DESIGN OF STRIPLINE BEAM POSITION MONITORS FOR THE ESS MEBT

S. Varnasseri, I. Bustinduy, A. Ortega, I. Rueda, A. Zugazaga, ESS Bilbao, Bilbao, Spain
R.A. Baron, H. Hassanzadegan, A. Jansson, T. Shea, ESS- ERIC, Lund, Sweden

Abstract

There will be overall 8 Beam Position Monitors (BPM) installed in the ESS MEBT. Seven of them will be used for the measurement of beam position, phase and intensity. One BPM will be used for the fast timing characterization of the chopped beam. The design is based on shortened stripline to accommodate the signal level for low velocity proton beam within MEBT. Due to mechanical space limits, all the BPMs are embedded inside quadrupoles; which requires special care on the magnetic properties of the materials within BPM sets and in particular the feedthroughs. The prototype electromagnetic and mechanical design is finished and its manufacturing is underway. This paper gives an overview of the electromagnetic and mechanical design and related analysis including position signal sensitivity of the BPMs.

INTRODUCTION

ESS MEBT (Medium Energy Beam Transport) with energy of 3.62 MeV is part of the European Espallation Source (ESS) to be operational at Lund, Sweden early 2020 [1]. It requires various beam diagnostics instruments including the position, phase and intensity measurement devices. As part of the beam diagnostics instruments necessary for future commissioning and normal operation of accelerator, we have designed and manufactured a prototype of stripline beam position monitor (BPM). The proton beam has a repetition frequency of 14 Hz of pulses of 2.8 ms and nominal amplitude of 62.5 mA. The BPM pick ups are of stripline type which are housed inside quadrupole magnets (Figure 1). The main reason is due to lack of longitudinal mechanical space within compact MEBT to install all the BPMs. The BPM sensitivity to displacement, voltage signal level, frequency response and mechanical restrictions are the main factors in the design of stripline. Table 1 shows the main beam parameter related to BPM design analysis.

Table 1: BPM Related Beam Parameters

Parameter	Value	Unit
Beam energy	3.62	MeV
Beam current (avg.)	62.5	mA
Particles/bunch	1.1e9	
Readout frequency	704	MHz
RF frequency	352	MHz
Bunch length	60-180	ps
Pulse length (max.)	2.8	ms

In principle the second RF harmonic of 704.42 MHz of the electrode signal is used for BPM signal processing readout system. The BPM sensitivity with the nominal MEBT beam requires to be larger than 0.8 dB/mm and the voltage amplitude reaching to electronics has to be compatible with margin to input level of electronics. The design of stripline monitors is based on transmission line with 50 Ω characteristics impedance. Furthermore the bunch length is not fixed during the passage within MEBT, so the voltage amplitude on electrodes slightly varies depending on the physical location of BPMs. In the following sections, the electromagnetic design, characteristics and mechanical realization of the first prototype is described.

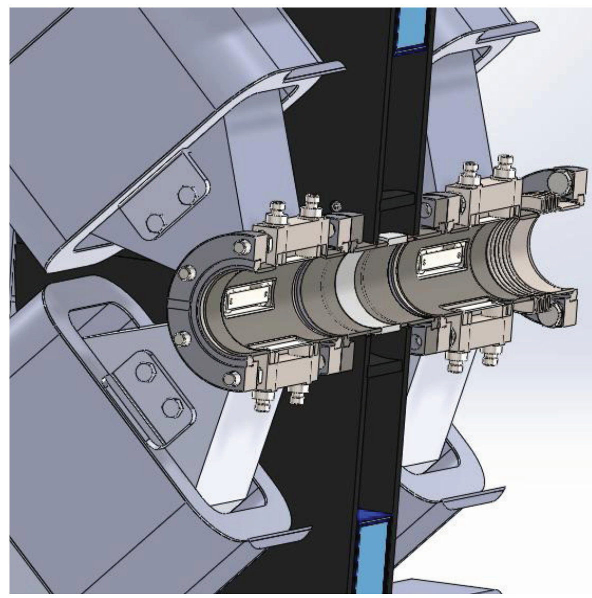

Figure 1: A CAD image of two BPM blocks embedded within two adjacent quadrupole magnets.

The overall BPM accuracy shall be smaller than +/-200 µm. This includes electronics errors, BPM sensor tolerances, errors of BPM welding on the beam pipe and alignment errors. Furthermore the BPM stripline shall be fabricated so that error contribution due to mechanical tolerances and electrodes imperfections does not exceed +/- 100 µm of the overall BPM accuracy. These values implied by other elements and overall tolerances within MEBT section.

ELECTROMAGNETIC ANALYSIS

The bunches passing through the BPMs distributed within MEBT section vary in length at different locations. This will change the bunch charge frequency spectrum and therefore the BPMs will generate slightly different signal amplitudes at different physical locations. This is true also for the signal timing shape which goes out of the BPM striplines due to different frequency components.

ISBN 978-3-95450-177-9

Fig. 2 shows the bunch charge frequency spectrum variation with the bunch length. At frequency of 704 MHz, there is around 24% increase in charge contribution of bunches with 60 ps in comparison with the 180 ps.

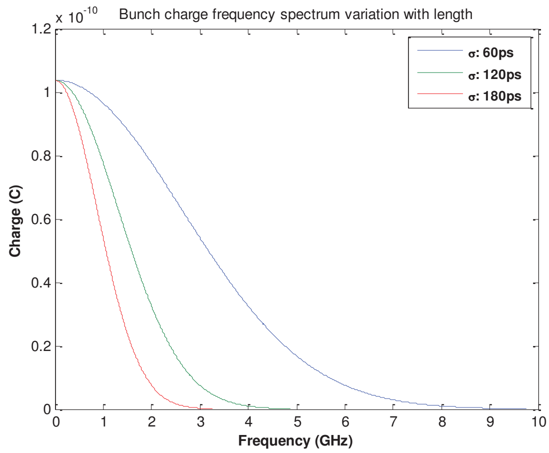

Figure 2: Bunch charge frequency spectrum variation.

Since the BPMs are installed inside the quadrupoles of MEBT, several options have been investigated and finally the stripline solution with shortened length of strip electrodes has been chosen. All the 8 BPM blocks are identical, however due to mechanical integration reasons, six of the blocks include also a 25 mm bellow. The BPM model is cylindrical with one pair of strips in each plane (parallel and perpendicular to gravity) with 45^0 transverse angle between adjacent strips. The 2D and 3D analysis at low velocity beam (ß=0.088) were carried for the whole block of BPM. Figure 3 shows a snapshot of the block for 704 MHz components. In order to foresee the electrode output signal characteristics, the electrode response at various possible bunch lengths and at the low energy of MEBT was analysed. The signal feedthroughs are non-magnetic weldable SMA type with outer diameter of 9.54 mm and pin diameter of 2.4 mm. For the brazing of ceramic to stainless steel body of connectors no magnetic material is used. The reason was to eliminate any magnetic noise disturbance from BPM on the magnetic field harmonics of quadrupole magnets. The quadrupole yoke gap is 15 mm, which provide 1 mm free space for mechanical alignment purposes of the BPM block. In the design of BPM stripline, the dimension of the SMA feedthrough was integrated in the model, and the whole model has been analysed as signal port device. Simulations show high dependence of the characteristics impedance of the BPM to the material, spacer dimensions and gap between the electrode and the body wall. So the alumina AL_2O_3 as spacer was chosen in order to secure the gap distance within required tolerances. Other materials like Macor was found not to provide higher performance than alumina; in addition has lower thermal conductivity of 1.46 W/m^0C in comparison to the alumina 96% with thermal conductivity of 24.7 W/m^0C. The gap between electrode and the body is 5±0.01 mm. The characteristic impedance reference is 50 Ω and the high resolution bandwidth (20dB) is 1.2 GHz. The length of the strips in combination with the strip thickness has been optimized in order to produce high signal amplitude at 704 MHz.

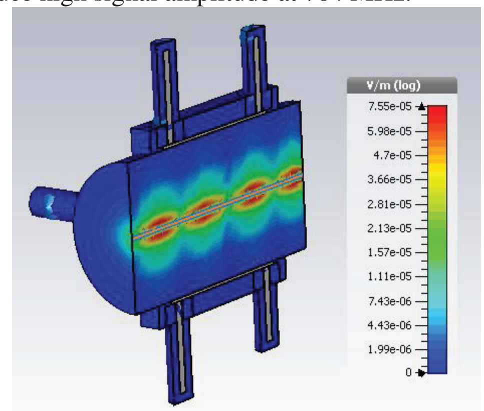

Figure 3: Snapshot of analysis for processing frequency of 704 MHz, 50 Ω and short terminations.

Both ends of strips are e-beam welded to feedthrough pins. Upstream port is connected via the coaxial cable to the electronics front end, while the downstream port is terminated with a 50 Ω termination. It is possible to terminate the downstream port to a short, when it is required for some dedicated measurements.

Signal Port Responses and Coupling

In order to match the stripline output impedance to the electronics input impedance of 50 Ω, the high frequency analysis of the BPM block was part of the design process. Furthermore, the high frequency coupling between adjacent and in-front electrodes are extracted from the S parameters. In the Figure 4, the transmission and reflection parameters and coupling of one electrode in relation to the adjacent electrode (S13) and in-front electrode (S15) is plotted. The plot shows at the frequency of interest 704 MHz, the coupling of adjacent electrodes is -50 dB and in-front electrodes coupling is -60 dB. Also the electrode reflection response around the interested frequency is expected to be better than -35 dB.

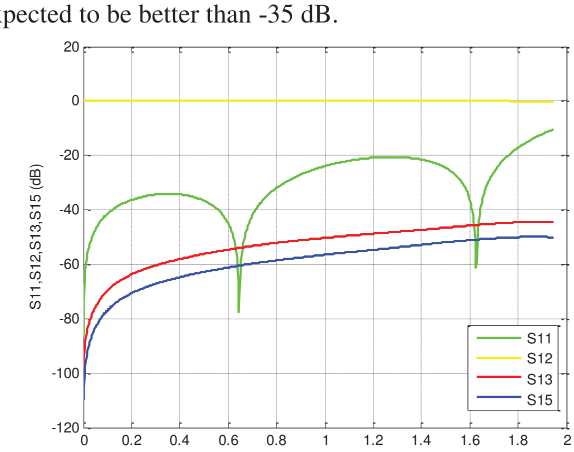

Figure 4: S-parameters of the Stripline electrode.

Beam Transfer Impedance

The beam transfer impedance is defined by equation 1.

$$Z_t(f) = \frac{V_{pu}(f)}{I_b(f)} \quad (1)$$

ISBN 978-3-95450-177-9

In which Z_t , V_{pu} , I_b are the transfer impedance, pick-up induced voltage and beam current respectively.

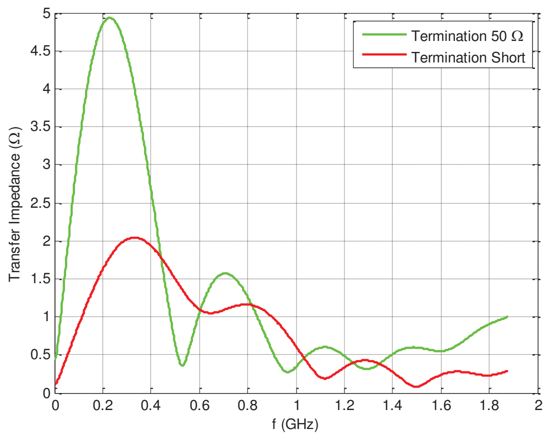

Figure 5: Transfer impedance for 50 Ω (green) and short termination (red) vs. frequency component of bunch.

Figure 5 shows the transfer impedance of one electrode vs. the frequency component of charge bunches. The design of BPM is optimized in order to have the peak output power for the interest frequency component of 704 MHz. The graph shows a transfer impedance of 1.6 Ω at the frequency of 704 MHz with a terminated port at strips downstream.

Single Bunch and Multi Bunch Time Domain Response

The nominal number of particle per bunch of 1.1e9 protons is considered for the 3D simulation in order to evaluate the voltage amplitude on the output port of the stripline. The multi bunch analysis was performed to evaluate the power available at the 2nd harmonic of the MEBT stripline signal. These analysis provided information for the BPM electronics design, and also an estimation of the undesirable high frequency modes excited by the beam. RF cables attenuation as function of frequency is considered in the analysis by taking into account the skin effect losses. Table 2 shows the total peak voltage of the stripline electrode output for low energy beam and various bunch lengths.

Table 2: Stripline Voltage Amplitude Variation with Bunch Length at 3.62 MeV

Bunch Length(σ)	Voltage (pk)
180 ps	295 mV
150 ps	302 mV
120 ps	308 mV
105 ps	320 mV
60 ps	340 mV

Note that these values are corresponding to the peak values. The electromagnetic simulation voltage results for single bunch were repeated at RF bunching frequency of 352 MHz to provide the RF power available at the interest harmonic. The result is shown in Figure 6, in which the simulations were performed for the rms bunch length of σ=180 ps.

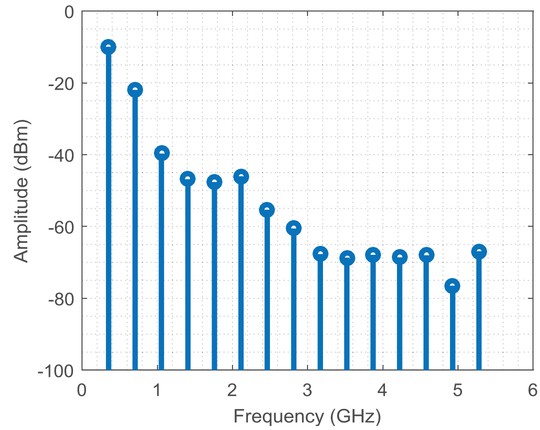

Figure 6: Multi bunch expected signal at the stripline for rms bunch length of 180 ps.

Linearity and Displacement Sensitivity

Simulation has been carried out for various scenarios of off-centre beam. The beam displacement (mm) with quanta of 1 mm up to 9 mm shows a linear variation of the strip voltage up to 3 mm with a sensitivity of 45 mV/mm as total voltage (including all frequency components). From 3 mm to 9 mm the total voltage amplitude (mV) starts to change from linear to slight quadratic fitting of $6.7x^2 +29x+295$. Δ/Σ interpretation gives a sensitivity of 0.13 [mm^{-1}] in both horizontal and vertical planes for the processing electronics.

MECHANICAL PROTOTYPE

A mechanical prototype is under fabrication at ESS-Bilbao. Several issues are investigated during the production, including the magnetic properties of materials after welding process, rf parameters of the ports, mechanical tolerances, vacuum leakage, e-beam welding process of the pieces, fabrication alignment, temperature stability and other related electrical measurements. The feedthrough, strips and body material is stainless steel and all the welding is based on e-beam. The tolerances vary between 5 μm of the ceramic spacer to 20 μm of the body outer diameter. The tight tolerances help to minimize possible errors from the fabrication part on the overall performance of the BPM blocks. Due to tight mechanical integration of MEBT components, the rotatable CF flanges on both sides of the block has been foreseen, which eases the screwing of the BPM blocks to upstream and downstream components.

REFERENCES

[1] https://europeanspallationsource.se
[2] R. Shafer, Beam Position Monitoring, AIP Conf. Proc. 212, (1990) p. 26-58