DEVELOPMENTAL STATUS OF PEFP/KAERI BEAM DIAGNOSTIC SYSTEM

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Abstract

High-power proton accelerator is being built by the PEFP/KAERI (Proton Engineering Frontier Project, Korea Atomic Research Institute) in Korea. Presently it aims to achieve 100-MeV beam energy with 20-mA (peak, 1-ms macro-pulse duration) beam current. Successful commissioning and operation of the machine require reliable beam diagnostic systems. The BPPM (Beam Position and Phase Monitor) system has been developed with the button-type PU (Pick-Up) and the full analogue position & phase detection electronics. The BCM (Beam Current Monitor) will adopt narrow-band CT (Current Transformer) that is tuned to one of the harmonics of the beam bunching frequency, which is expected to provide stable and reliable current measurements.

INTRODUCTION

The PEFP/KAERI is one of HPPAs (High-Power Proton Accelerators) which are under construction at the KAERI in KOREA. Presently it aims to achieve 100-MeV beam energy with 20-mA (peak, 1-ms macro-pulse duration) beam current. Refer to Table 1 for major beam parameters of the PEFP/KAERI accelerator.

Table 1: Beam parameters of PEFP/KAERI accelerator

	Operation Mode	note
	Pulse	
Beam Energy	3 - 20 - 100 MeV	BPM operation region
β	0.08 - 0.20 - 0.43	
V	1.003 - 1.021 - 1.107	
Average Beam Current (I_{av})	Peak 20 mA	
Pulse Width	Few ms	
Bunch Length	160ps	PARMILA simulation result
Bunching Frequency	350 MHz	

The PEFP/KAERI are designed to have very high beam intensities, so that even the buttons could generate enough signals for precision beam position and phase measurements. The beam phase measurements is defined phase difference between the phase of RF reference and the phase of beam signal. The phase difference is detected by signal processing of the BPPM electronics. The BCM will adopt narrow-band CT that is tuned to one of the harmonics of the beam bunching frequency, which is expected to provide stable and reliable current measurements.

Button-type capacitive PUs have been simple and reliable, but their application to the proton machines has been limited because of their insufficient response to low-intensity beams. Modern HPPAs such as the PEFP/KAERI are designed to have very high beam intensities, so that even the buttons could generate enough signals for precision beam position measurements. In this context, we have chosen the button-type PU for use in the PEFP/KAERI accelerator. One of the disadvantages of the buttons is that, it is difficult to predict the PU sensitivity using analytic formulas. In fact, the PU sensitivity for low-beta beams can not be practically determined even by experimental methods, due to the difficulty of simulating electromagnetic fields from the low-beta beams. In this regard, we have decided to utilize the computer code for determining the sensitivity of the button-type PU. We have chosen the MAGIC code which is a kind of the PIC (Particle-In-Cell) code and can treat the particle and electromagnetic system in the full three dimensional manner.

BEAM POSITIONS AND PHASES MONITOR

Physical Design

The theoretical estimation of the sensitivity of stripline PU was established by R. E. Shafer.[1] It is basically 2D theory and can not be used for designing the button-type PUs which are 3D features. There are commercial electromagnetic codes that can simulate 3D geometries, including the MAFIA T3. But the MAFIA T3 can handle only ultra-relativistic particles and can not be applied to low-beta beams. (The port boundary of the MAFIA T3 can accept only TEM mode whose phase velocity is equal to that of the light. And low-beta beams generate fields that are not in the simple TEM mode.) Limitations of the Shafer's theory and the MAFIA code have led us to consider on using the MAGIC code. It is versatile and can handle arbitrary combinations of particle beams and electromagnetic structures.

Figure 1 shows the 3D model of the button PU for the MAGIC simulation and its cross-sectional view in the transverse plane. In the left figure of Figure 1, proton bunches travel left-to-right direction. Beam signals are coupled to the four buttons that are installed around the circumference of the beam pipe. Buttons are connected to 50-ohm coaxial lines whose dimensions are different from those of usual fabrication. This simplified the simulation geometry without sacrificing reliability of the simulation.

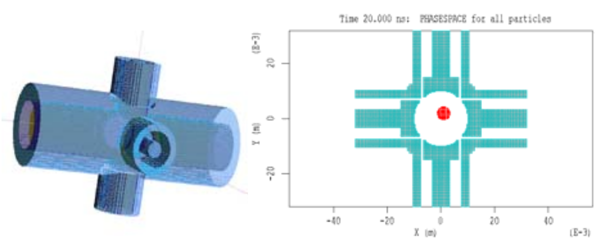

Figure 1: Modelling of four-button-type PU for MAGIC simulation. Left figure: 3D model, Right figure: Cross-sectional view. Dot inside beam pipe in right figure indicates proton beam. Diameter of beam pipe is 20 mm.

Prototype BPPM PU

The fabrication of the PU that consists of buttons, coaxial feed-throughs, and vacuum chamber is in progress at the Hitachi Electronics in Japan. A sample PU that is composed of four-button, feed-through and vacuum chamber will be fabricated by the company and its electrical performance will be tested in the Pohang Accelerator Laboratory. Figure 2 and 3 show that is the prototype assembly of 4-Buttons type PU of the BPPM.

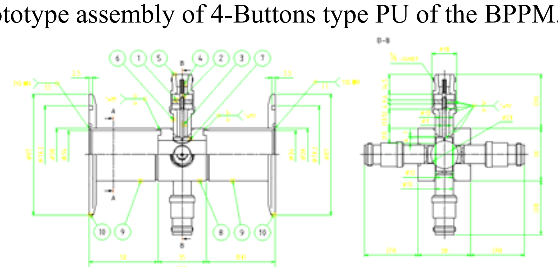

Figure 2 Drawing of the BPPM PU that is 4-Button type.

Figure 3 The prototype assembly of 4-Buttons type PU of the BPPM.

BPPM Electronics

The BPPM electronics consist of the part for measuring beam position and the part for measuring beam phase for the beam current ranging from 0.2 to 20 mA (40-dB dynamic range). The resolution and stability are required to be better than 50 μm. The beam-position measurement shall utilize the Log-Ratio algorithm that has been realized by the use of logarithmic amplifiers and commercially available from the Bergoz Instrumentation. The fabrication scheme of the BPPM electronics at hand is two-fold: The First, procure commercial LR-BPMs. Develop separate PMs (Phase Monitors) in house. Provide necessary signal branching means for feeding PU signal to the two LR-BPM and PM parts. Provide RF reference to the PM. provide necessary timing signals to the PM and LR-BPM. The seconds, integrate the PM circuit into the existing LR-BPM circuit board. This would require additional costs for fabricating a prototype BPPM board. This work shall be done mostly in the Bergoz.

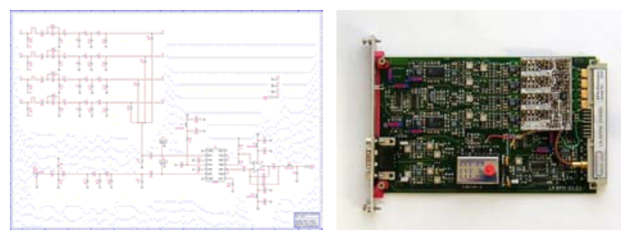

Figure 4: The Diagram of the electric-circuits for phase measuring of the BPPM (Left) and a prototype BPPM board (Right).

Required specifications for the BPPM electronics are shown in Table 2. One of important requirements is that the BPPM electronics should provide beam position phase measurements for pulsed operations of the accelerator. The pulsed operation will generate the pulse-modulated bunches with the pulse (the envelope of bunch trains) duration of 2 ms. The pulse repetition rate would vary from several Hz up to 1 kHz.

Table2: Specification of BPPM electronics for the PEFP/KAERI Accelerators.

	Position	Phase
Operation frequency	350 MHz	←
Minimum Signal	-57.5 dBm @ 100 MeV	←
Powers	-4.56 dBm @ 3 MeV	←
Resolution & Stability	<50 μm @ 20-mmφ beam pipe	**< ± 1 degree**
Operation Modes	CW or Pulsed	←
Bandwidth of output signal	**> 5 MHz**	←

Figure 5 show the BPPM electronics are measured phase and position signal. The upper signal is a RF reference signal, the middle is a beam position signal, and the bottom is a beam phase signal. The difference of the beam phase and the RF reference phase output voltage signal, the voltage signal proportionally increases with the phase difference.

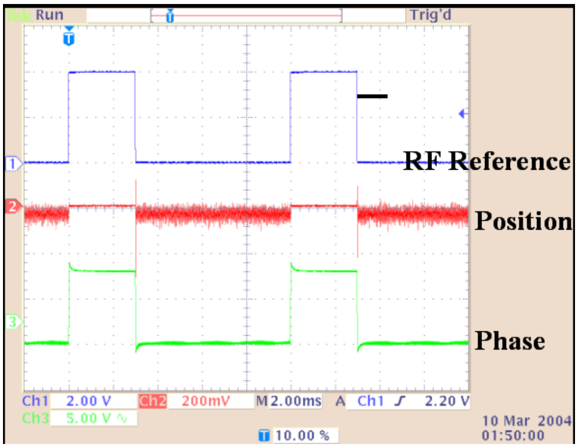

Figure 5. The BPPM electronics are measured phase and position signal. The upper signal is a RF reference signal, the middle is a beam position signal, and the bottom is a beam phase signal.

FAST CURRENT TRANSFORMER (FCT)

The Front End, Linac will have a 20mA peak current pulse of about 2 ms duration (macro-pulse) bunched at the RFQ frequency of 350MHz (mini-pulse). Mini-pulses consist of approximately a 160ps bunch length and approximately a 2.8ns gap. The BCMs (Beam Current Monitors) will adopt narrow-band CT (Current Transformer) that is tuned to one of the harmonics of the beam bunching frequency, which is expected to provide stable and reliable current measurements. Commercial versions are available which are well suited to observing the mini-pulse. For example, Bergoz offers a unit with 338-picosecond rise time (Risetime = 0.35 / F_{high}, for F_{high} = 1000 MHz) and 0.8%/µS droop (Droop = 2π × F_{low} (-3dB), for F_{low} = 1.33 kHz) [1]. When observing the macro-pulse the baseline will gradually shift such that the area above zero is equal to the area below zero (average = zero). Figure 6 is show the In-Flange FCT.

Figure 6. The drawing of the In-Flange FCT for the measurements of the end of the RFQ.

CONCULUTIONS

The PEFP/KAERI accelerator successful commission and operate of the machine require reliable beam diagnostic systems. We conclude this article with the following summarizing remarks:

1. A button-type PU for use in the PEFP/KAERI accelerator was designed utilizing the MAGIC code.
2. A prototype PU that is composed of four-button, feed-through and vacuum chamber will be fabricated by the company and its electrical performance will be tested in the Pohang Accelerator Laboratory.
3. The BPPM electronics consist of the part for measuring beam position and the part for measuring beam phase for the beam current ranging from 0.2 to 20 mA (40-dB dynamic range).
4. For FCT, Bergoz offers a unit with 338-picosecond rise time (Risetime = 0.35 / F_{high}, for F_{high} = 1000 MHz) and 0.8%/µS droop (Droop = 2π × F_{low} (-3dB), for F_{low} = 1.33 kHz)

REFERENCES

[1] Private communication with Bergoz Instrumentation.