ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAL021

STUDY OF A TUNER FOR A HIGH-ACCURACY BUNCH SHAPE MONITOR

K. Moriya[†], Y. Kawane*, A. Miura, J-PARC JAEA, Tokai-mura, Ibaraki, 319-1195, Japan
K. Futatsukawa, T. Miyao, J-PARC KEK, Tsukuba, Ibaraki, 305-0801, Japan

Abstract

In the J-PARC linac, a higher precision bunch shape monitor (BSM) was developed to measure the longitudinal-beam distribution. To transform a longitudinal-beam profile into a transverse one with a radio frequency (RF) field, we need a field with an acceleration synchronizing frequency. The RF deflector of a BSM comprises a λ/2 cylindrical cavity and two electrodes for deflection. In general, the resonance frequency can be tuned by adjusting the electrode length. We designed a new tuner using CST studio, wherein control over the resonance frequency was achieved by adjusting not only the electrode length but also the cavity volume. We found the optimum electrode lengths and volume for tuning.

INTRODUCTION

We cannot reduce the beam loss without measuring the following features of the beam: current, centroid position, distribution, etc. We produced a matched beam with the measurement results. In high-intensity proton accelerators such as J-PARC, we must consider the space-charge effect too; however, the space-charge effect has not been clearly understood yet.

In linear accelerators, a longitudinal phase advance has almost the same value as the transverse one because the accelerated gradient of linacs is greater than the circular accelerators' gradient, leading to longitudinal–transverse coupled resonance (LTCR) [1]. This resonance, induced by the space charge, exchanges transverse emittance for the longitudinal one and causes the beam to mismatch when the transverse and longitudinal phase advances fulfill certain conditions. In general, we avoid this condition to reduce beam loss. Although this phenomenon has been measured indirectly [2], to the best of our knowledge, it has not been measured directly.

We need monitors for measuring both transverse and longitudinal profiles to investigate the LTCR in detail. In the Japan Proton Accelerator Research Complex (J-PARC) linac, the transverse beam profile is measured with a wire scanner monitor (WSM) and the longitudinal one is measured with a bunch shape monitor (BSM). As the dynamic range of WSM is more than 10^4, we can observe the transverse distribution, including the beam halo [3]. However, the dynamic range of BSM is about 10^2. To measure the longitudinal profile more accurately, we developed a high-accuracy BSM in the J-PARC linac. In this paper, we report the numerical results obtained using CST studio.

BUNCH SHAPE MONITOR

A BSM, the longitudinal-beam profile monitor developed by Feschenko [4], is currently installed and operated for contributions to beam dynamics designs for many linear accelerators: not only for the INR but also for the J-PARC [5], SNS [6], Linac4 [7], etc.

Principle

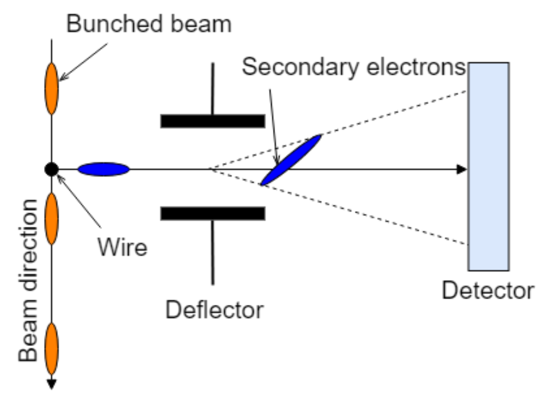

Figure 1: Principle of the bunch shape monitor (BSM).

The BSM is used for measuring the longitudinal-beam width. Figure 1 shows the working principle of a BSM. When a beam hits the wire of the BSM, secondary electrons are emitted from the wire. The typical wire diameter is 0.1 mm. Because −10 kV of voltage is typically applied to the wire, the electrons expand almost radially from the wire and contain the same longitudinal information (time structure) as the beam collides against the wire. Therefore, the detector of the BSM can be placed in any direction as long as the detector direction is orthogonal to the wire axis. In the J-PARC linac, we installed the BSM in the direction orthogonal to the beam direction (see Fig. 1). It is difficult to measure the beam's time structure directly because the typical value is tens of picoseconds in the J-PARC linac. Accordingly, instead of direct observation, we transposed the longitudinal distribution on the transverse one with the deflector.

The deflection angle θ induced by deflectors can be written as

$$\theta = \frac{1}{B\rho}\int_{\tau_-}^{\tau_+} E_x \sin(\omega\tau + \phi)\, d\tau,$$

where $B\rho$ is the secondary electron's rigidity; $\omega = 2\pi \times 324$ MHz, which is the accelerating RF frequency; E_x and ϕ are the electric field's amplitude and phase, respectively,

[†]moriya.katsuhiro@jaea.go.jp
*Present affiliation: NIHON KOSHUHA Co., Ltd.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAL021

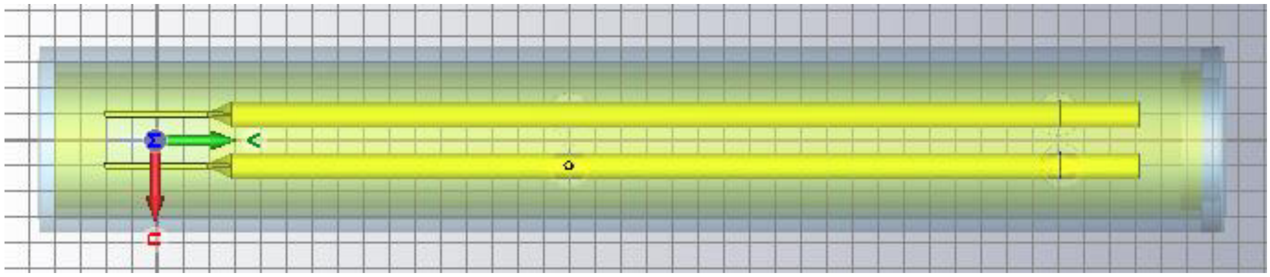

Figure 2: Deflector of the BSM.

induced between two deflector plates; $\tau_{\pm} = t \pm L_d/2\beta c$; L_d is the deflector length; β is the Lorentz factor; c is the speed of light; and $t = 0$ when the particle passes through the center of deflector. When the electrons reach the detector, each particle's transverse spread caused by the deflector can be expressed as

$$x = L_s\theta = \left\{\frac{2E_xL_s}{B\rho\omega}\sin\left(\frac{L_d}{2\beta c}\right)\right\}\sin(\omega t + \phi),$$

where L_s is the distance between the center of the deflector and the detector. A slit is installed in front of the detector. We can detect the particles satisfying $\omega t + \phi = 0$ because the condition does not change the particle orbit due to the deflector plates. The spread caused by the deflector must be much larger than the slit width. According to the above equation, E_x and L_s need to be large. Needless to say, L_d is decided by the secondary electron velocity. In the case of the J-PARC linac, it is difficult to increase L_s because of the limited installation space for the BSM. In other words, we have no choice but to increase the amplitude E_x.

Resonance Frequency

Figure 2 shows the deflector part of the BSM. The deflector part comprises two electrodes and a cylindrical pipe. In the case shown in Fig. 2, the left side of the electrode is shaped as a square plate, and the electrons pass between the parallel plates in the direction of the depth of the plane of the paper.

This deflector is a cavity resonator. The AC electric field, which is induced between the plates, is necessary to synchronize the acceleration frequency. Since the acceleration frequency is 324 MHz, we applied an AC voltage of 324 MHz to the deflectors. So it is important to match the resonant frequency of the BSM to 324 MHz to realize the large amplitude of E_x.

In general, for the BSM, the ideal frequency is realized by adjusting the electrode length. To adjust the length, the electrode for the deflector has a spacer. In other words, the electrode length is λ/2. When the resonant frequency is 324 MHz, the λ/2 length is 462.6 mm. However, we cannot fix the optimum length easily because the structure is not a regular cylindrical shape.

Subsequently, we performed numerical simulations to investigate the features of the cavity resonator of the BSM, and CST studio was employed for this purpose. CST studio is an electromagnetic simulation software [8]. The software simulates not only electromagnetic-field analysis but also charged-particle tracking, and the software is suited for the optimization of the BSM. Figure 3 shows the dependence of the length of the spacer on the resonant frequency. Considering the J-PARC BSM, the length of the electrode is 396 mm, and the diameter is 10 mm. In Fig. 3(a), the vertical line shows the s-parameter from the input to the output (s_{21}) and the horizontal one corresponds to the frequency. The graph is color-coded according to the spacer lengths, and the frequency decreases as the spacer length increases. Each peak value of s_{21} is almost the same, and the width of frequency is approximately 900 kHz.

To easily check the dependence of the spacer length on resonant frequency, the vertical line shows the resonant frequency with the peak value of s_{21}, and the horizontal one shows the spacer length, as shown in Fig. 3(b). The resonant frequency exhibits almost-linear characteristics for the spacer length. Therefore, Fig. 3(b) indicates that an approximately 7-mm spacer is optimum to achieve a 324-MHz resonant frequency.

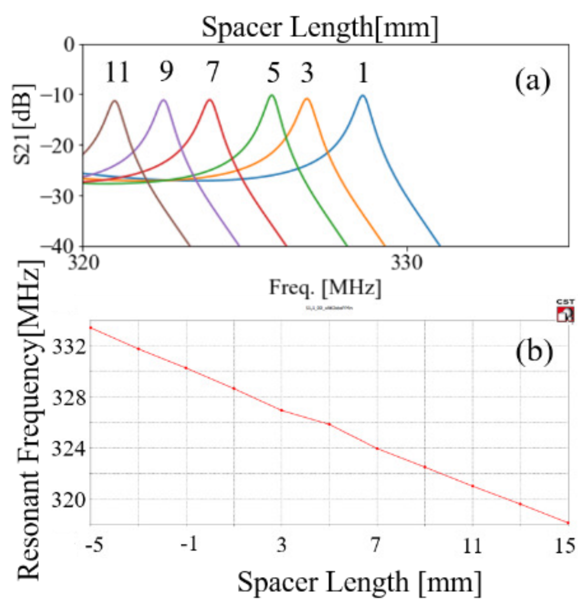

Figure 3: Dependence of the resonant frequency of the deflector on the spacer length.

However, because the electrode and spacer comprise copper, the processing accuracy is not high, e.g., 0.5 mm, and this length corresponds to 340 kHz. In other words, the adjustment method using spacers has poor accuracy, and

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAL021

we require the elimination of vacuum to change a spacer each time.

TUNER FOR HIGHER ACCURACY

The aforementioned issues can be solved by insulating the cylindrical volume on the top of the deflector of the BSM, as shown in Fig. 4. We hypothesize that the insulated volume changes the capacitance of the equivalent circuit.

Figure 5 shows the dependence of the cylindrical insertion length on the resonant frequency. We calculated the dependence via CST studio, wherein the cylindrical diameter is 34 mm, and the length of the spacer is 6.0 mm. The resonant frequency decreases as the insertion length increases. The resonant frequency exhibits nonlinear characteristic relative to the insertion length. When the cylindrical body is close to the electrodes, the resonant frequency changes significantly. In other words, to adjust the

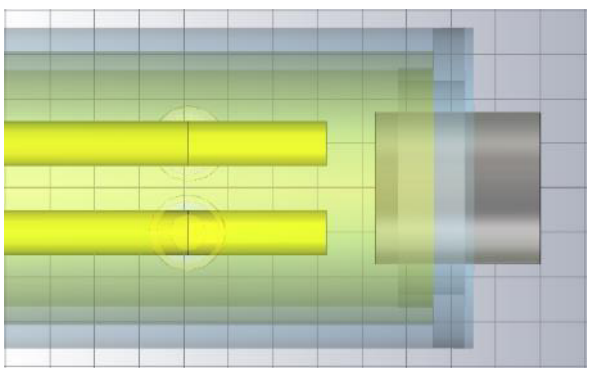

Figure 4: New tuner (refer to the right part of Fig. 2).

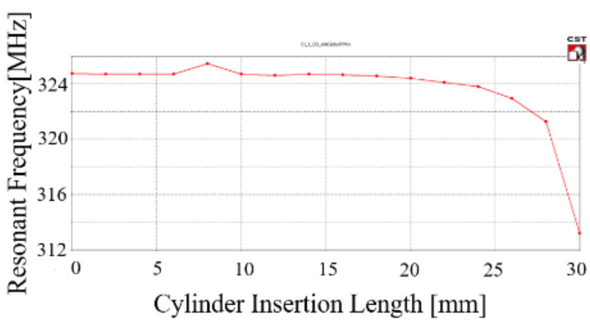

Figure 5: Dependence of the cylindrical insertion length on the resonant frequency (spacer length: 6.0 mm).

resonant frequency to 324 MHz using the spacer and cylindrical body, we need to

1) select a spacer that is a little shorter than the designed length for coarse adjustment and

2) insert the cylindrical body for fine adjustment.

In the case shown in Fig. 5, the optimum insertion length is about 22 mm. The insertion accuracy is 0.1 mm, and this length corresponds to 25 kHz. This accuracy is about one order better than that obtained by the adjustment of the spacer. In addition, we do not have to break a vacuum when we finetune the frequency using the cylindrical body.

The design study using above simulation has already been completed. The fabrication of the monitor has been progressed with utilizing by the high-accuracy tuner system. This monitor will be installed and operated from this summer. Just before then, we will conduct the offline test of the vacuum and the rf system which includes the verification of the tuning system.

CONCLUSION

The deflector of the BSM is a resonant cavity. To match the resonant frequency to the accelerating frequency, we adjusted the resonant frequency by changing the length of the electrode of the deflector. However, the processing accuracy of the electrode is not high because the electrode made of copper is soft. Then, we used CST studio for checking that the resonant frequency is adjusted by changing the electrode length and cylindrical insertion length. Using a spacer for coarse adjustment and the insertion of the cylindrical body for fine adjustment, the frequency accuracy about one order better than that offered before (from 340 kHz to 25 kHz).

The design of tuner using simulation has already been completed. We are building the BSM with the new high-accuracy tuner. We will conduct the offline test of the vacuum, the rf system, and the verification of the new tuner system. And this monitor will be installed and operated from this summer.

REFERENCES

[1] I. Hofmann *et al.*, Phys. Rev. ST Accel. Beams, **6**, 024202 (2003).

[2] C. Plostinar *et al.*, Proceedings of IPAC2013, THPWO087, Shanghai, China 2013.

[3] A. Miura *et al.*, J. Korean Phys. Soc. **69**, 1005 (2016).

[4] A. V. Feschenko, Proc. Part. Acc. Conf. PAC 2001, Chicago, 2001.

[5] A. Miura *et al.*, JPS Conf. Proc. **8**, 011003 (2015).

[6] A. Feschenko *et al.*, Proceedings of LINAC 2004, TUP63, Lubeck, Germany, 2004.

[7] G. Bellodi *et al.*, Proceedings of LINAC 2014, MOPP025, Geneva, Switzerland, 2014.

[8] https://www.cst.com/