BEAM DIAGNOSTICS AND TIMING MONITORING FOR SUPERKEKB INJECTOR LINAC

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Abstract

The KEK e^+/e^- linac has multiple operation modes for the electron beam injection into three rings, the SuperKEKB HER (High Energy Ring), PF (Photon Factory) Ring and PF-AR, and the positron beam injection into the damping ring (DR) and the SuperKEKB LER (Low Energy Ring). The operation modes can be switched every 20 millisecond, repetition rate of 50 Hz, with arbitrary order. The beam parameters such as charges, energies are different for each of the rings. Moreover, the bunch charges of the electron beam for HER, 5nC, is 5 times higher and the transverse emittance of ~10 mm mrad is 30 times lower than those of the KEKB injector.

Thus, the development for the BPM readout system with a wide dynamic range, the installation of optical fiber detectors with a good S/N ratio for the wire scanners and bunch-length monitor have been performed. For stable operation of the linac, many timing signals have to be monitored as well. To that end we have developed 32-bit multi-hit time-to-digital converters (TDCs) with 1-ns resolution. The first beam tests of those systems are reported.

COMPONENTS OF THE LINAC

The SuperKEKB injector linac is under development to achieve the required performance [1]. The layout of the linac with energy evolution from downstream of the 180-degree arc for each operation modes is shown in Fig. 1. The linac consists of eight sectors (A – C, 1 – 5). Each sector has eight accelerating units except for sector A, 1, and 4. The black square represents an accelerating unit which provides an average energy gain of 160 MeV. In sector A, a new photocathode RF gun designed to obtain high charge (5 nC) and low emittance (10 mm mrad) electron beam [2-3] is set on beginning of the sector. The linac also has a conventional thermionic gun which is dedicated to PF/AR in sector 3. Thus, electron source for PR/AR rings can be exchange. A magnetic chicane to give an energy chirp for bunch compression in the arc section and a diagnostic beamline are located on downstream of the RF gun.

A new positron source which consists of a tungsten target with a 2-mm diameter beamline-centered hole for electron, a beam spoiler, a flux-concentrator and six large-aperture S-band (LAS) accelerating structures inside DC solenoids have been installed in sector 1 [4,5]. In case of beam injection to PF or HER, the electron beam goes through the hole of the target. To obtain positron beam, an electron/positron separator chicane has been installed at downstream of the last LAS accelerating structure. To reduce the geometric emittance down to 41(horizontal)/2(vertical) nm, the positron beam injected to the damping [6] is stored 40 ms, the store time depends on the injection rate, then return to the linac. Thus, trigger timing of upstream (sector A – 2) and downstream (sector 3 - 5) for the RF system and the BPMs will be controlled independently [7].

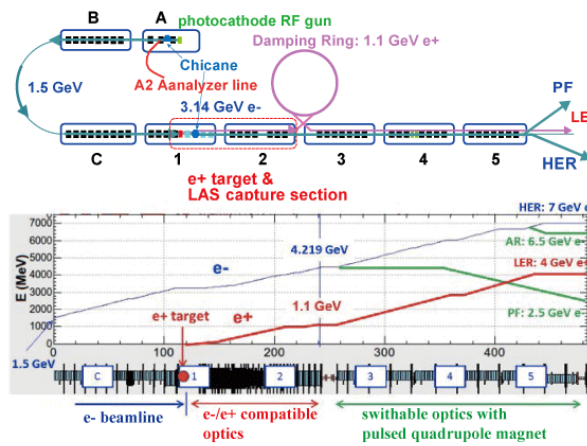

Figure 1: Schematic layout of the linac and energy-evolution patterns for each operation mode.

MONITORING SYSTEM

The beam positions and charges are monitored by stripline BPM. There are more than 90 BPMs and 23 oscilloscopes for fast BPM data acquisition (DAQ) system [8]. The position resolution of the BPM system is about 50 μm. To achieve emittance preservation of high bunch charges of 5 nC electron beam, the alignment error of 0.1 mm for each section and a dedicated orbit correction are required. These specifications require less than 10 μm position resolution for the BPM, but current DAQ system does not satisfy it. Then, we have been developed a VME-based readout system. The position resolution of 3 μm was achieved that was measured on the basis of 3-BPM method in the linac [9]. To measure the beam size and emittance, Al_2O_3 ceramic screen (30 μm thick) is set in the vacuum chamber at the chicane downstream of the gun, 4 sets of four successive wire

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scanners are installed in sector B, C, 2, 5 [10]. The temporal laser profiles for the RF gun and electron bunch length are monitored by using streak camera. In order to confirm bunch compression at the arc section and orbit correction, an X-band RF deflector will be set at the end of the linac.

OPTICAL FIBER LOSS MONITOR

The optical fiber is already used as a beamloss or/and a profile monitor in TTF1 [11], FLASH [12] and many facilities. In the KEK linac, the fiber loss monitors have been installed around a pulsed bending magnet for PF ring and the end of sector 5. So far, photomultiplier tube without any scintillator, the glass in front of the photocathode works as dielectric medium for Cherenkov radiation, has been used as the detector for the wire scanner. But, the way is not suited to the measurement at the location with heavy beamloss.

Beam Loss Monitor at the End of the Linac

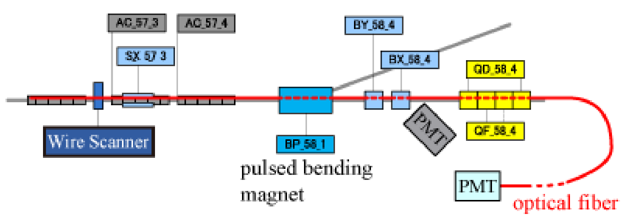

Figure 2: Schematic Layout of the linac end (sector 5).

The schematic layout of the linac end is shown in Fig. 2. The optical fiber is set along the beamline. The fiber passes through the pulsed bending magnet, steering magnets (BX, BY) and quadrupoles (QF, QD). It was revealed that the electron beam tail hits the vacuum chamber installed in the pulsed bending magnet from analysis of the signal of the fiber. The beam sizes measured by a wire scanner are shown in Fig. 3. The signals measured by the PMT without fiber is deteriorated due to the background of heavy beamloss. On the other hand, the data measured by the fiber shows clear beam profile. That good S/N ratio has been achieved by to set appropriate ADC gate timing that corresponds to quadrupoles. It appears that the fiber passed through in

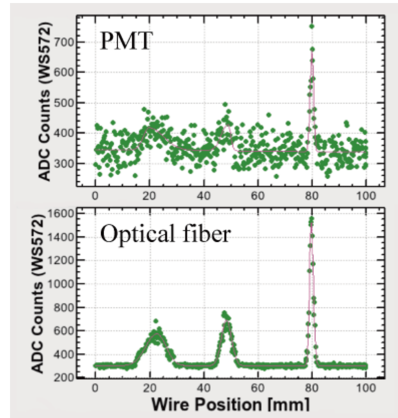

Figure 3: Signals from a PMT without any scintillator (top) and a PMT coupled to the optical fiber (bottom) vs wire position. The left, center and right peaks correspond to vertical, oblique and horizontal beam profiles. These scales of the vertical and horizontal should be divided by $\sqrt{2}$.

quadrupoles is much closer to beam axis and recoil electrons which lose energies are over focus or defocus in the quadrupole.

Loss Monitor in Downstream of the Positron Source

The target system for positron production was changed that electron beams go through a small hole with 2.0 mm diameter on axis, while the beam had been bypassed the target in the KEKB injector. Although the radius of the hole is designed so that the electron beam passes through without any beamloss, the target could cause beamloss due to any position jitter, beam halo or other reasons.

The construction of positron source was started in 2013 and wire scanner system in sector 2 had been installed. Then, initial positron beam commissioning has started. To find the good S/N position for wire scanner, the optical wire was set along the beamline (Fig. 4). The background signal originating from beamloss at the target is shown in Fig. 5. Although, the primary electron beam passed through the target hole without any clear charge losses monitored by BPMs, six strong signals that corresponds quadrupoles were observed. The bottom in Fig. 5 presents signals with insertion of the wire scanner. The growth of 5th and 6th signal indicates electron beam

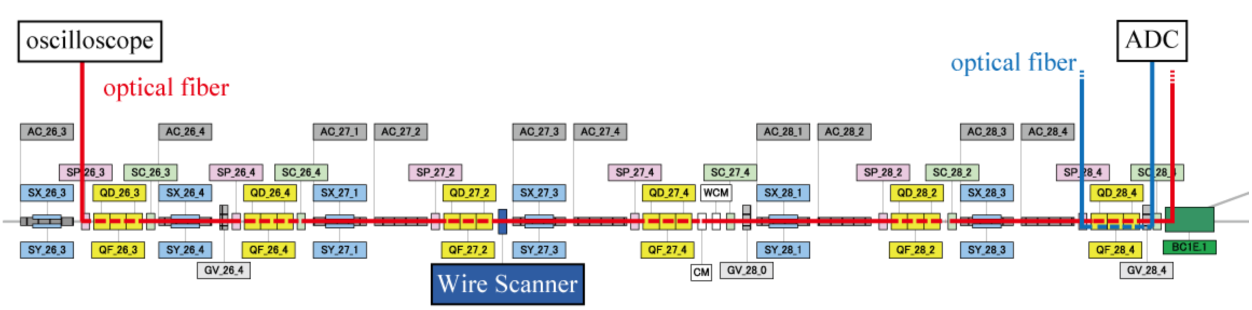

Figure 4: Layout of the beamloss monitor at sector-2 end which located ~100 m-downstream of the positron source.

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scattering in the wire. In case of two-bunch operation, those peaks are overlap other. Thus, the optical fiber dedicated to beamsize measurement using wire scanner has been set in last quadrupoles (QF_28_4, QD_28_4 in Fig. 4). The beam profile was measured, nevertheless high background as shown in Fig. 6.

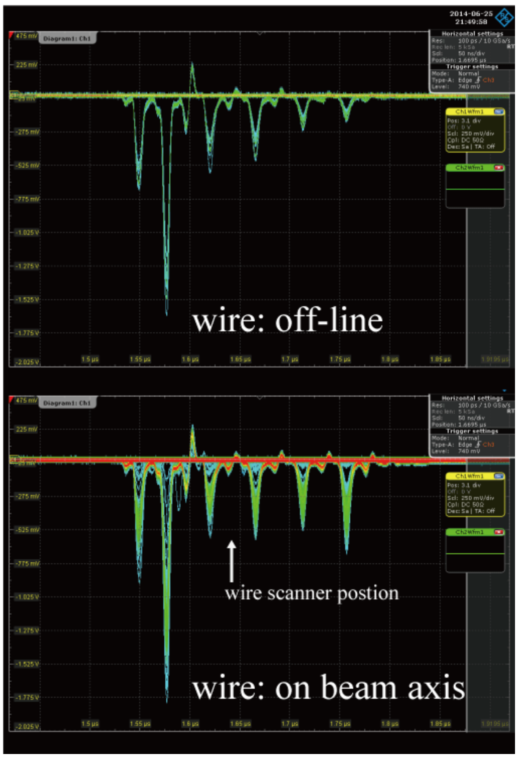

Figure 5: Background signals due to a beamloss at the positron source, in case of the primary electron beam passes through the target hole. The top/bottom corresponds to without/with insertion of the wire scanner.

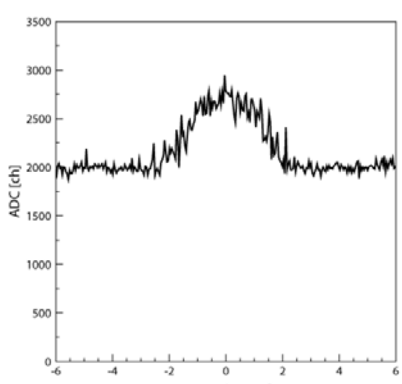

Figure 6: Vertical beam size at the wire scanner.

TIMING MONITORING SYSTEM

The trigger timing system of the linac is based on Event Timing System on VME [13]. The timing system distributes trigger timings and parameters for the linac components, such as RF phases, currents of magnets, etc., through event code and data buffer. The injection beam for the HER and LER requires timing jitter of less than 30 ps. It is confirmed that the system satisfies that the requirement under a variation of temperature in the linac [14]. To accomplish multiple injections to HER, DR, LER, PF ring and PF-AR, sequence of injection will be put every ~2 s. The trigger timings and parameters are decided by each beam mode. Those trigger timings range from ns to several hundred μs and the interval between the beam pulses is 20±1 ms and should be scheduled precisely. Thus, timing monitoring system with a wide dynamic range of more than 20 ms and a resolution of 1 ns is required. Then, a FPGA-based TDC has been developed [15].

FPGA-BASED TDC

The basic specification of the FPGA-based TDC listed in Table 1. The TDC has a common strat input and 16 multi-stop input channels. The inputs to the modules are standard NIM logic levels. Since handling FPGA with 1 GHz is not easy, the 4X oversampling technique is employed to the TDC with a 250MHz clock. The timing charts are shown in Fig. 7. Four clocks which have π/2 relative phase reference, then the time duration T is given by $T = NT_{clk} + \Delta T_1 + \Delta T_2$ and a resolution of $T_{clk}/4$ is obtained.

Table 1: Margin Specifications

Parameters	Value
Number of common start	1
Number of stop channels	16
Number of multi-stops	4
Dynamic range	4.3 s
Resolution	1 ns
Clock	250 MHz

The performance test has been performed by using the TDC and the Digital Delay generator (SRS, Model DG645, rubidium time base) from the delay time of 1 ns to 800 ms. The accuracy which is given by the absolute time difference divided by the setting delay time and variations in the time difference of the measured to the setting delay time are shown in Fig. 8. The accuracy is 0.13 ppm up to ~3 ms which corresponds to the roll-off point. Those results are acceptable in our trigger timing monitoring system.

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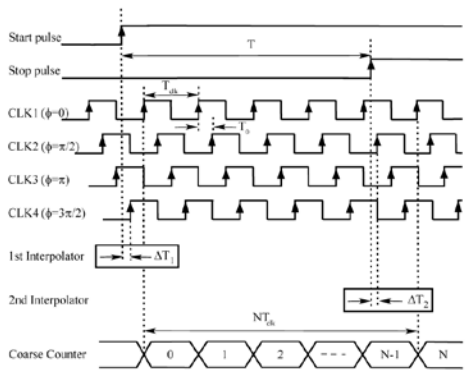

Figure 7: Schematic timing diagram for the FPGA-based TDC.

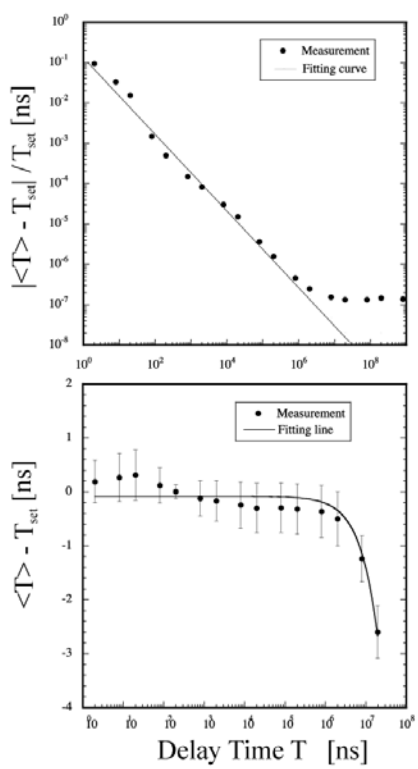

Figure 8: Accuracy and timing jitter. The bar shows standard deviation.

CONCLUSION

In the SuperKEKB injector linac, a new RF gun for low emittance, high bunch charge electron beam and a new positron source had been installed. Although the beam commissioning was just started, in case of the electron beam passes through the hole on the positron target, a beamloss was found by using the optical fiber set along the beamline. The optical fiber dedicated to beamsize measurement by using wire scanner has been also installed. A clear beam profile was obtained by using the system under the background which stems from the target. Trigger timings for the linac components ranges from ns to several hundred μs and the modulators of high power klystron should be triggered by 20±1 ms. Thus, wide dynamic range TDC with 1 ns resolution has been developed. The TDC shows good performance enough to monitor the linac timing system.

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