PERFORMANCE OF THE REFERENCE AND TIMING SYSTEMS AT SPRING-8

Y. Ohashi, T. Asaka, H. Ego, M. Hara, Y. Kawashima, T. Ohshima, T. Takashima and H. Yonehara, SPring-8, Hyogo 679-5198, Japan

Abstract

Reference RF and timing systems were developed at SPring-8 in order to handle beams in a stable and flexible manner under various conditions of machine operation. A synchronous universal counter plays an essential role in the timing system. Here, the method to realize high-precision timing is described, as well as the tools that were required to confirm that the system operates as designed. Furthermore, a new scheme for the synchronization of the different RF signals from linear and circular accelerators is described.

1 INTRODUCTION

The SPring-8 accelerator complex consists of an 8 GeV storage ring (SR), a booster synchrotron (SY), and a 1 GeV linac. A common master oscillator provides the 508.58 MHz RF reference signal to the SR and SY, whose harmonic numbers are 2436 and 672, respectively. The linac is operated at 2856 MHz and a repetition rate of 60 Hz. The SR is a third generation light source that provides high-brilliance synchrotron light to various experimental groups. Any kind of beam filling and refilling patterns are achievable by the successful development of a synchronous universal counter (SUC) [1] and a stable signal-transmission system.

The 508 MHz SUC must perform the following functions; 1) trace the location of the RF buckets by synchronous non-stop revolution counting, 2) act as a timing/delay pulse generator with synchronization of 508.58 MHz. A SUC is widely used by the users who require precise timing relative to the beam. A phase-stabilized optic fiber (PSOF) [2] is commercially available and a temperature coefficient in the phase drift of about two orders of magnitude smaller compared to a phase-stabilized coaxial cable. In addition to that, electric-to-optic (E/O) and optic-to-electric (O/E) signal transmitters with small temperature coefficients became commercially available also. An optic signal-transmission system has the advantage over the conventional electric one with respect to phase stability. In combination with the synchronization feature of the SUC mentioned above, a high-precision timing-signal transmission system, for which time jitters are minimum and almost independent of the transmission distance and delay period, is established.

A development of reference RF and timing system was started in 1991, and its feasibility was confirmed by the end of 1993. Construction of the timing system was completed in 1996, and the system is running properly and stably since beam commissioning in March 1997.

A single-bunch beam is created from the linac beam of 1 ns width by RF knockout system installed in the SY [3]. Acceleration of a beam in a single RF bucket of 2856 MHz is desirable in order to make the single-bunch purity better. There is no simple relation between two RF frequencies of 508.58 and 2856 MHz, however, two RF signals had to be synchronized for precise beam injection. We paid attention to the fact that the linac is not operated in CW. A new scheme of synchronizing multiple RF frequencies has been implemented [4].

2 SYNCHRONOUS UNIVERSAL COUNTER

Recent digital technology made it possible to perform a direct counting at a rate of over 500 MHz for accelerator applications. The 508 MHz SUC has a capability to count up to 30 bits in order to cover 1 sec of ramping time of the SY. The circuit block diagram is shown in Fig. 1.

We describe some details of the SUC used at SPring-8. Application to a different environment is simple. The SUC counts the RF bucket number corresponding to the harmonic number (N=2435) of the SR, and it then provides a pulse corresponding to the revolution number.

Fig. 1. Block diagram of a 508 MHz SUC.
frequency of SR from ‘1/N out’. The output ‘M out’
corresponds to the particular RF bucket within a
revolution. Beams are injected into the targeted RF
buckets from the SY by setting the number ‘M’ as
desired. ‘M’ can be set either externally or manually. By
resetting the SUC, a delayed pulse is generated from ‘1/N
out’ (‘M out’) with a delay time of N(M)/508.58MHz in a
synchronous way. The device is packaged in a single
width standard NIM module, and it can be applied
whenever precise timing is required.

3 REFERENCE AND TIMING SIGNAL DISTRIBUTIONS

An optic signal-transmission system was adopted where
phase/timing precision is crucial. Proper methods to
distribute the signals were selected in consideration of the
environmental factors. There are two ways to distribute
the reference RF signal to the four RF control stations; 1)
sequential transmission from station to station relying on
the phase-locked-loop (PLL) feedback system between
two stations, 2) single loop with optic directional couplers
around the SR with a single PLL feedback between
transmitted and returned signals. The SR-building is kept
at a steady temperature of 25±1°C by air conditioning to
meet with the strict experimental requirements from
synchrotron-light-source users. Because of the excellent
phase stability of the PSOF, we selected the latter method
(Fig. 2), also because of the fact that the sequential use of
PLL feedback piles up phase errors. On the other hand,
we introduced a different method for the signal
distribution to the injectors, since temperature along the
fiber path of ~700 m is not controlled as well as in the SR
case. A PLL feedback, using the signal returned in the
same optic fiber reflected by the mirror located at the end
point was applied [5].

Devices used for the timing-signal distribution are
similar to the ones used for the reference RF signal. Time
jitters due to the unstable output pulse amplitude from the
E/O module are compensated by inserting a constant
fraction discriminator (CFD). A more precise timing
signal is delivered by synchronizing it with a reference RF
signal in the place where precision is required. This is
simply realized by introducing a signal concerned into the
input ‘External reset’ of the SUC. Timing precision is
restored to a few ps. Annual drift in the reference RF
phase is about 5 degrees in the SR and 3 degrees in the SY
without PLL feedback control. They become within 1
degree with PLL feedback control. Time jitters in the
timing pulse transmission without synchronization vary
depending on the system. For example, it was measured to
be 7.4 ps (standard deviation) in the electron gun system
of the linac [1].

4 PERFORMANCES

There are several ways to check the stability of the
reference RF and timing system.
1) A picosecond pulsed laser used in a time-resolved
experiment must inject laser beam in a sample exactly
when synchrotron light beam hits the sample. Timing
between the two beams was measured using a streak
camera. A stability of ±2 ps was obtained for a few
hours [6].
2) Impurity level of a single-bunch beam was measured in
the SR and was less than 10^-9 (below detection level)
over several hours [7]. Reduced beam current during
user experiment period is restored by the beam refills.
3) The beam orbit deviates due to the tidal forces. The
beam energy shifts due to changes in the
circumference of the SR caused by the deformation of
the ground. The beam orbit correction system
compensates such deviations, and it results in a shift of
the RF frequency. Maximum peak-to-peak variation of
about 70 µm in the circumference is properly
corrected, where the correction step is currently set to
0.3 µm [8].

5 NEW SYNCHRONIZATION SCHEME
BETWEEN TWO RF’S

A simple way to synchronize two RF frequencies is to
generate those RF frequencies from a common sub-
harmonic oscillator together with frequency dividers/
multipliers. Although this method should in principle be
applicable, a compromise between hardware availability
and performance has to be found. Since a conventional
method was not applicable to the SPring-8, a new idea
was sought by freeing the constraint between two RF’s
required for synchronization. A 2856 MHz RF is actively
used for a short period that corresponds to a small duty

Fig. 2. Reference RF signal distribution for the
storage ring.
factor of the linac. When the beam injection takes place, a pulse synchronized with 508.58 MHz triggers the 2856 MHz generation each time. Fig. 3 shows the block diagram of the new synchronization method [4]. The 2856 MHz RF generator is simple and consists of an arbitrary waveform generator (AWG), bandpass filters, and a frequency multiplier. The numbers in Fig. 3 indicate the current parameter setting. The duration of 2856 MHz generation is 290 µs. The spectra from the synthesizer and the present device are shown in Fig. 4. The difference of 18.7 kHz is small enough and does not affect practical operations. Suppression of time jitters in the ‘start signal’ in Fig.3 is essential to obtain a high precision synchronization of the two RF signals, and it is realized by using the SUC. Only one master synthesizer of 508.58 MHz is present after elimination of the one in the linac. The method described here can be applied widely and easily to similar facilities. One can choose the best RF components suited for the project without caring about their frequencies any more.

6 CONCLUSIONS

The SUC is a key tool in the SPring-8 timing system for flexible beam handling. It gives the revolution and RF bucket information with small time jitters. The reference RF signal distribution system was successfully constructed using PSOF, E/O and O/E with small temperature coefficient and time jitters. Annual phase drift is within 1 degree by a PLL feedback. A timing signal distribution system, which requires extremely small time jitters, was constructed by using the synchronization function of the SUC, and it is thus less sensitive to the transmission distance or delay. A new synchronization system for two different RF’s performed well. We now have only one synthesizer as a master in the SPring-8 accelerator complex. Application of the tools and systems described in this paper is simple to other facilities.

REFERENCES


Figure 4: Spectra of 2856 MHz RF’s: (a) generated by the new method; (b) generated by a synthesizer.