Design and Fabrication of a prototype stripline BPM for PEFP beam lines

Ji-ho Jang [a*], Hyeok-jung Kwon [a], Dae-il Kim [a], Han-sung Kim [a], Kyung-jean Min [a], Bum-sik Park [a], Kyung-tae Seol [a], Sung-su Cha [a], Yong-sub Cho [a]
[a] *PEFP, KAERI, P.O.Box 105, Yusong, Daejeon, Korea*
[*] *Corresponding author: jangjh@kaeri.re.kr*

1. Introduction

A beam position is the important diagnostic information of the charge particle beams in an accelerator and beam lines. In the PEFP (proton engineering frontier project) 20-MeV proton linac which is in operation at KAERI site, a button BPM (beam position monitor) is used to measure the beam position at the end of the proton accelerator [1]. The button BPM, however, is not sensitive enough to measure the long bunches in the end resgion of the PEFP beam lines which will be installed at the Gyeongju site. In order to measure the beam position of the relative long proton bunches, we developed a stripline BPM. This work is related with the design and fabrication of the prototype stripline BPM.

2. Design and Fabrication of the Stripline BPM

The main advantage of a stripline BPM is the larger signal strength compared with a button BPM [2]. The typical electrode length of the stripline BPM is 5~30 cm and the transverse coverage is smaller than 70 degrees. In this work, we designed a prototype stripline BPM with a shorted end for both 20-MeV and 100-MeV beam lines.

2.1 Theory of the stripline BPM

In a stripline BPM, the voltage signal is characterized by a transfer impedance [1] which is defined as a proportional coefficient between the induced voltage and beam current,

$$V(\omega) = Z_t I_{beam}(\omega)$$

in frequency space .

The induced voltage is generated by the combination of a direct image current from the input bunch and the reflected image current from the shorted end. It is given by

$$V(t) = \frac{Z_{\text{strip}}}{2} \cdot \frac{\alpha}{2\pi} \left(I_{\text{beam}}(t) - I_{\text{beam}}(t - l \cdot \zeta) \right),$$

where Z_{strip} is the characteristic impedance and α is the angular coverage of the electrode. ζ is $1/c + 1/v_{beam}$ with the light speed of c and the beam speed of v_{beam}. The parameter l represents the electrode length. If we assume the Gaussian beam profile,

$$I_{beam}(t) = I_0 e^{-t^2/(2\sigma_t^2)},$$

then the voltage becomes

$$V(t) = \frac{Z_{\text{strip}}}{2} \cdot \frac{\alpha}{2\pi} \cdot I_0 \left(e^{-t^2/(2\sigma_t^2)} - e^{-(t - l\cdot\zeta)^2/(2\sigma_t^2)} \right).$$

From a properly defined Fourier transformation, we can obtain the transfer impedance as follows,

$$|Z_t(\omega)| = Z_{\text{strip}} \cdot \frac{\alpha}{4\pi} \cdot e^{-\omega^2 \sigma_t^2/2} \cdot \sin\left[\frac{\omega l}{2} \left(\frac{1}{c} + \frac{1}{v_{\text{beam}}} \right) \right] \quad (1),$$

where $\omega = 2\pi f$ with a bunch frequency f. We choose the characteristic impedance of 50 Ω in this design.

2.2 Beam Size in Beam Lines

Table I shows the beam half width σ_t from the beam optics calculation. The beam size at the end of 20-MeV beam lines becomes about 27 times larger than that of the extracted beam from the linac. In the 100-MeV beam lines, it becomes about 8 times larger.

Table I: Beam Half Width σ_t.

σ_t (10^{-10} sec)	20-MeV beam line	100-MeV beam line
First part	±0.33	±0.18
Last part	±8.8	±1.5

2.3 Electrode Length

The optimum electrode length is given by the condition that sine term in Eq. (1) becomes one or

$$l_{\text{opt}} = \frac{\lambda}{2} \times \frac{\beta}{1+\beta},$$

where $\lambda = c/f$ is the wavelength and $\beta = v_{beam}/c$. Because the bunch frequency is 350 MHz, the optimum lengths are 72 mm and 128 mm for 20-MeV and 100-MeV proton beams, respectively. We note that the optimum length depends on the bunch frequency and the energy of proton beams. The transfer impedance decreases around the target rooms because of beam spreading. The reduction in 20-MeV beam line is more serious and we choose the electrode length of 70 mm for this prototype BPM. Figure 1 shows the transfer impedance as a function of the beam half width σ_t. The blue and red lines present the impedances for 20-MeV and 100-MeV beam lines, respectively. For very short bunches just after beam extraction, the impedances are about 4.2 Ω and 3.1 Ω in 20-MeV and 100-MeV proton beams, respectively. They reduced to 0.6 Ω and 3.0 Ω at the end of the beam lines.

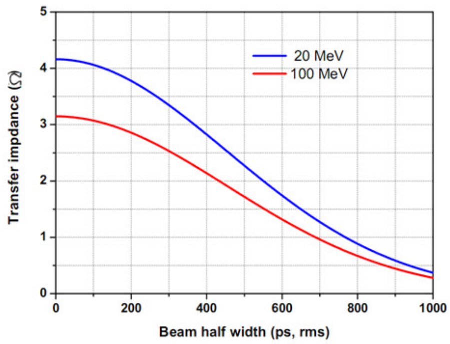

Fig. 1. Transfer impedance as a function of beam half width: blue and red lines for 20-MeV and 100-MeV beam lines with the electrode length of 70 mm.

2.4 Gap Distance and Inter-electrode Coupling

The gap distance between the electrode and wall is given by the condition that the characteristic impedance is 50 Ω. The electrode inner diameter is 100 mm. From the two dimensional calculation (Figure 2) by using POISSON/SUPERFISH [3], we obtained the gap distance of 9.5 mm and 12.9 mm for the angular coverage of 45° and 60°, respectively.

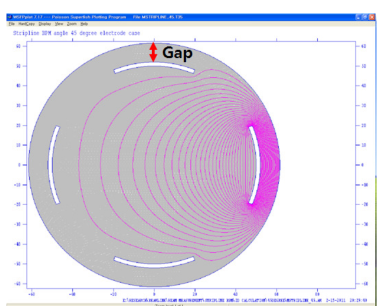

Fig. 2. POISSON/SUPERFISH calculation to determine the gap distance.

We also studied the inter-electrode coupling between four electrodes by using MWS [4] calculation. Figure 3 shows the 3-dimensional calculation model of the stripline BPM. The coupling between near electrodes becomes 32.1 dB and 26.4 dB for 45° and 60° cases, respectively. They are 42.5 dB and 37.4 dB between opposite electrodes.

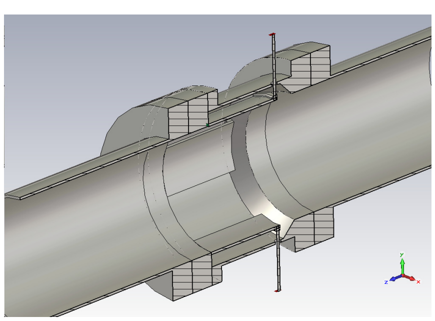

Fig. 3. Three dimensional model for the MWS calculation to obtain the inter-electrode coupling.

2.5 Fabrication

Figure 4 shows the drawing of the stripline BPM. We choose the angular coverage of 45° and the gap distance of 9.5 mm. The total length and the electrode length of the BPM are 135 mm and 70 mm, respectively. The fabricated and installed prototype BPM is given in Figure 5.

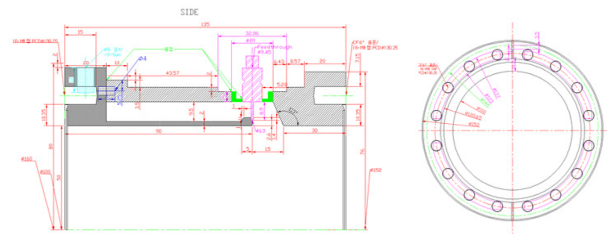

Fig. 4. Drawing of the prototype stripline BPM.

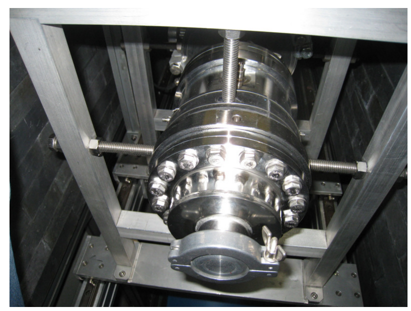

Fig. 5. The fabricated and installed prototype stripline BPM.

3. Conclusion

We designed and fabricated a prototype stripline BPM which will be used in the PEFP 20-MeV and 100-MeV beam lines. This BPM will be tested in the test beam line of the 20-MeV proton linac at KAERI. The result will be reflected in the next version of the stripline BPM.

ACKNOWLEDGEMENT

This work was supported by Ministry of Education, Science and Technology of the Korean Government.

REFERENCES

[1] K. J Min, H. S. Kim, K. T. Seol, J. S. Hong, H. J. Kwon, and Y. S. Cho, "Current Status of Beam Position Monitoring for the PEFP 20-MeV Linac", The 14th International Conference on Accelerator and Beam Utilization, Gyeongju, October 7-8, 2011.
[2] P. Forck, P. Kowina, and D. Liakin, "Beam Position Monitor", CERN-2009-005, p 187, 2009.
[3] J. H. Billen and L. M. Young, "Poisson Superfish", LA-UR-96-1834, Revised September 5, 2002.
[4] CST MICROWAVE STUDIO, version 4.