

# BEAM PHASE MEASUREMENT FOR PEFP LINEAR ACCELERATOR\*

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## Abstract

According to the commissioning plan of the PEFP proton linac, an accurate measurement of beam phase is essential, especially for setting up the RF operating parameters of DTL. Beam position monitors (BPMs) installed between DTL tanks can provide information about the beam phase as well as about the beam transverse position. By using a BPM as a beam phase monitor, beam phase can be measured without additional devices on the linac or the beam line. The signals from 4 electrodes in the BPM can be summed by using a 4-way RF combiner, by which the effect of the transverse beam offset on the phase measurement can be eliminated. The combined BPM signal (350 MHz) is mixed with LO signal (300 MHz) and down-converted to IF signal (50 MHz), then fed into the signal processing unit, where the phase information is extracted by using IQ demodulation method with a sampling frequency of 40 MHz. In this paper, the beam phase measurement system and signal processing scheme will be presented.

## INTRODUCTION

The main facility of the PEFP is 100-MeV proton linac with a high duty factor [1]. Currently the installation of the accelerator is under-going. For the determination of RF set-point during the commissioning of the linac, the beam phase must be measured accurately. A strip-line type beam position monitor (BPM) will be used for the beam phase measurement. Figure 1 shows the layout of beam diagnostic devices along the linac [2]. Note that there is only one BPM between 20-MeV section of linac and MEBT. The 20-MeV section consists of 4 DTL tanks and is driven by single klystron. Therefore, 4 DTL tanks would be considered as single large tank from the view point of RF system [3]. To adjust RF phase of each tank

in 20-MeV section, we installed high power RF phase shifter in each RF waveguide branch to each tank.

A 100-MeV section is composed of 7 DTL tanks and one BPM is allocated right after each DTL tanks. One additional BPM is located in front of the beam dump and will be used for RF set-point determination. The initial goal of the linac commissioning is the beam power of 100W with the peak beam current of 20 mA, the pulse width of 50 $\mu$ s in 1 Hz operation [2].

## BPM FOR PHASE MEASUREMENT

To measure the beam phase as well as the beam position, we designed and fabricated a strip-line type BPM. The design of the BPM is based on the beam parameters such that the beam energy ranges from 20 MeV to 100 MeV with minimum peak current of 1 mA. The minimum beam pulse width is 50 us, which was determined considering the LLRF control system.

One of the major constraints in BPM design was space limitation. The BPM should be installed between DTL tanks. The shortest gap is between the first and the second DTL tank and is less than 125 mm. The isolation vacuum gate valve and flexible bellows must be installed in that gap as well as the BPM, which leaves only about 50 mm of the net space for the BPM installation.

The electrode aperture is 20 mm in diameter, which is same as the inner diameter of the drift tube. The electrode angular span is 60 degree to increase the output signal amplitude. The electrode is made of stainless steel with thickness of 2 mm to give enough mechanical stability. For the proper operation of the strip-line type BPM, the characteristic impedance should be well matched and the gap was determined to be 3.5 mm based on the POISSON calculation. Figure 2 and 3 show the drawing of the designed BPM and fabricated one, respectively [4].

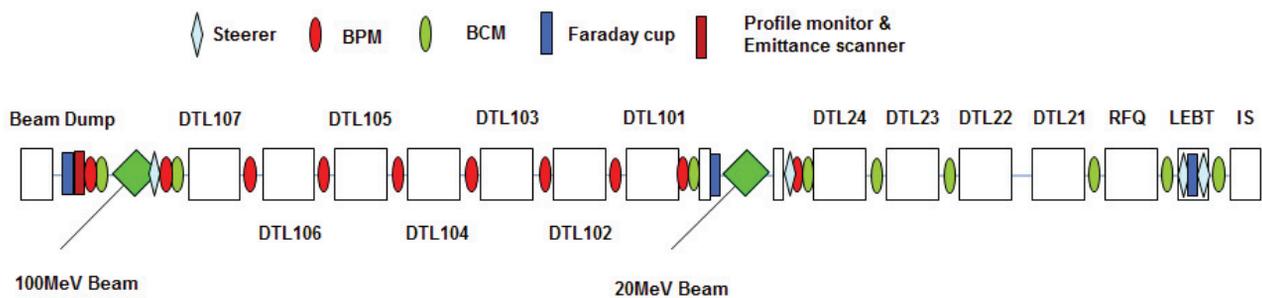


Figure 1: Layout of beam diagnostics in PEFP linac.

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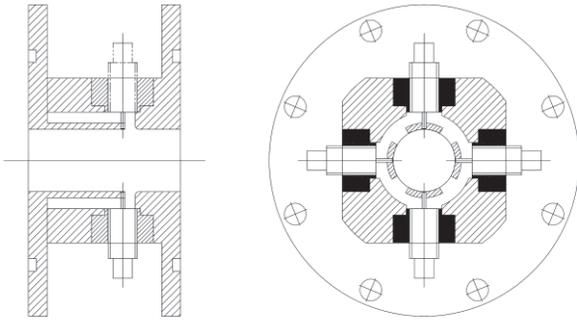


Figure 2: Drawing of the BPM for linac.



Figure 3: Fabricated BPM for linac.

**SIGNAL PROCESSING SCHEME**

The signal from the BPM will be processed by using digital IQ demodulation method, which is almost same method used for LLRF system. The output signal contains harmonics of the fundamental frequency of 350 MHz, therefore, we use bandpass filter with a center frequency of 350 MHz. Then each signal is divided into two; one is used for obtaining the position information by using the log-ratio method with a dedicated Bergoz electronics and the other is for phase information. Four signals from a BPM are combined into one by using a RF combiner to remove the dependency of the phase signal on the beam position offset.

To apply the digital IQ demodulation method, the combined signal is mixed with 300 MHz LO signal, which results in 50 MHz IF signal. If we digitize the IF signal with a sampling frequency of 40 MHz, we can obtain IQ data flow as shown in Fig. 4, from which the phase and amplitude information can be calculated.

For digital IQ demodulation, we use a commercial FPGA board (7142 FPGA board, Pentek). It includes 4 ADCs with 125 MHz maximum sampling frequency, 14 bits resolution and 1 DAC with 320 MHz, 16 bits resolution. Xilinx Virtex-4 model FPGA was used for 7142 FPGA PCI mezzanine card. The FPGA board is installed on MVME5100 host board, which includes CPU

and memory blocks. For the FPGA core programming, we use VHDL with ISE integrated development tool for FPGA synthesis and implementation. The essential parts of the VHDL code for IQ demodulation is shown in Fig. 5. The application program interface was developed by using Tornado with VxWorks kernel. The signal flow block diagram for the BPM signal processing is shown in Fig. 6.

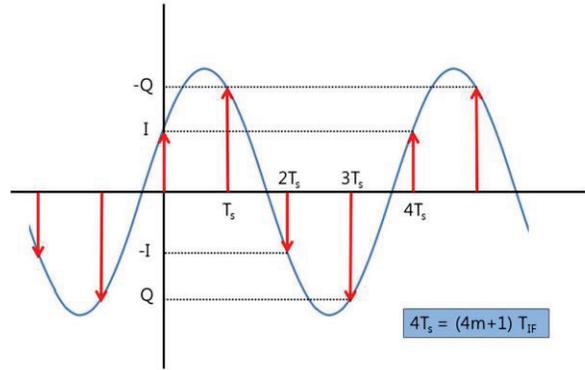


Figure 4: Digital IQ demodulation scheme.

```

process(clk_40MHz)
begin
if rising_edge(clk_40MHz) then
case led_4 is
when "00" => data_set(13 downto 0) <= ADC_IN;
when "01" => data_set(27 downto 14) <= ADC_IN;
when "10" => data_set(41 downto 28) <= ADC_IN;
when others => data_set(55 downto 42) <= ADC_IN;
end case;
end if;
end process;

input_data_buffer : infifo56by2048
port map (
clk => clk_10MHz,
din => data_set,
rd_en => gate_s,
rst => gate_s_n,
wr_en => gate_s,
dout => data_buf,
empty => open,
full => open);

-- Averaging I and Q --
Q_measure : subtracter14by14
port map (
A => data_buf(27 downto 14), -- data_buf(13 downto 0),
B => data_buf(55 downto 42), -- data_buf(41 downto 28),
Q => Q_meas_i,
CLK => clk_10MHz,
SINIT => gate_s_n);

I_measure : subtracter14by14
port map (
A => data_buf(13 downto 0), -- data_buf(27 downto 14),
B => data_buf(41 downto 28), -- data_buf(55 downto 42),
Q => I_meas_i,
CLK => clk_10MHz,
SINIT => gate_s_n);
    
```

Figure 5: VHDL code for IQ demodulation

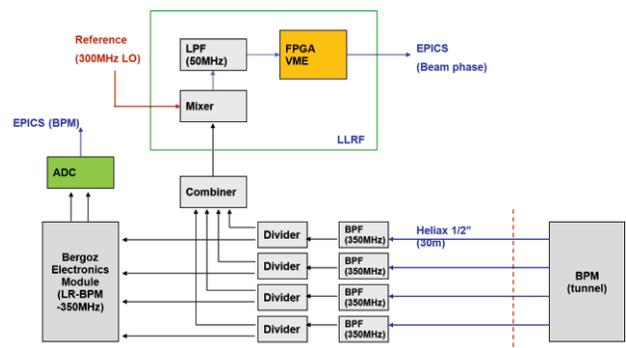


Figure 6: Signal flow block diagram for BPM.

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### PHASE SCAN METHOD

To determine the RF set-point during the commissioning, we will use the phase scan method, which is a well-established technique to set the RF amplitude and phase of the accelerating cavity [5]. The phase scan method is based on the measurement of beam phases at the end of the accelerating cavity under the variation of the input RF amplitude and phase. Then the measured results are compared with the simulation results as shown in Fig. 7, where the RF and beam phases are shifted by  $a$  and  $b$  to get the best fitting results. Therefore the beam phase and RF phase can be related as following,

$$\phi_{\text{beam}} = b + f(\phi_{\text{rf}} - a).$$

The parameters  $a$  and  $b$  can be determined by minimizing  $\chi^2$  which is defined as follows,

$$\chi^2 = \frac{1}{N} \sum_{i=1}^N [f_{\text{ex}}(\phi_i) - (b + f(\phi_i - a))]^2,$$

The number  $N$  and function  $f_{\text{ex}}(\phi_i)$  represent the number of different RF phase measured during the phase scan experiment and their beam phases, respectively. From the fitting of the  $\chi^2$ , we can determine the RF amplitude set value.

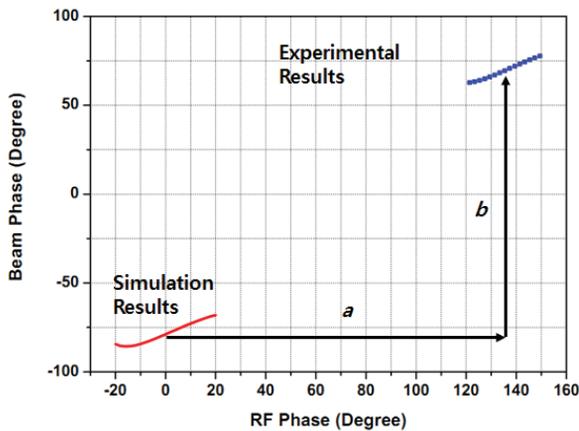


Figure 7: Experimental results compared with the simulation, fitted by shifting RF phase and beam phase.

To facilitate the phase scan procedures, we have developed an RF set-point determination program based on MATLAB GUI with a nonlinear optimization routine, LEVMAR. Figure 8 shows the screen shot of the developed program, which is composed of 4 parts. The first is for input parameters such as DTL tank identification, RF amplitudes of simulation results, the input LLRF (low level RF) value of the RF amplitude, and initial values for shift,  $a$  and  $b$ . Each parameter has a default value and subjects to be changed to obtain the correct results. The second displays the comparison between the experimental data and simulation results after moving simulation data by the shift parameters,  $a$  and  $b$ .

It calculates the  $\chi$  value in each case. The fitting results are summarized in the third part of the screen. It includes the determined values of the RF amplitude and phase. The fourth part is dedicated to the quadratic fitting of the  $\chi$  data obtained in the second part. To test the developed program, we generated the artificial experimental data and applied the RF set-point program. It shows that the program works as expected.

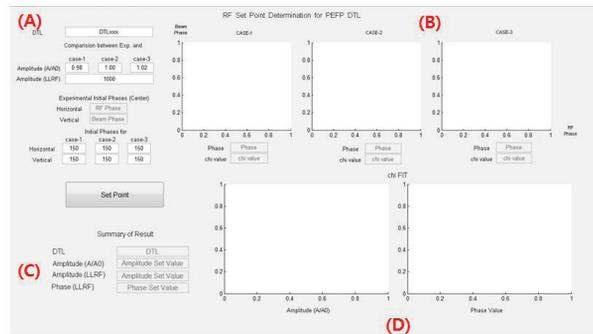


Figure 8: Screen shot of the RF set-point program; (a) input parameters (b)  $\chi^2$  calculation by comparing the experiments and simulations (c) determined RF amplitude and phase by quadratic fittings in (d).

### CONCLUSION

For the beam phase measurement, which is essential for the RF set-point determination during the commissioning of the PEFP linac, we designed and fabricated strip-line type BPM. The signal processing of the BPM will be performed based on the digital IQ demodulation method by using FPGA. To make it easy to carry out the phase scan procedure, we developed the MATLAB-based GUI program to determine the RF amplitude and phase. Currently the PEFP linac is under installation and the commissioning will be started in early next year.

### REFERENCES

- [1] K. Y. Kim, Y. S. Cho, J. Y. Kim, K. R. Kim, and B. H. Choi, "The Proton Engineering Frontier Project: Accelerator Development", J. of Korea Phys. Soc., 56 (2010) 1936.
- [2] J. H. Jang, H. J. Kwon, and Y. S. Cho, "Beam Commissioning Plan of PEFP 100-MeV Linac", Proceedings of IPAC2011, (2012).
- [3] H. S. Kim, Y. S. Cho, S. H. Han, J. H. Jang, Y. H. Kim, and H. J. Kwon, "Initial Test of the PEFP 20 MeV DTL", Proceedings of PAC2005, (2006).
- [4] J. Y. Ryu, H. J. Kwon, J. H. Jang, H. S. Kim, K. T. Seol, and Y. S. Cho, "Development of Beam Position Monitor for PEFP Linac and Beam Line", Proceedings of IPAC2011, (2012).
- [5] T. L. Owens, M. B. Popovic, E. S. Mccrory, C. W. Schmidt, and L. J. Allen, "Phase Scan Signature Matching for Linac Tuning", Particle Accelerators, Vol.48, p.169, 1994.