higher than the expected value. This indicates that the calibration of the BPMs is on the average very good. However, the rms variation of θ_n is about 7%, which is larger than the magnetic field error expected (<1%). A reason for that can be hysteresis effects on corrector magnets. Results of BPM gains are shown in Table 1.

Table 1: Results of horizontal BPM gains from the analysis of three response matrix measurements

BPM	**σ_x [mm]**	**Horz. Gain**		
		I	II	III
ACC2	0.030	1.08	1.09	1.08
ACC3	0.060	0.89	0.89	0.89
ACC4	0.070	0.98	0.98	0.96
1EXP1	0.020	1.05	1.04	1.05
2EXP1	0.025	1.00	1.00	1.02
3EXP1	0.035	1.88	1.95	1.84
4EXP1	0.025	1.21	1.15	1.15

5 CONCLUSION

Stripline BPMs are used in the TTF beamline with a resolution better than 0.05 mm. Their linearity, gain and stability has been studied. The BPMs provide a linear response in the range of about ±5 mm. The relative gain error is within ±10%. The measurement of the magnetic centre offset of a quadrupole with respect to the nearby BPM resulted in about 0.1 mm. The stability of the BPM readings is good, allowing to detect beam position jitter due to other sources in the beam line.

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7 REFERENCES

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