Trigger-timing signal distribution system for the KEK electron/positron injector linac

T. Suwada,[1] K. Furukawa, N. Kamikubota, and M. Satoh,

Accelerator Laboratory, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

The KEK electron/positron injector linac provides a short-pulse electron beam with an energy of 2.5 GeV for the Photon Factory (PF) storage ring, that with an energy of 3 GeV for the Advanced Ring (PF-AR) for pulse X-rays, and single-bunch electron and positron beams with energies of 8 GeV and 3.5 GeV for the KEK B-Factory (KEKB) storage rings, respectively. A trigger-timing signal distribution system of the injector linac was newly developed and extended for stable injection to the KEKB rings with the required injection-timing accuracy highly stabilized to less than 30 ps in root mean square because the old trigger system distributed the trigger-timing signals for the injection to the PF ring and the PF-AR with an injection-timing accuracy of 300 ps. In this report the design and its performance of the new trigger-timing signal distribution system are described in detail.

Key words: Trigger-timing signal distribution system; rf synchronization; Electron linear accelerator
PACS: 29.17.+w, 29.27.Ac, 41.85.Ar

1 Introduction

The KEK electron/positron injector linac [1] injects a short-pulse electron beam with a pulse width of 1 ns to the PF ring and the PF-AR once and three times in daily operation, respectively, and also injects single-bunch electron and positron beams with a bunch width of ∼10 ps directly into the KEKB rings [2] about twenty times in daily operation. The beam commissioning of the KEKB started in 1997 for testing CP violation in the decay of neutral

[1] Corresponding auther. E-mail address: tsuyoshi.suwada@kek.jp

B mesons with an asymmetric electron-positron collider comprising 3.5-GeV positron and 8-GeV electron rings.

The injector linac was upgraded for injection to the KEKB rings, which requires a precise trigger-timing control of the injector linac for more stable operation. One of the many items for the injector upgrade is the development of an integrated trigger-timing signal distribution and its control system, which have been newly extended for performing stable injection to the KEKB rings along with the existing trigger control system for injection to the PF ring and PF-AR.

Thus, the injector linac has an injection system for the four storage rings, that is, the PF ring, the PF-AR and the two KEKB rings, according to their various operation modes for which the mode switch should be performed both rapidly and stably more than fifty times in daily operation. The trigger-timing signal distribution system provides trigger-timing signals for the pulsed operation of two sets of electron guns and pre-injectors (one is for the PF and the PF-AR, and the other is for the KEKB), 59 acceleration rf units, rf monitors, beam monitors, a pulsed focusing coil for positron generation, and other equipments. The linac beam pulse should be synchronized with rf frequencies of the PF (500.1 MHz), the PF-AR (508.6 MHz) and the KEKB (508.9 MHz) in order to inject a single rf bucket of each ring within an allowable timing jitter.

The existing trigger control system for the PF and the PF-AR has been already described in detail previously [3,4]. Here, in this report, the new trigger-timing signal distribution system, which has been developed and extended for the KEKB operation, is described in detail along with the interrelation between this new system and the existing trigger system.

2 Overview of the trigger-timing signal distribution system

The injector linac with an overall length of 600 m is partitioned into eight sectors. Additional three sectors (A, B and C) were newly extended for KEKB operation in 1997, while five sectors (1-5) have already been used for PF and PF-AR injection operation since 1982. Each sector corresponds to a basic unit of an rf power distribution system. As following the rf power distribution system the trigger-timing signals are distributed from a main station to eight stations (sector stations) installed at the beginning of each sector (see Fig.1). The main station is installed close to the main control room of the injector linac. It provides master-trigger signals to the sector stations, beam-timing signals to the electron guns, and injection-timing signals to septum and kicker magnets according to the revolution frequency of the KEKB and PF (or PF-AR) rings. Each sector station receives the trigger-timing signal and distributes it to a sub-booster klystron for its pulsed rf generation, to the modulator of the sub-booster klystron, to an rf pulse compression device [1], and to beam monitors and rf monitors for their timing of their data-acquisition system. For KEKB injection operation, the first sector station (sector station A) provides the trigger-timing signal to the operation of half of the rf-power distribution unit and to the pre-injector system, which comprises an electron gun, two sub-harmonic bunchers (SHBs) and a traveling-wave buncher. The trigger-timing signal for high-voltage modulators of eight high-power klystrons is directly distributed from each sector-control station, while it is regenerated on the base of the trigger-timing signal sent from each sector station.

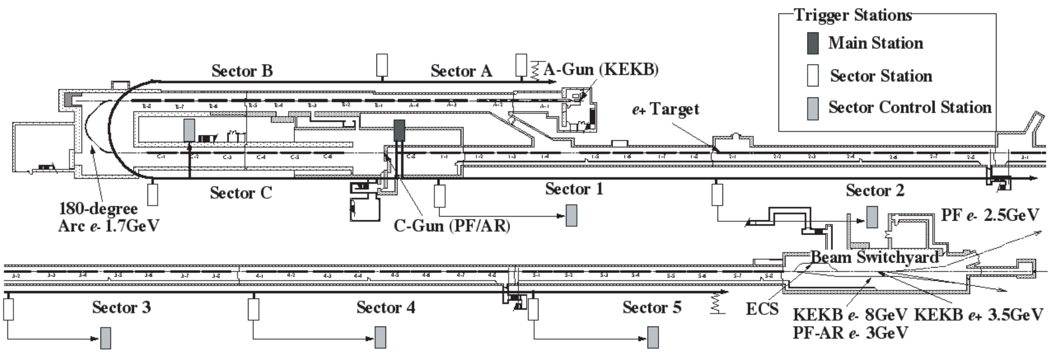

Fig. 1. Layout of the KEK electron/positron injector linac and the location of trigger stations.

3 Trigger-timing signal distribution system

3.1 Clock generation and subharmonic frequencies

It is strongly required for its injection with an accuracy of 30 ps in root mean square (r.m.s.) from the timing center of a ring's rf bucket in order to suppress any amplitude growth of synchrotron motion in the KEKB rings to be as small as possible. This means that the trigger-timing signal distribution system of the injector linac should be designed to synchronize accurately. For its synchronization accuracy, the injector linac needs to inject single-bunch electron and positron beams to the KEKB rings with a common sub-harmonic frequency between the linac and the KEKB rings. The fundamental rf frequency is 10.38546 MHz, which has a common harmonic number of 275 times for the rf acceleration frequency (2856 MHz) for the injector linac and that of 49 times for the KEKB rings (rf acceleration frequency 508.9$\pm$0.3 MHz). Thus, it is designed that the single-bunch beams need to be bunched by using two SHBs (rf frequencies of 114.24 MHz and 571.20 MHz) for which the two rf frequencies can be generated by the fundamental rf frequency. The relationship between the fundamental and sub-harmonic rf frequencies for the injector linac and the KEKB rings is shown in Table 3.1. These rf frequencies are generated and provided by frequency-multiplying and frequency-dividing the fundamental rf signal generated from a 571.2-MHz rf signal generator installed at a main rf staton [5]. The fundamental rf frequency can possibly change the frequency with a step of 0.1 Hz in order to correct the circumference particle-orbit length of the rings due to the temperature variation in the ring tunnel during a day. The 571.2-MHz rf signal is also used as a clock signal in the trigger-timing signal distribution system. This means that the trigger-timing step is variable with a step of 1.75 ns.

Table 1
Fundamental and common rf frequency relationship between the injector linac and the KEKB rings.

RF Device	Multiplication	RF Frequency [MHz]
Fundamental	-	10.38546
SHB1	×11	114.24
SHB2	×55	571.20
Linac Acceleration rf	×275	2856
KEKB-ring Acceleration rf	×49	508.8875

3.2 Trigger-timing signal generation at the main station

A block diagram of the trigger-timing signal generation in the main station is shown in Fig.2. The maximum repetition rate (50 Hz) of the trigger pulse is generated from a line-locked generator. It was designed to provide triggers at a fixed phase of the 50-Hz power-line frequency so as to stabilize the klystron beam current heated by the 50-Hz power line and the function of a charging unit for a high-power klystron modulator. The trigger pulse is then synchronized by a trigger synchronizer with a bucket-selected trigger pulse of the ring through the KEKB bucket selection system [6]. The bucket-selected trigger pulse is generated with a maximum delay time of 500 μs after the linac line-locked trigger by synchronizing with the ring's revolution frequency (2.03 kHz). It is derived by dividing the fundamental frequency by the harmonic number (h=5120) of the KEKB rings, while it is synchronized by the revolution frequency of 1.6 MHz for the PF (or 0.8 MHz for the PF-AR). An injection mode selector switch selects the operation mode required by an operator through the linac control system [7]. Each trigger synchronizer generates basically three kinds of the trigger-timing signals. These are a master trigger, a kicker trigger to each ring, and a trigger to a grid pulser of the electron gun for which the trigger timing is controllable by using a 16-bit digital time-delay module (TD-4) [8] through a CAMAC-based control system. The time-delay module is a single-width CAMAC module which counts a 571.2-MHz clock signal by a D-type flip-flop with a 16-bit presettable BCD counter with high speed integrated emitter-coupled-logic (ECL) circuits. It generates a delayed trigger pulse synchronized with the 571.2-MHz rf. The maximum delay is about 115 μs in steps of 1.75 ns, and its maxmum clock frequency is available up to about 720 MHz. The jitter of the output pulse is less than 3 ps in r.m.s. The master trigger is sent to a trigger transmitter module where the master trigger signal is regenerated by combining 571.2-MHz rf and a monocycle signal generated by a monocycle pulse generator with fine adjusting of the relative phase. In the transmitter module the power level of the 571.2-MHz rf is amplified to the level of 36 dBm (or 4W) from the input level of 10 dBm, where the power level is stabilized within 1% by an amplitude gain controller (AGC), and the phase is well stabilized within 3 ps in r.m.s. by a phase-locked loop (PLL). The jitter measurement result is shown in Fig.3, where the phase jitter of the 571.2-MHz rf was measured by detecting its zero-cross signal jitter. A signal picture of the master trigger signal is shown in Fig.4. The trigger transmitter sends the master trigger signals to sector stations A, B and C, and also to sector stations 1-5 through coaxial cables (diameter of 30 mm) with low loss and good phase stability (WF-H50-7S, Mitsubishi cable industries, LTD.[9]). The relative timing chart of the generated trigger pulses and rf signals for the KEKB is summarized in Fig.5.

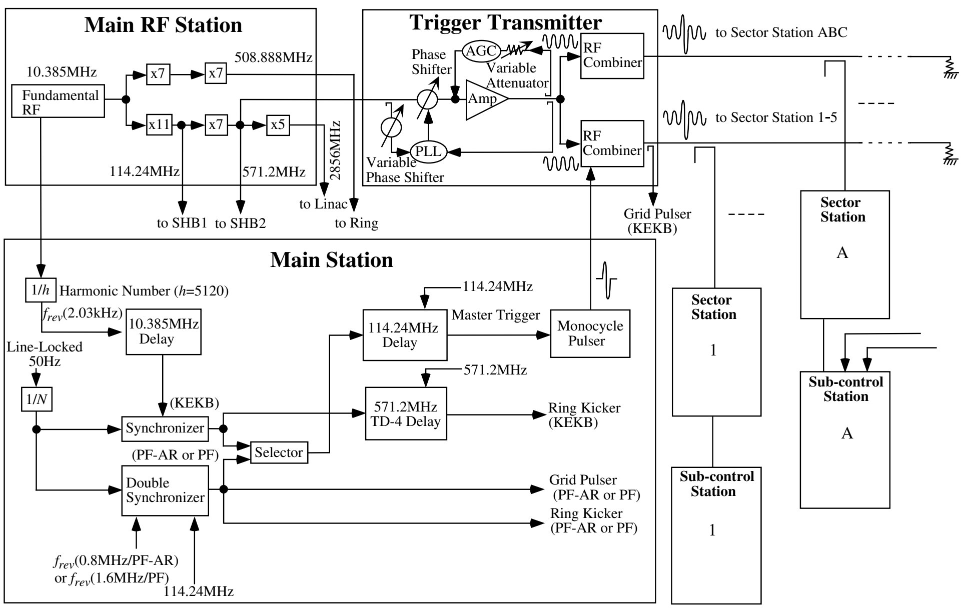

Fig. 2. Block diagram of the trigger-timing signal generation in the main station.

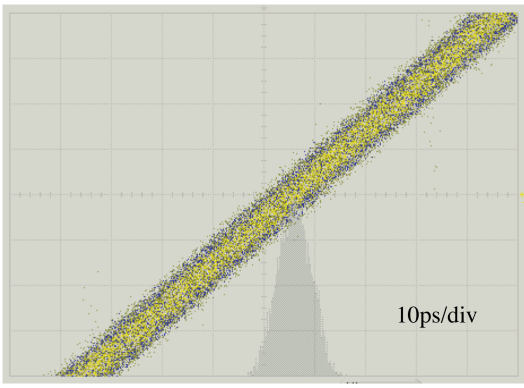

Fig. 3. Phase-jitter measurement result of the master trigger in the main station. The digital signal shows the phase jitter of the zero-cross level for the 571.2 MHz rf.

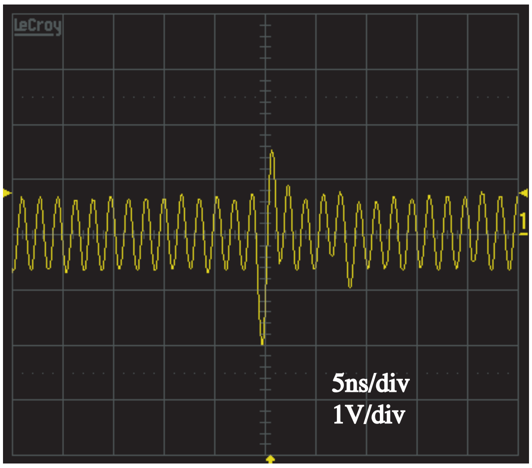

Fig. 4. Master trigger signal generated in the transmitter module.

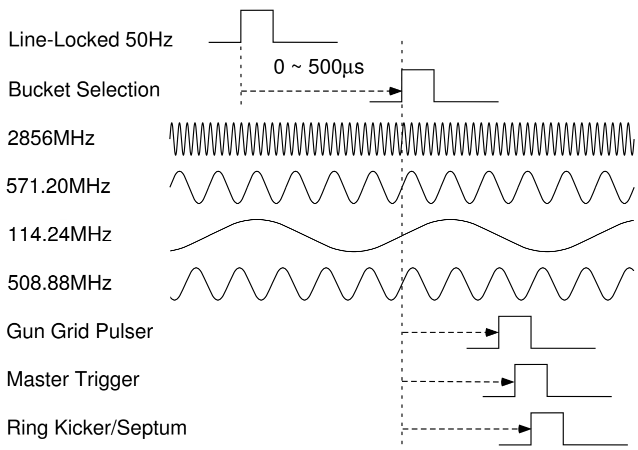

Fig. 5. Relative timing chart of the generated trigger pulses and rf signals for KEKB operation.

3.3 Trigger-timing signal distribution at the sector station

A block diagram of the trigger-timing signal distribution in the sector station is shown in Fig.6. The transmitted master trigger is picked up by a directional coupler with a coupling strength of 16 to 20 dB, depending on the location of each sector station. The master trigger with an rf power level of about 12 dBm is sent to a trigger receiver module installed at each sector station. A trigger-timing one-shot signal (NIM standard) is generated by detecting the positive leading edge of the monocycle trigger signal with a voltage discriminator circuit in the trigger receiver module. This signal is used for a start pulse of the time-delay module. On the other hand, the 571.2-MHz rf is regenerated from the master trigger signal through a 571.2-MHz bandpass filter in the trigger receiver module. This rf is distributed as a clock signal of the delay module. Thus, the trigger-timing signals are regenerated for the pulsed rf and high-voltage generation of the sub-booster klystron as well as the phase flip timing for the rf pulse compression device, for the high-voltage generation of the positron pulse modulator, and for the rf monitors and the beam monitors according to preset digital time delays in each sector station.

On the other hand, the trigger-timing signals for eight high-power klystron modulators are regenerated and distributed in each sector-control station placed at the center of each sector, except for a common sector control station for the new sectors (A, B and C). The trigger receiver module sends the 571.2-MHz rf clock and trigger signals directly to the sector control station through coaxial cables, where similar 16-bit digital time-delay modules (TD-4V) are controlled through a VME-based control system. The specification of the TD-4V module is almost the same as that of the TD-4 module, except for its control interface. This module was historically developed as a CAMAC-based module, while the VME-based control system became a standard interface towards the upgrade to the KEKB operation in the injector linac.

3.4 Control software

The control of the timing system is a part of the integrated linac control system. It is based on the multi-layer architecture, in which lower layer servers support each different hardware, and upper layer servers are designed to provide hardware-independent services to the application layer [7]. The timing control is named as "trig" and upper layer server is called "rtrigd". Rtrigd serves various timing related functions to the application layer through TCP-based remote procedure calls (RPC), while it communicates with several different lower-layer servers, such as for CAMAC-based TD-4 and VME-based TD-4V, via UDP-based RPC.

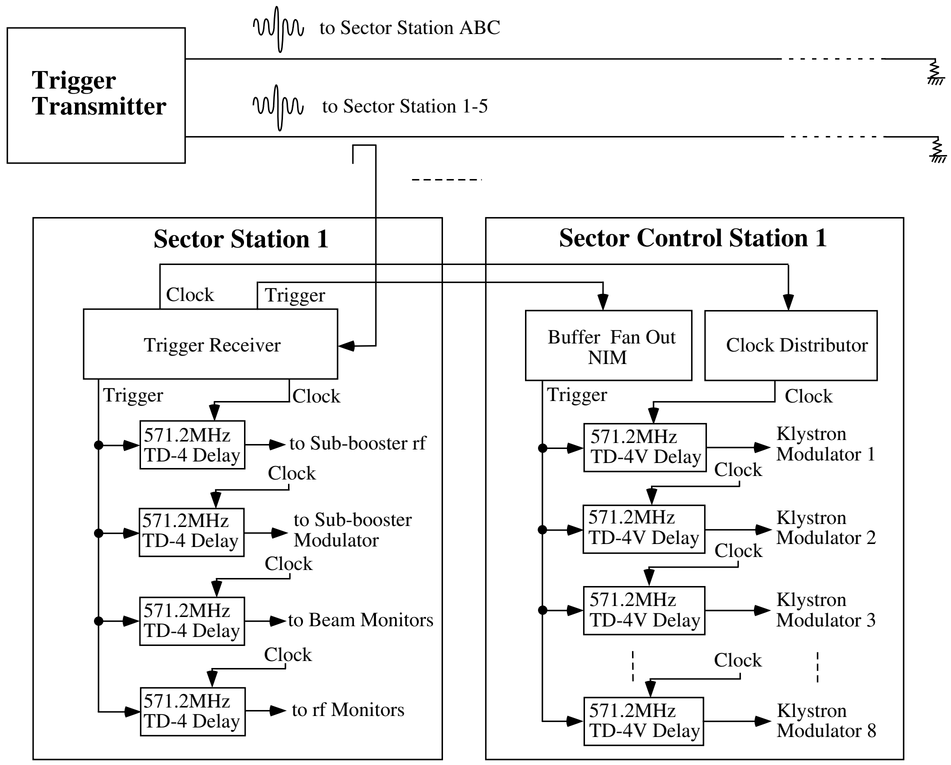

Fig. 6. Block diagram of the trigger-timing signal distribution in the sector station and the sector-control station.

The common application software is used for the routine operation and for the optimization of beams, which includes a beam mode switch panel, a parameter save-restore panel, active and passive correlation plots, beam and device feedback systems. Device specific application panels are also used by operators. They all provide the basis of the stable linac operation. Furthermore they are essential to operate on the positron injection to KEKB with two bunches in a pulse since the two-bunch beam is sensitive to its timing [10].

4 Performance of the new trigger-timing signal distribution system

The performance of the new trigger system was tested by measuring the timing jitter of the trigger signal generated at all the sector stations with a digital sampling oscilloscope with a frequency band of 20 GHz. The trigger pulse and the rf clock regenerated in each sector station were returned back to the main station by using similar coaxial cables in order to measure their timing and phase jitter. The measurement result is shown in Fig.7. The result shows that the maximum timing jitter of the trigger pulse regenerated from the sector station 5 was less than 5 ps in r.m.s., while the timing jitter of the trigger pulse from other sectors was less than 4 ps in r.m.s. They were measured by detecting the zero-cross signal jitter of the rf clock in the main station with the trigger pulse coming from each sector station. The result is sufficiently satisfied with the required injection-timing accuracy for the KEKB rings.

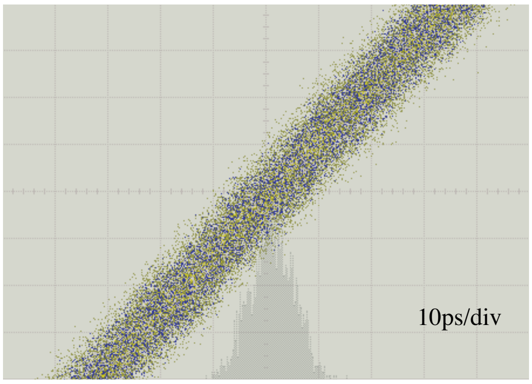

Fig. 7. Timing jitter measurement result of the trigger signal generated at sector 5. The digital signal shows the phase jitter of the zero-cross level for the 571.2-MHz rf.

The new trigger system was also tested by measuring a single-bunch structure at the outlet of the pre-injector with an optical transition radiation monitor with a streak camera system [11]. The result is shown in Fig.8. The full width at half maximum is about 7.1 ps, where the bunch width is strongly dependent of the beam-timing accuracy for the electron gun, the trigger-timing accuracy for the streak camera and the relative timing accuracy between the bunch and the acceleration phase. This measured bunch width is very consistent with a simulation result based on the beam dynamics at the pre-injector within the measurement error. It should be emphasized that the new trigger-timing system of the injector linac works very well under the condition for KEKB operation.

5 Conclusions

A new trigger-timing signal distribution system was developed for KEKB operation at the KEK electron/positron injector linac. The new system was extended from the existing trigger control system with its good extensibility and flexibility. The jitter measurement of this system shows that the specification for the injection accuracy within 30 ps in root mean square is sufficiently satisfied for both the single-bunch electron and positron beams to the KEKB rings. The new trigger system has been working well along with the existing trigger-timing system for the PF and the PF-AR since the start of the KEKB commissioning in 1997.

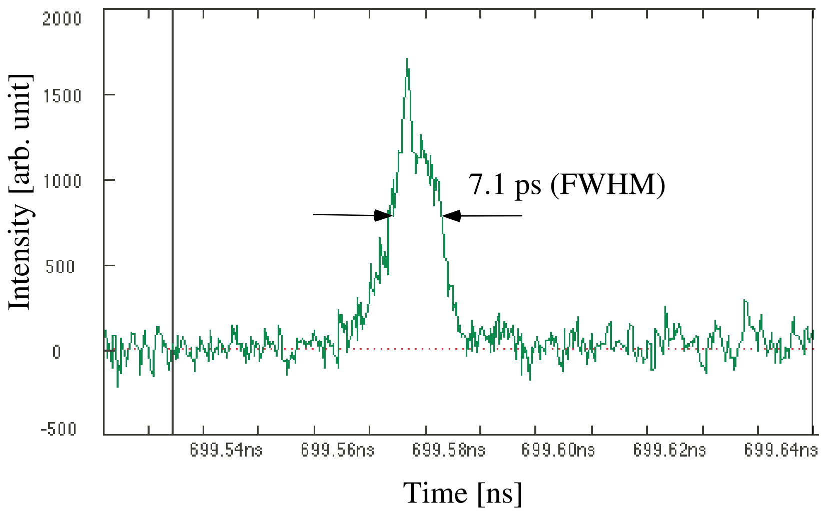

Fig. 8. Single-bunch structure of an electron beam measured by an optical transition radiation monitor at the pre-injector.

Acknowledgements

The authors are very grateful to Dr. T. Urano for his contributions to the design and construction of the trigger-timing and its control system in the injector linac as our previous group leader.

References

[1] I. Abe *et al.*, Nucl. Instr. and Meth. A 499 (2003) 167.

[2] S. Kurokawa and E. Kikutani, Nucl. Instr. and Meth. A 499 (2003) 1.

[3] T. Urano and K. Nakahara, Nucl. Instr. and Meth. A 247 (1986) 226.

[4] T. Urano, Y. Hosono and K. Hasegawa, Nucl. Instr. and Meth. A 327 (1993) 529.

[5] H. Hanaki, S. Anami, S. Fukuda, H. Katagiri, T. Matsumoto and S. Michizono, *Proc. First Asian Particle Accelerator Conf. (APAC'98)*, KEK, Tsukuba, Japan, 1998, p. 139.

[6] E. Kikutani, Y. Ogawa and M. Tobiyama, *Proc. the Second Asian Particle Accelerator Conference (APAC2001)*, Beijin, China, September 17-21, 2001, p. 669.

[7] K. Furukawa, N. Kamikubota, T. Suwada, and T. Urano, *Proc. the Int' l Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS' 99)*, Trieste, Italy, Oct. 4-8, 1999, p. 98.

[8] Private communication from M. Tobiyama.

[9] Mitsubishi Cable Industries LTD., 4-1 Marunouchi, chiyoda-ku, Tokyo 100-8303, Japan.

[10] K. Furukawa, N. Kamikubota, T. Suwada and T. Obata, *Proc. the Int' l Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS2001)*, San Jose, U.S.A., Nov. 27-30, 2001, p. 266.

[11] Y. Ogawa et al., *Proc. the First Asian Particle Accelerator Conf. (APAC' 98)*, KEK, Tsukuba, Japan, 1998, p. 534.