100-M V PROTON BEAM PHASE MEASUREMENT BY USING STRIPLINE BPM*

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Abstract

In Korea Multi-purpose Accelerator Complex (KOMAC), a 100-MeV proton linac, which is composed of a proton injector based on the microwave ion source, 3-MeV RFQ with a four-vane type and 100-MeV DTL with electromagnetic quadrupoles has been developed and currently provides the proton beam to users for various applications. To increase the beam power up to the design value, several improvements are required including the fine adjustment of the RF set-point during the operation. A stripline BPM is used for the beam phase measurement, where the pickup signals from four electrodes are combined by using the RF combiner, then mixed with 300 MHz LO reference signal resulting in 50 MHz IF signal which is processed by digital IQ demodulation method. In this paper, the details of the beam phase measurement setup and results will be presented.

INTRODUCTION

A 100-MeV proton linac in KOMAC has been provided the proton beam for various users and applications including basic research and the industrial uses since July, 2013. The KOMAC accelerator consists of a 50-keV proton injector, a 3-MeV RFQ and a 100-MeV DTL. The DTL section is composed of total 11 tanks and one of unique feature of the DTL is that there are MEBT and dipole magnets to extract the 20-MeV beam for low energy beam applications [1].

The average beam power is gradually increased by lengthening the beam pulse width with higher repetition rate. To further increase the beam power, it is important to adjust the RF set points precisely such as the RF amplitude and phase in each accelerator sections [2].

The RF phase can be measured by using the beam position monitor (BPM). The proton linac at KOMAC has total 10 stripline-type BPMs, which are located between each DTL tank as shown in Fig. 1. The layout for the beam current transformers for measuring the beam current and the beam loss monitors based on scintillation detector is also shown in Fig. 1.

STRIPLINE BEAM POSITION MONITOR

Design and Fabrication

To measure the RF phase, we designed, fabricated and installed the stripline BPM [3]. The design of the BPM was performed based on the Microwave Studio code and Superfish code. Two different types of the stripline BPMs were used in KOMAC proton accelerator. One is for the linac and installed between DTL tanks and the other is for beamlines to measure the beam position. Table 1 shows the design parameters of the BPMs both the linac BPM and the beamline BPM; the differences are mainly due to the different aperture size. The fabricated BPM is shown in Fig. 2.

Low Power Performance Test

We performed the low power RF test for the BPM to check the design and fabrication of the BPM on the test bench. We used a probe wire with 3 mm in diameter which is connected to the RF signal generator to simulate the beam.

The design value of the coupling between the beam and each electrode of BPM is 30 dB at 350 MHz and 23 dB at 700 MHz. The measured values showed some scattered distribution with maximum error of about 3%. These scattered data are considered mainly due to difference between the physical center and the electrical center.

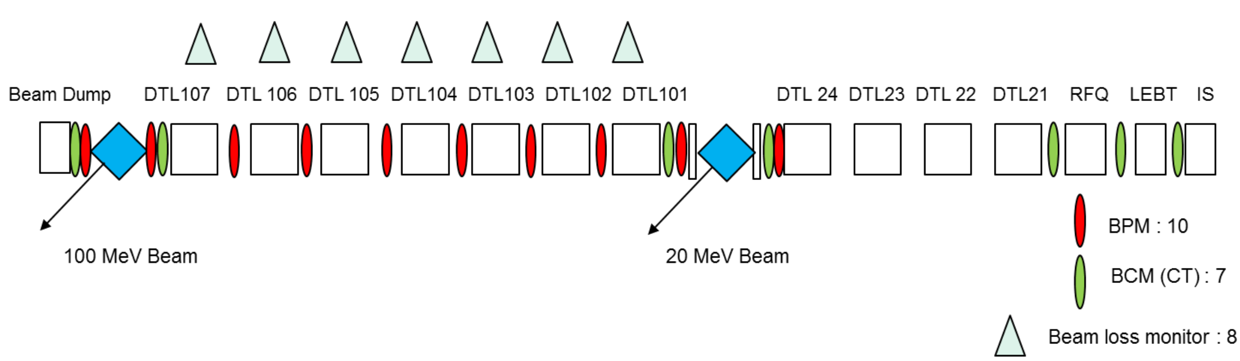

Figure 1: Layout of beam position monitors, beam current monitors and beam loss monitors along the linac.

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Table1: Design parameters of the BPMs.

BPM type	Beamline BPM	Linac BPM
Electrode aperture	100 mm	20 mm
Electrode thickness	2 mm	2 mm
Electrode angle	45 deg.	60 deg.
Electrode length	70 mm	25 mm
Electrode gap	15 mm	3.5 mm
Feedthrough	SMA	SMA
Signal frequency	350 MHz	350/700MHz

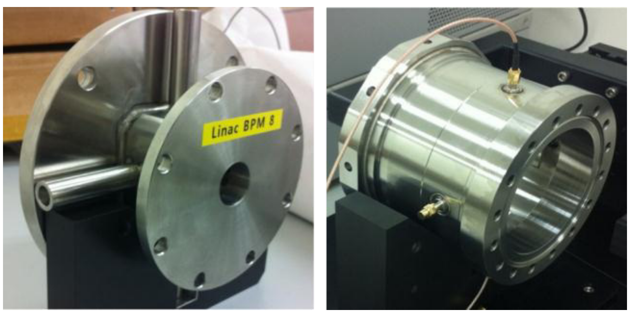

Figure 2: The fabricated linac BPM (left) and the beamline BPM (right).

The inter-electrode coupling was measured by applying the 350 MHz RF signal to one electrode and measuring the response of the other electrodes. The electrode port 1 and port 3 are diagonally opposite position in vertical direction and the electrode port 2 and port 4 are so in horizontal direction. The electrode angle of linac BPM is 60 degree whereas that of beamline BPM is 45 degree, therefore the inter-electrode coupling of the linac BPM is stronger than that of beamline BPM. The measurement results are summarized in Table 2 and shows reasonable agreement between the simulation and measurement.

Table 2: Measurement of inter-electrode coupling.

Electrode	Measurement	Simulation
Beam line BPM		
S_{14} [dB]	-32.3	-32.1
S_{24} [dB]	-41.1	-42.5
S_{34} [dB]	-32.2	-32.1
Linac BPM		
S_{14} [dB]	-27.9	-28.2
S_{24} [dB]	-37.0	-37.0
S_{34} [dB]	-28.1	-28.2

BEAM PHASE MEASUREMENT SETUP

A schematic diagram of the beam phase measurement system setup is shown in Fig. 3. The signal from each electrode of the BPM is filtered by using the band-pass filter with the center frequency of 350 MHz. Then the signal is divided in two-way by using 3-dB divider. One of divided signal transferred to the Bergoz electronics to generate the beam position output. The other is combined with the signals from the other electrodes. This combined signal reduces the effect from phase mismatch between each electrode of the BPM and results in better accuracy in beam phase measurement.

We used digital IQ demodulation method to detect the beam phase. Before analog-to-digital conversion, the 350 MHz signal is mixed with 300 MHz RF reference and converted to 50 MHz intermediate frequency (IF) signal by suing analog mixer. IQ demodulation is achieved by sampling the 50 MHz IF signal with ADC which is operated at 40 MHz. The sampled data is transferred to the FPGA for further processing and data distribution.

Because the signals from four electrodes of a BPM are combined, the amplitude of the combined signal can be useful for beam current indicator. This feature is especially useful when the beam current monitors are not installed between each tank as for the case of the proton linac at KOMAC.

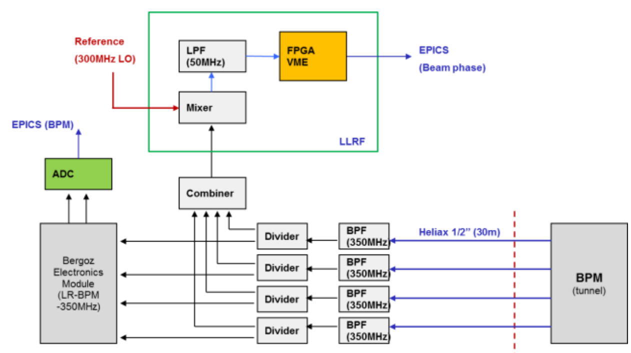

Figure 3: Data path of BPM signal for beam phase measurement

The beam phase measurement scheme for each DTL tank is shown in Fig. 4. By using the same scheme the beam energy can be measured as well based on the time of flight method through the phase measurement via 2 BPMs which are located in the downstream of the DTL tank under measurement.

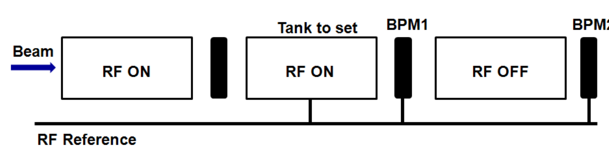

Figure 4: Schematic plot for beam phase measurement of a DTL tank by using BPM.

ISBN 978-3-95450-142-7

PRELIMINARY BEAM PHASE MEASUREMENT RESULT

During the beam operation, we performed the beam phase measurement. The user interface for the beam phase measurement is shown in Fig. 5. Each plot in the figure 5 displays the amplitude and phase of each BPM signal. The beam condition during the experiment is 100 us pulse length and 1 Hz repetition rate. The RF power was supplied to the entire DTL tank.

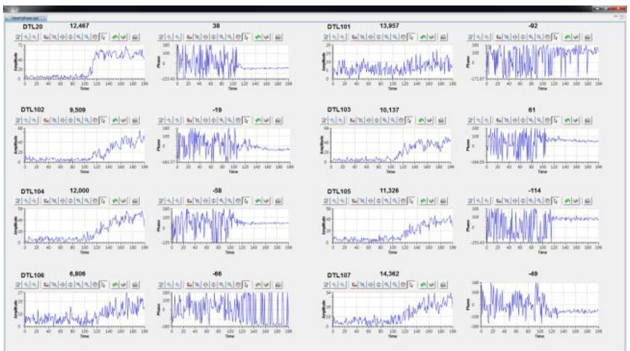

Figure 5: User interface for the BPM signal.

RF SET-POINT DETERMINATION

We made the RF set-point determination scheme based on the RF phase measurement [4]. The well-known phase scan method is going to be used and for that purpose, a MATLAB routine with the nonlinear optimization algorithm was developed [5]. First, we calculate the beam phase as a function of RF phase by using PARMILA code. In the process we assumed that the input energy becomes the designed value. An experimental data of the beam phase as a function of RF phase with the fixed relative amplitude A/A_0 is compared with the simulation to generate a χ-value for each case of A/A_0 as shown in Fig. 6. The quadratic fitting of the χ-values is used to determine the RF amplitude and phase as shown in Fig. 7.

The MATLAB routine was tested by using an artificial experimental data set of a DTL tank with $A/A_0 = 1$ and RF phase shift of 135.4°. The data were generated by PARMILA code with random Gaussian errors with σ=0.5° in the beam phase. The resulting values of the program are 1.001 and 135.2° for the amplitude and phase, respectively.

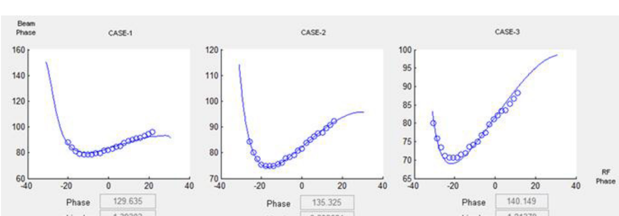

Figure 6: Comparison the artificial experimental data to the simulation results with different relative amplitudes (A/A_0 = 0.98, 1.0, 1.02).

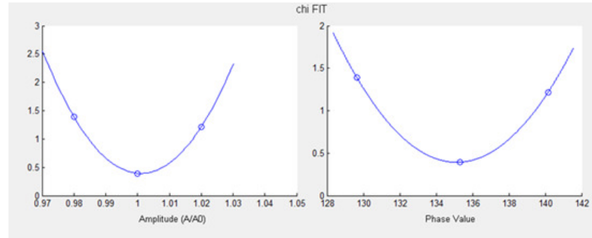

Figure 7: Determination of the RF amplitude (left) and phase (right) by using a quadratic fitting.

SUMMARY

A stripline BPM were used to measure the beam phase of the proton linac at KOMAC. For the phase detection, we used digital IQ demodulation method by using ADC and FPGA, which is same method used for LLRF system. The integrated user interface for beam phase measurement and MATLAB routine for RF set-point determination are also prepared. Based on the beam phase measurement, the RF set-point including RF amplitude and phase will be precisely adjusted for better beam quality in near future.

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