Timing system of SPring-8

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Abstract

The timing system of SPring-8 has completed and multi-bunch and single-bunch beam operations were tested during the commissioning of SPring-8. In both the beam operations, aimed rf buckets of the storage ring could be repeatedly filled with the beam from the synchrotron. The multi-bunch beam with the bunch train of 1 μs or 40 ns was injected from the linac to the synchrotron, the single-bunch beam was formed by the rf knockout system in the synchrotron and the beam was injected into the storage ring.

1. Introduction

SPring-8 accelerator complex is composed of a linac, a synchrotron and a storage ring. The synchrotron accelerates an electron beam from 1 GeV to 8 GeV. The repetition rate is 1 Hz [1]. SPring-8 is operated in the multi-bunch and the single-bunch modes of an electron or a positron beam. The electron beam with the bunch train of 1 μs and 1 ns from the linac are used for the multi-bunch mode and the single-bunch mode, respectively. The positron beam with the bunch train of 40 ns and 1 ns are also used in the same way. As the beam current of the positron is very low, in order to save the injection time the beam is injected eight times from the linac to the synchrotron in one repetition cycle. The radio frequency of the linac is 2856 MHz, that of the synchrotron and the storage ring is 508.58 MHz. There is no relation of the phase of these two frequencies, which are supplied by individual oscillators. To fill a beam in the same buckets of the storage ring repeatedly, an accurate timing system was required especially in the beam injection of the single-bunch from the linac to the synchrotron. Therefore, the beam with the bunch train of 1 ns from the linac must be filled in only one bucket of the synchrotron with the time interval of about 2 ns. The accuracy of the timing signal which fires a gun of the linac is limited by the relation between the energy spread of the beam and the phase difference between the rf of the aimed bucket of the synchrotron and the beam from the linac. The time jitters must be less than 100 ps.

2. Timing system

To realize the accurate timing system, optic fibers, electric to optic transmitters (EO) and optic to electric receivers (OE) are used for the transmission line. Furthermore, a 508.58 MHz non-stop-counter was developed for a master signal [2]. The radio frequency of a 508 MHz and the master signal of 1 Hz are made in the E-station of the storage ring. The rf signal is divided and transmitted to A,B,C and D-stations of the storage ring and the control room for the injector. The master signal is also used for the assignment of the buckets in the storage ring. On the basis of these two signals, all of the triggers for the linac and the synchrotron are made by the timing system of the synchrotron [3].

2.1 Timing system of the storage ring

The timing system of the storage ring is placed at the E-station in the neighborhood of the A-station. There are a synthesized frequency generator of 508.58 MHz and a 508 MHz non-stop-counter which generates a master signal of 1 Hz. The counter has 30 bits and can put out a pulse at the interval of 2 s at most. The signal of 508.58 MHz is divided into the five stations. The master signal is transmitted to the control room of the injector. The optic fibers and EO/OE are used in the transmission line. Especially for the transmission line of the rf signal, the phase fluctuations between the E-station and the other one are monitored with the mirror which reflects a part of received optic signal. If necessary, a phase-lock-loop (PLL) can be driven to keep the phase stable.

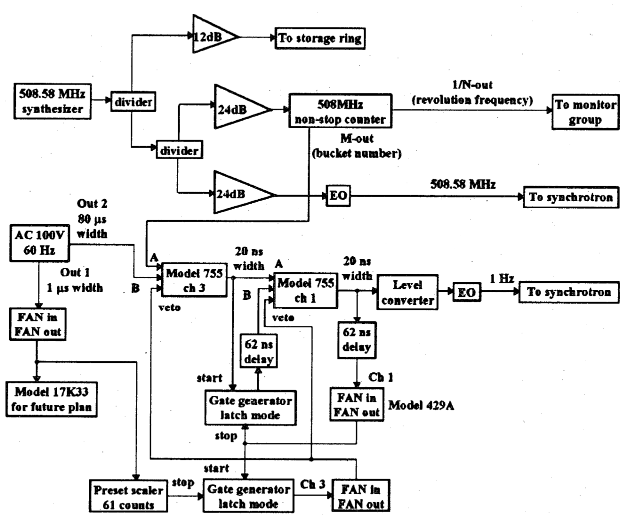

Fig. 1 Block diagram of the timing system at E-station.

Figure 1 shows the block diagram of the timing system at the E-station. The master signal is exactly coincident with the revolution frequency of the storage ring and the commercial line frequency of 60 Hz. The harmonic number of the storage ring is 2,436 and the revolution frequency is acquired by counting 2,436 of 508.58 MHz with a 508 MHz non-stop-counter. There are two input and two output ports in the counter. The input ports are connected with a 508 MHz and a reset signal. The output ports are 1/N and M-out.

1/N means that a pulse is put out every N counts of the 508 MHz and the N is 2,436 here. M-out means that a pulse is put out at the M-th of N. The beam can be filled in any buckets by appointing the number of M. In order to make stable the excitation of all power supplies, the master signal is synchronized with the commercial line frequency of the power station. The master signal is acquired as the second pulse of the revolution frequency after counting 61 of the commercial frequency with two AND-circuits and two gate-generators. The first pulse is not used so that the master signal is not triggered by the commercial frequency which has much time jitters.

2-2. Timing system of the synchrotron

In the timing system of the synchrotron, all of the trigger signals for the power supplies are made from rf signal of 508 MHz and the master signal of 1 Hz. About 100 triggers are used for a gun and modulators of the linac, power supplies of bending, quadrupole, sextupole, correction and pulse magnets, beam monitors and so on. The synchrotron is operated by the timing signal. Especially in the single-bunch mode operation, the jitters for the gun trigger must be less than 100 ps and the jitters for the other one must be less than a few ns. All the timing signals are made by counting 508 MHz or the frequency of 508 MHz divided by 21, respectively. The delay times from the master signal to the triggers are given by a preset value. All of the delay times are decided with consideration of the distance from the timing system to the power supply and from the power supply to the machine, the electric delay in the circuit, the rise time of the pulse and passing time of the beam at the machine from the gun.

3. Performance

The overall performance of the timing system for the SPring-8 is measured with a phase detector and a sampling oscilloscope. The fluctuation of the rf phase between E-station and the synchrotron without the PLL is less than 1 degree of the 508 MHz. The distance between the two stations is about 700 meters. This measured value is comparable to the performance of the phase detector. With the PLL, the fluctuation can be decreased to less than 0.1 degree. The time jitters between the rf signal of 508.58 MHz from E-station and the linac trigger of the timing system is 4 ps for one standard deviation (1σ) and 22 ps for the overall width. In 1994, the jitters between the linac trigger and the beam current of the linac at the injector section was measured with the same timing system. Figure 2 shows the measurement system with the injector of the linac. The jitters for 1 σ was 7.4 ps. The total jitters for 1 σ was less than 10 ps and the overall width for 3 σ was estimated to be less than 60 ps.

Once in a beam operation, the efficiency of the beam injection from the synchrotron to the storage ring was suddenly decreased because of the failure of a optic coupler of the transmission line. This could be repaired immediately by replacement of the module.

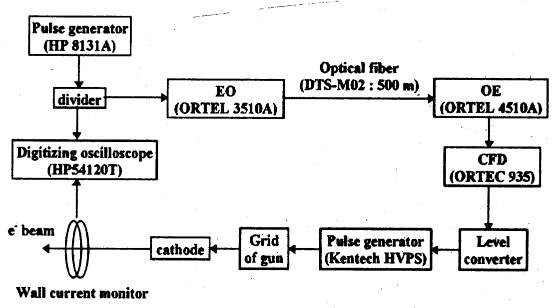

Fig. 2 The measurement system of the jitters with the injector of the linac.

4. Beam operation

The beam commissioning of the linac, the syncrotron and the storage rings were started in August, in December 1996 and in March 1997, respectively.

4-1. Multi-bunch operation

At first the beam commissioning of the synchrotron was practiced in the multi-bunch mode operation of an electron beam with the bunch train of 40 ns and 1 μs from the linac [4]. As the delay time of the timing system was adjusted previously, the delay times except the gun and kicker magnets did not need to be changed. The beam commissioning of the storage ring was also started in the multi-bunch mode operation of a beam with the bunch train of 1 μs. The stored beam current per pulse in the storage ring was about 0.5 mA. To store a beam current of 20 mA of which value was limited by the radiation security, 40 beam pulses were injected in the storage ring repeatedly. When the beam current was decreased to less than 15 mA, the beam was injected again. The beam from the synchrotron were almost put into the aimed buckets of the storage ring, and it was exactly confirmed by a single-bunch mode operation.

4-2. Single-bunch operation

In the storage ring a multi-bunch and a single-bunch mode operations are required. However it takes a week to replace the circuit of the gun grid-pulser for the multi-bunch mode operation by that for the single-bunch mode operation. The experiment which converts a multi-bunch beam from the linac into a single-bunch beam with an rf knockout system installed in the synchrotron, was tested.

The beam is kicked out in the vertical direction by the rf knock-out system at the injection energy of 1 GeV. Because the vertical aperture is smaller than the horizontal one and the damping time of 0.87 s at 1 GeV is estimated to be longer than that of 2 ms at 8 GeV and the required rf-knockout power at 1 GeV is smaller than that at 8 GeV. The phase difference of the rf current on the four electrodes for the rf-knockout must be 180 degree alternately as shown in figure 3. The maximum rf power is 50 watt per electrode. At the resonance point of the betatron tune the beam is kicked out in the vertical direction, and the beam is lost within about 30 ms after the beam injection. The condition of the resonance is expressed in equation (1).

$$f_{knockout} = [n \pm \{\nu_y - \mathrm{Int}(\nu_y)\}] \times f_{revolution} \qquad (1)$$

n : 0 or positive integer

where the $f_{revolution}$ is 756.8 kHz. The ν_y is a vertical tune. The $\mathrm{Int}(\nu_y)$ means a integer of ν_y. The vertical tune value were selected to 8.7833. Figure 3 shows the block diagram of the rf knock-out system for the formation of the single-bunch mode. The beam bunch train of 1 μs or 40 ns for the multi-bunch mode operation is injected into the synchrotron, most of the beams are kicked out at the vertical betatron resonance with the rf knock-out and only one bunched beam is remained. Most of the beams are kicked out at the vertical betatron resonance with the rf knock-out. The signal of the knock-out is made by composition of a sine wave resonating with vertical betatron oscillation and three rectangle pulse of $f_{rf}/12$, $f_{rf}/21$ and $f_{rf}/32$. Equation (2) is the knockout signal for the single-bunch mode operation.

$$V_{knockout} = V_0 \sin(2\pi f_{rf}/376)t \times \mathrm{rectangle}(2\pi f_{rf}/m)t \qquad (2)$$

m : 12, 21, 32

The f_{rf} is the radio frequency of 508.58 MHz. The $f_{rf}/376$ means the knockout frequency of 1.3526 MHz. It corresponds to n=1 in the equation (1). The least common multiple of 12, 21 and 32 is equal to the harmonic number of 672. There are only two points of a revolution cycle at which the beam is not kicked out commonly by three kinds of rectangle pulses. If the beam is not injected at the one point but at the other point, only one bunched beam remains. The three kinds of rectangle pulses are switched at the interval of 40 ms one after another in the flat bottom of 150 ms [5][6]. Figure 4 shows the signal for the rf knock-out. Figure 5 shows the wave-form of four equally-spaced bunches in the storage ring with the aimed bucket changing four times. The interval of bunchs is 609 buckets.

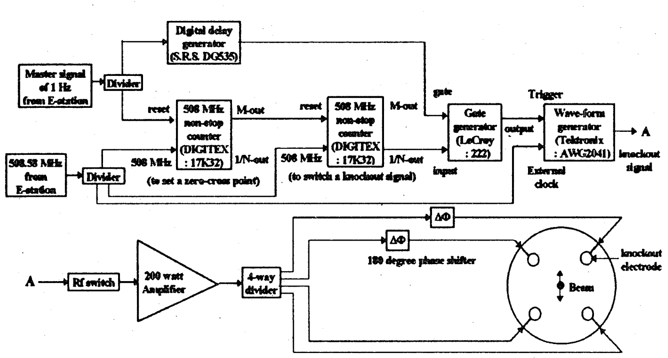

Fig.3. The block diagram of the rf knock-out system for the formation of the single-bunch mode

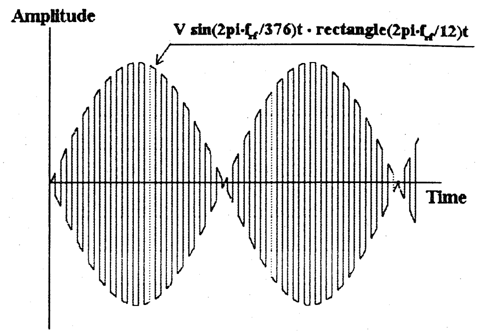

Fig.4. The signal for the rf knockout.

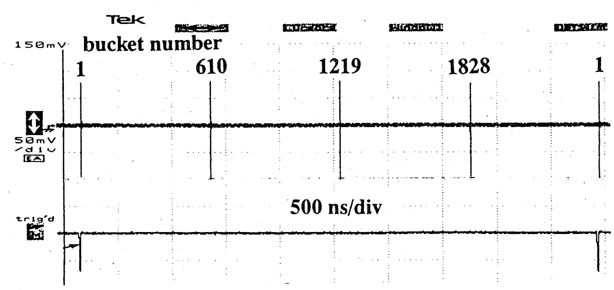

Fig.5. The wave-form of four equally-spaced bunches in the storage ring with the aimed bucket changing four times.

5. Conclusion

The timing system of SPring-8 is successfully completed. The performance is confirmed with the multi-bunch and the single-bunch beam operations. The commissioning of the SPring-8 was succeeded smoothly with the timing system. The beam is supplied steadily to the storage ring. The first beam-line experiments will be started in October 1997.

The beam test to inject eight equally-spaced single bunch beams into the synchrotron is planned in September 1997. The impurity of the single bunch in the storage ring, which is defined as the ratio of the neighborhood-bunch beam to the aimed-bunch beam will be measured with the photon counting method from September. There is not yet an rf knockout system and any equipment to prevent the increase of the impurity of the single-bunch beam in the storage ring. To make the purity better, the knockout system should be installed as soon as possible.

References

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