THE TIMING SYSTEM OF KEKB 8-GEV LINAC

K. Furukawa*, T. Suwada, N. Kamikubota, M. Satoh
High Energy Accelerator Research Organization (KEK),
Tsukuba, Ibaraki, 305-0801, Japan

Abstract

The timing system of the KEK electron linac has been restructured for the KEKB project since a higher precision was required compared with the previous project. It provides precise timing signals for more than 100 accelerator devices such as guns, rf sources, beam instrumentation, etc. along the 600-m linac. The signals can be synchronized to one of four rings, KEKB HER/LER, PF and PF-AR. The clock system consists of five synchronized frequencies to drive different rf systems. The main clock of the timing system is 571.2 MHz, which is distributed through a coaxial cable overlapped with timing pulses. The delayed signals for over 100 devices are generated at 15 timing stations along the linac. Gate pulses are also distributed to enable intermittent measurement, etc. Timing signals are controlled through VME and CAMAC with the linac standard control architecture. The delay step of the timing signals is 1.75 ns and the precision is better than 5 ps depending on the location. It enabled stable long-term operation of the linac and also the recent "two bunch in a pulse" operation with its precise controls.

1 INTRODUCTION

The KEK electron/positron linac injects beams into four storage rings; 3.5-GeV positron to the low energy ring and 8-GeV electron to the high energy ring of KEKB, 3-GeV electron to PF-AR and 2.5-GeV electron to PF ring [1]. The beam for KEKB injection is a S-band single bunch with the bunch length of less than 10 ps.

It is required to provide stable and high-quality beams so as to achieve optimal experiment results. Trigger timings for accelerator equipment are important to maintain stable operation, since they directly affect the beam quality and energy through the single-bunch operation with the rf compression systems (SLED). Timing precision of the beams should be at least better than 10 ps inside of the linac. For KEKB injections it should be better than 30 ps (rms), since their synchrotron motion should be suppressed as small as possible and they have to pass through the long and winding transport lines [2].

Because of such higher timing precision requirement, the development of the integrated trigger-timing signal distribution and its control system had become a key issue of the KEKB project. Thus, it was re-designed with more than 10-times better precision compared with the previous system [3]. The reliability of the system was considered most important in the design. And it should support the basis of the stable operation of the linac though all of the electron source, acceleration system and monitoring system. Timing signals are provided for two sets of electron guns, 59 rf acceleration units, a pulsed positron focusing coil, injection kickers, rf and beam instrumentation systems.

2 TIMING SYSTEM ARCHITECTURE

The linac is sub-divided into eight sectors and the total length is about 600m. Each sector is a basic unit of an rf power distribution system. The timing signal is generated at the main timing station synchronizing with several timing sources. It is distributed with a basic clock to 15 remote timing stations, and then delayed timing signals are provided for accelerator devices.

2.1 Basic Clock

In the previous project TRISTAN, the rf frequencies of ring and linac are asynchronous. However, in the KEKB project rf frequencies need to have an integer relation as in Table 1 since a single-bunch beam with a small jitter have to be injected.

Table 1: rf frequencies of KEKB linac

Purpose	**Ratio**	**Frequency**
Fundamental	–	10.38546 MHz
Linac SHB1	×11	114.24 MHz
Linac SHB2	×55	571.2 MHz
Linac Main	×275	2856 MHz
KEKB Ring	×49	508.8873 MHz

These rf sources are generated by frequency multiplying and dividing, and are distributed to rf systems [4]. The frequencies are adjusted by 0.1-Hz steps in 10.385 MHz in order to correct the beam orbit in the ring corresponding to the change of the circumference of KEKB rings.

2.2 Beam Timing Signal

The maximum beam repetition rate is 50 Hz, which is limited by modulators of high-power rf systems. The beam timing is generated by synchronizing to both the revolution frequency of each ring and the power line frequency for the noise elimination. Then a delay may be added to select a bucket in the ring. For KEKB the timing is chosen to select one of 5120 buckets with synchronizing to the fundamental clock, 10.385 MHz [5]. Figure 1 shows the simplified timing chart.

---

*< kazuro.furukawa @ kek.jp >

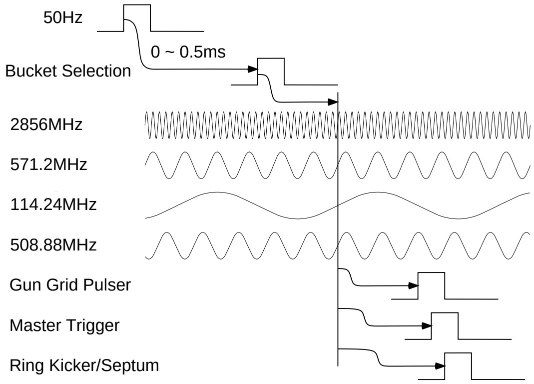

Figure 1: Simplified relation between clock and timing signals.

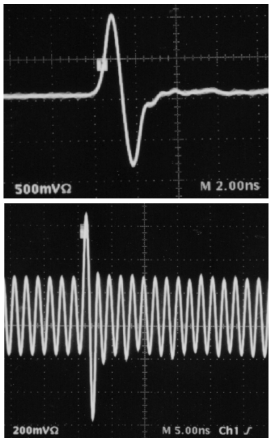

Figure 2: 50-Hz mono-cycle pulse (above) and the combined 571.2-MHz clock and 50-Hz timing signals transmitted to remote stations.

2.3 Distribution of Clock and Timing Signal

Since many of the timing signals require high precision and they are synchronized to 571.2 MHz in the linac, it is decided to distribute the timing signal with the clock signal. The clock is used to generate delays appropriate for the corresponding purposes and to re-synchronize the timing for the precision.

A 50-Hz mono-cycle pulse with a width of 1 ns and the 571.2-MHz clock of about 36 dBm are combined in a trigger transmitter module at the main timing station as in Fig. 2. It is transmitted on a single 30-D coaxial cable with low loss and good phase stability. Then it is split with directional couplers at remote sector stations, where timing and clock signals are regenerated separately with trigger receiver modules.

2.4 Generation of Delayed Timing Signals

Various delayed timing signals are generated depending on the purposes at the remote timing stations . They are generated by counting the 571.2-MHz clock starting from the beam-timing signal with delay modules. Those modules are called TD4V, TD4 and TD4R depending on the control interfaces of VME, CAMAC and RS232C.

Table 2: Timing signal transmission and generation

Station	Beam Station	Primary Sector Station	Secondary Sector Station
Location	Electron Gun	Sub-booster	Control Room
Number	1	9	5
Clock	TD4R	Trigger-Receiver	From Primary Station
Delay	TD4R	TD4	TD4V
Field Bus	RS232C	CAMAC	VME
Purpose	Beam	Low-level rf Beam Monitor	High Power Supply

The 16-bit ECL counter in the module can delay a signal up to 114 μs with a timing jitter about 3 ps (rms). Since each accelerator device requires different timing, delay modules are installed separately, and the number of modules is about 160.

2.5 Pulsed rf Modulation

Timing system is used both for low-level microwave generation and high-voltage pulse generation in the rf system. Timing signals for low-level rf are generated at the primary sector stations located at the sub-booster klystrons, and define the rf pulse envelope and the phase-flip timing for rf compressors (SLED). Pulsed rf from a sub-booster klystron is distributed to high-power klystrons (up to 8) inside the sector. While SLED timing is important to maintain stable high-power rf, the system provides sufficient accuracy. The low-level rf timing is optimized to acquire the highest beam energy and to equalize the beam energies of two bunches in a pulse [7].

Timing signals for high-voltage pulses are generated at the secondary sector stations located at the sub-control rooms. They are delayed separately and transmitted to high-power klystron modulators.

There are 59 high-power klystrons in the linac and some of them are put into stand-by mode depending on the operation mode. Two low-level pulse envelopes are generated. One of them synchronized to the beam and another is 57 μs apart which corresponds to the stand-by mode. One of them is selected with the high-voltage pulse timing.

2.6 Beam and rf Instrumentations

Timing signals for beam and rf instrumentations are generated at the primary sector stations almost the same way as for rf systems. However, beam repetition is sometimes lower than 50 Hz. Thus, four kinds of gate signals are generated at the main timing station, and are distributed using twisted-pair cables to select the appropriate beam pulses depending on the devices. The TD4 module is equipped with a inhibit input, with which one of the gate signals is connected to inhibit the output signal.

Delayed timing signals from TD4 are transmitted to 30 rf measurement stations and 18 beam measurement stations which covers streak cameras, beam position monitors, timing-shutter cameras, wire scanners as well as injection septa and kickers.

3 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 different pieces of hardware, and upper layer servers are designed to provide hardware-independent services to the application layer [6]. 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 TD4 and VME-based TD4V, via UDP-based RPC.

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 [7].

4 PERFORMANCE CONSIDERATION

Timing switch and adjustment are carried routinely from operation software such as automatic beam stabilizers, a beam mode switch panel, etc. They work sufficiently well. The system is also utilized efficiently to support the two-bunch injection mode, which was adopted recently.

During the commissioning of KEKB, it was found that some TD4 modules stopped the outputs for just 200 ms and the event occured about once a month. Because of such rare events, it took more than a year to ascribe the issue to a comparator circuit. After all of the comparators in TD4s were replaced, we have never experienced the trouble.

An evaluation of the timing jitter of this system was carried using a 20-GHz sampling scope. The timing signals regenerated at remote sector stations were transmitted back to the main timing station through a 20-D coaxial cable and compared the original signal. The typical jitter value was 4 ps (rms) and the maximum measured jitter was 5 ps for the farthest station. They were found to have sufficient precision.

Figure 3 shows the beam bunch structure measured by a streak camera. The measured bunch length was 9 ps (FWHM) for a 10-nC single-bunch beam, and it agrees well with a result from beam simulation codes. Thus, the timing jitters for the electron gun and the streak camera are considered to be much better than 9 ps. The stability of the resultant beam is satisfactory.

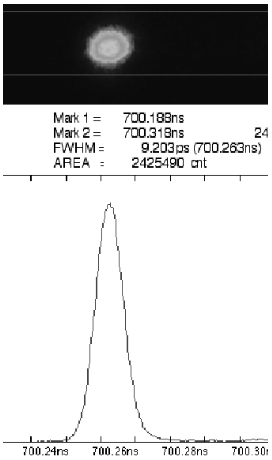

Figure 3: Beam bunch structure measured by a streak camera. The bunch length is 9 ps for a 10-nC bunch.

5 CONCLUSIONS

The timing system of the KEKB linac has been designed and operated stably and it performs well beyond its requirements. It also works well for the two-bunch acceleration of the linac, which was not planned originally.

6 ACKNOWLEDGMENTS

The authors are grateful to the previous group leader Dr. T. Urano who originally designed and constructed most part of the system.

7 REFERENCES

[1] K. Furukawa *et al.*, "Present Performance and Future Upgrade of the KEKB Electron Linac", *Proc. of LINAC2002*, Gyeongju, Korea, 2002, p.382.

[2] "KEKB B-Factory Design Report", KEK Report 95-7, 1995, Chap.12.

[3] T. Urano and K. Nakahara, Nucl. Instr. and Meth. **A247**, 1986, p226.

[4] H. Hanaki *et al.*, "Low-Power rf Systems for the KEKB Injector Linac", *Proc. APAC'98*, Tsukuba, Japan, 1998, p.139.

[5] E. Kikutani *et al.*, "The KEKB Bucket Selection System", *Proc. APAC2001*, Beijing, China, 2001, p.669.

[6] K. Furukawa *et al.*, "Accelerator Controls in KEKB Linac Commissioning", *Proc. of ICALEPCS'99*, Trieste, Italy, 1999, p.98.

[7] K. Furukawa *et al.*, "Beam Feedback and BPM Read-out Systems for the Two-bunch Acceleration at the KEKB Linac", *Proc. ICALEPCS2001*, San Jose, USA., 2001, p.266.