

# THE BPM DAQ SYSTEM UPGRADE FOR SUPERKEKB INJECTOR LINAC

M. Satoh<sup>#</sup>, F. Miyahara, T. Suwada, and K. Furukawa, Accelerator Laboratory, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan  
T. Kudou and S. Kusano, Mitsubishi Electric System & Service Co., Ltd, 2-8-8 Umezono, Tsukuba, Ibaraki 305-0045, Japan

## Abstract

The KEK electron/positron linac is a 600-m-long injector that provides the beams of different energies with four independent storage rings. A non-destructive beam position monitor (BPM) is an indispensable diagnostic tool for a long-term stable beam operation. In the KEK linac, around one hundred BPMs with the four strip-line type electrodes are utilized for the beam position and charge measurement. The measured beam positions can be used for the beam orbit and energy feedback loops. The current data acquisition (DAQ) system of BPM comprises 23 fast digital oscilloscopes based on WindowsXP.

Toward the SuperKEKB project, the upgrade of injector linac is now going on for increasing the beam intensity and reducing the beam emittance. For the SuperKEKB injector linac, the electron beam emittance should be reduced one-fifth smaller than that of former KEKB injector. For this reason, a high precision of the beam position measurement is strongly required. In this paper, we present the performance of a new BPM DAQ system in detail.

## INTRODUCTION

The KEK linac sequentially provides the electron and positron beams of different energies and intensities with the four independent storage rings. For increasing the integrated luminosity and stored current stability, the simultaneous injection between KEKB electron and positron rings has been strongly required. In addition, the PF top-up injection has been also strongly demanded even during the KEKB injection. In 2004, the injector upgrade project has started aiming at the simultaneous top-up among KEKB electron/positron and PF rings. This upgrade has been completed in April 2009, and the simultaneous top-up injection for the three independent rings has been successfully achieved [1-4].

Whereas the KEKB project has been completed in the summer of 2010, the SuperKEKB project has been started for aiming at the peak luminosity of 40 times higher than that of KEKB project. For this purpose, the injector linac upgrade is now going on for increasing the beam intensity and reducing the beam emittance. In this upgrade, the key issues are the construction of a positron damping ring, the development of a new positron capture system for increasing the positron charge of four times present, and the development of a new electron gun for a low

emittance beam production [5-11]. The desired precision of beam position measurement is ten micro meters or less since the transverse (vertical) normalized emittance required for electron (positron) beam is less than 20 (6) mm-mrad.

## SYSTEM DESCRIPTION OF BPM DAQ SYSTEM

### Present System

In the KEK linac, many kinds of feedback loops have been developed and utilized to stabilize the beam orbit, energy, and energy spread [12-14]. These feedback loops make use of the beam position acquired by a non-destructive BPM [15]. Around one hundred BPMs with the four stripline-type electrodes have been installed in the KEK linac.

The twenty three DAQ systems have been installed in the linac klystron gallery at a nearly equal interval along the beam line. The each DAQ system deals with the analogue signals from 3 to 6 BPMs. Figure 1 shows a schematic drawing of the present DAQ system. It comprises a fast digital oscilloscope and a cable combiner box.

The four analog signals from one BPM are fed to two signal combiners (vertical and horizontal) together with the signals from other BPMs. The delay cables corresponding to a time delay of 7 ns are used to avoid the waveform overlaps at the signal combiners. The each

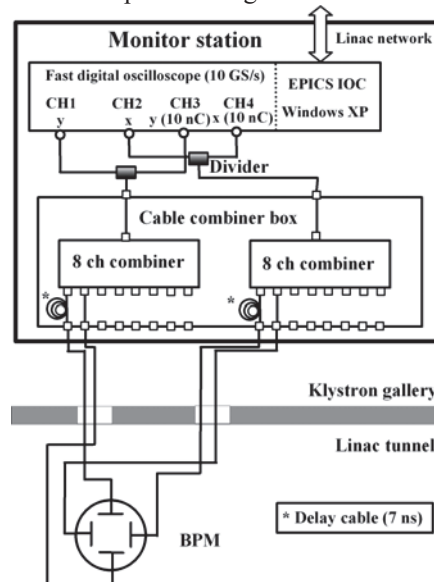


Figure 1: Schematic drawing of the present BPM DAQ system.

<sup>#</sup> masanori.satoh@kek.jp

output of combiner box is divided again into two signals with equal amplitude. Since it is impossible to change the vertical scale of oscilloscope in 20 ms interval, CH1/CH2 and CH3/CH4 are used for the measurement of low charge (0.1~1 nC) and high charge (10 nC) beams, respectively. The waveforms digitized at a sampling rate of 10 GSa/s are used for the calculation of beam position and charge. The DAQ software is running on the fast oscilloscope, and each system can work as an EPICS IOC [16, 17].

The beam position measurement precision of the present system has been evaluated by using the 3-BPM method [15], and its result shows around 50  $\mu\text{m}$  for both the horizontal and vertical directions. Toward SuperKEKB linac, the new BPM DAQ system should be developed since the beam position measurement precision of about 50  $\mu\text{m}$  is not enough for the control of a low emittance beam transport.

### New System

For the new DAQ system, the beam position measurement precision of about 10  $\mu\text{m}$  or less is one of key requirement. In addition, a fast beam position measurement is required for all beam pulses of 20 ms interval since the SuperKEKB injector linac should perform the simultaneous injection among the four independent storage rings. The electron and positron beams of different energies and intensities are delivered in every 20 ms. For this reason, a fast and precise attenuation control is also one of key requirement for the new system.

We adopt the Libera Brilliance Single Pass (LBSP) unit as a candidate of the new system [18]. It is a commercial product of Instrumentation Technologies. It is a module dedicated for BPM DAQ and widely used at many recent accelerator facilities. The LBSP unit comprises four signal input ports, four analog-to-digital converters (ADCs) of 125 MHz sampling frequency and 16 bit resolution, two pass band surface acoustic wave (SAW) filters of a center frequency 511 MHz with a 3 dB bandwidth of 24 MHz, a single-board computer (SBC), a field-programmable gate array (FPGA), and so on. It has also the variable attenuator with maximum attenuation of 31 dB. The attenuation level can be adjusted in 1 dB step.

The typical analogue signal shape from BPM electrode is a bipolar of 3 ns in width. After applying two SAW filters, the signal is stretched to around 100 ns because of the limited band pass width. Using 12 of digitized data points, the sum of squares of them is utilized for the beam position and charge calculation. The data processing of digitized waveform is carried out on the FPGA part. The calculated beam positions and other parameters are transferred to SBC part which is the embedded Linux operation system with a fast Gigabit Ethernet port. All the parameters can be accessible via EPICS channel access protocol from a client software.

## PERFORMANCE EVALUATION

Using the 3-BPM method, we evaluated the beam position measurement precision of LBSP unit with the electron beam of 0.3 nC. In this experiment, three LBSP units were connected to three adjacent BPMs as shown in Fig. 2. In this figure, we measured the three BPMs encircled by light blue colour for the beam test. The eleven different settings were applied for the horizontal and vertical steering magnets situated at upstream of used BPMs. For each steering setting, the beam positions were measured over 1000 successive beam pulses.

The fine phase adjustment among four signals from each electrode was carried out prior to the 3-BPM measurement. To attain a higher precision of position measurement, the fine phase adjustment is indispensable since the ADC clock of LBSP is not synchronized with the rf frequency used for the beam acceleration. Figure 3 shows the phase differences among the four signals before and after fine phase adjustment. The maximum phase

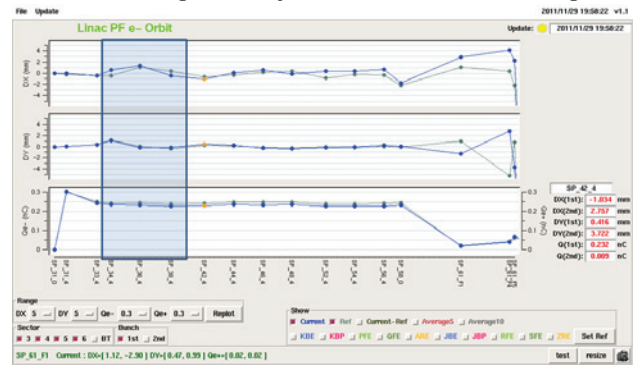


Figure 2: Electron beam positions of horizontal (upper), vertical (middle) directions, and beam charge (bottom) along the KEK linac during the 3-BPM measurement.

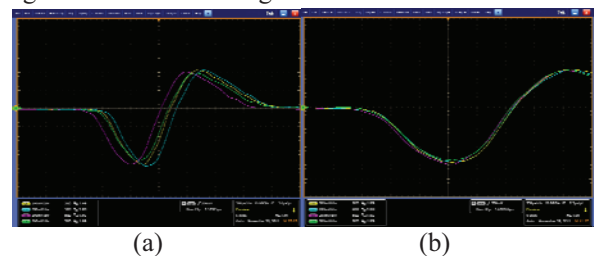


Figure 3: Phase differences among four signals from different electrodes before (a) and after (b) fine phase adjustment.

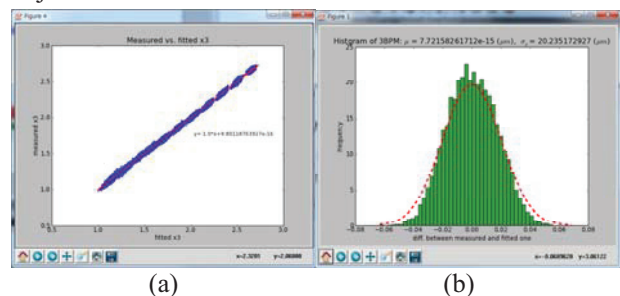


Figure 4: Measurement precision of horizontal direction evaluated by the 3-BPM method. (a) presents the measured versus expected beam position at BPM#3, and (b) shows the histogram of the residual between them.

difference of about 1.5 ns was corrected to around 100 ps by inserting the different number of SMA connectors to each signal input port of LBSP.

Figure 4 shows the 3-BPM result for horizontal direction. Using the linear multiple regression analysis, the expected beam positions at BPM#3 were calculated from the measured beam positions at BPM#1 and BPM#2 over the 11000 measured data as shown in Fig. 4-(a). The residuals between the expected and measured beam positions at BPM#3 were calculated, and its histogram was fitted by a Gaussian distribution function as shown in Fig. 4-(b). The similar result was also obtained for the vertical direction. From these results, the position measurement precisions of LBSP in horizontal and vertical directions are 20.24  $\mu\text{m}$  and 19.12  $\mu\text{m}$ , respectively. These results show that the precision of LBSP is much improved in comparison with that of current DAQ system though the target precision is still not archived.

## SUMMARY AND FUTURE PLAN

Toward the SuperKEKB project, the injector linac upgrade is going on for increasing the beam intensity and reducing the beam emittance. For the low emittance electron beam transport without a damping ring, the high precision beam position measurement and control are strongly required. For this purpose, we evaluated the performance of a candidate LBSP unit of Instrumentation Technologies.

To eliminate the pulse-by-pulse jitter of beam position and angle, we carried out the 3-BPM method with the electron beam of 0.3 nC at the KEK linac. The test result shows that the measurement precision of LBSP archives approximately 20  $\mu\text{m}$  for both the horizontal and vertical directions. The further improvements of using ADC with higher sampling rate and tuning the analog frontend are now going on for aiming at the measurement precision of beam position less than 10  $\mu\text{m}$ . We will conduct the 3-BPM test with the improved Libera units at KEK linac in this autumn.

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