RF Reference Line for KEKB

Kiyokazu EBIHARA, Masaaki SUETAKE, Kazunori AKAI, and Eizi EZURA
High Energy Accelerator Research Organization (KEK)
1-1, Oho, Tsukuba-shi, Ibaraki-ken 305-0801 Japan

Abstract

KEKB, which is an electron-positron double-ring collider, requires precise synchronization between the two rings. Phase accuracy required to the RF voltage is very stringent and a phase error must not exceed 1 deg over rings. A master oscillator is placed at the upstream position of the klystron gallery of the injector linac. The RF reference signal has a frequency of 508.887MHz and is transmitted through a coaxial cable to the central control room (CCR) of KEKB located at a distance of 750m. A ring oscillator for the KEKB rings is placed in the CCR and locked to the master oscillator. From the CCR the RF signal is sent to the local control room (LCR) in building D7 and there divided in two ways: one is a clockwise and the other a counter clockwise route along the ring, forming a double loop. The total cable length of a single loop is ~4km. The signal is sent through the cable to the next LCR and the phase between the LCRs is stabilized by a phase-locked loop.

In order to accomplish the required phase stability, we improved the control modules, which were used for the reference line in TRISTAN. After the improvement, we measured a phase variation between the two reference-line loops at the two LCRs. The result is that the phase in a half round of the ring varies within 1.3 deg and in a full round within 2.5 deg during a week.

1 Introduction

KEKB, an e^+-e^- double-ring collider for B-physics [1], was built in the TRISTAN tunnel, which has a circumference of 3km. One ring is the low-energy ring (LER) for positrons at 3.5GeV and the other the high-energy ring (HER) for electrons at 8GeV. Figure 1 shows a distribution of the RF stations for KEKB. The RF stations of HER are distributed at four buildings called D4, D5, D10 and D11. At present, six normal conducting cavities (ARES) [2] are set up at the D5 tunnel, four ARESs are being set up at the D4 tunnel, and four superconducting cavities (SCC) [3] are set up at the D11 tunnel. It is planned that, in near future, four SCCs and two ARESs will be installed in the tunnel of D10 and D4, respectively. The RF stations of LER are arranged in D7 and D8 and the ARES cavities are set up at each tunnel. Further two RF stations will be constructed at D1 and D2 for crab cavities [1]. In double-ring colliders such as KEKB, a phase error of one ring relative to the other gives rise to a displacement of the colliding point. The RF phase should, therefore, be controlled with an accuracy of 1 deg not to degrade the luminosity, even under extremely heavy beam loading imposed by the maximum beam current of 2.6A in LER and 1.1A in HER. To stabilize the RF phase, we have graded up the reference line used at TRISTAN [5] as follows.

In KEKB, we reuse most of the modules used in the RF system of TRISTAN. Because phase drifts are mainly due to a variation of the ambient temperature, we concentrated our efforts on the improvements of phase-temperature characteristic of the modules. To improve the characteristics of modules, we measured the phase-temperature characteristics of the control modules and components used in the RF system. The results showed that the modules that include ferrite or dielectric materials had larger phase-temperature coefficients. These modules have been improved to have a smaller phase change to the temperature change. We also measured the phase-temperature characteristic of the coaxial cables connecting modules and replaced the cables which had large coefficients with the phase-stabilized ones. We also concentrated our efforts on the improvements of the accuracy of measurement of the RF phase. Offsets and nonlinearity of the modules, which are also responsible for phase error, have been reduced.

2 RF Reference Line

The master oscillator generates the ring RF frequency (508.887MHz), which is phase-locked to the frequency of the injection linac (2856MHz). It is placed at the upstream position of the linac klystron gallery and the output is transmitted through the coaxial cable to the CCR of KEKB 750m apart.

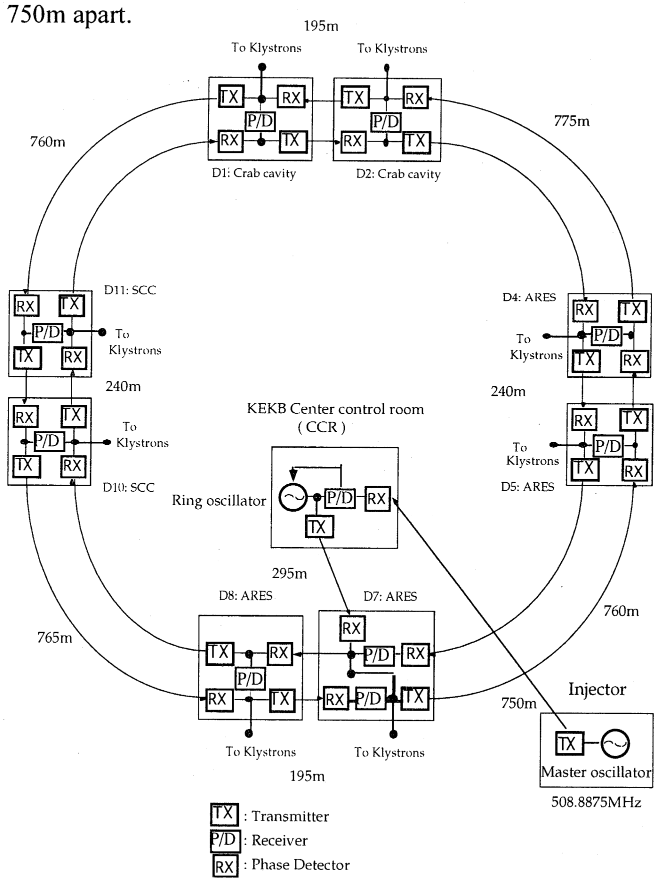

Fig.1 KEKB RF reference line

The oscillator was designed to keep phase fluctuations below 1 deg including drifts and jitters. The ring oscillator is placed at the CCR and locked to the master oscillator. The frequency of the ring oscillator is normally the same as that of the master, but, when unlocked, it can be changed in keeping phase continuity. One output of the oscillator is sent to the LCR of D7 and the other sent to the timing system of KEKB placed in the CCR. The signal received at D7 is divided in two ways: one is passing clockwise through D7-D8-D10-D11-D1-D2-D4-D5-D7 path and the other is travelling counterclockwise round the ring. The advantages of the double loops are: 1) we can always monitor the line status by measuring the phase difference between the two lines at each LCR; and (2) in case of having a trouble with one of the reference lines, the other can serve as a backup. To reduce the phase variation due to a change of the ambient temperature, we use the phase-stabilized cables (HF-H50-13 and -7) for the RF transmission to the next LCR through the tunnel. The temperature of the tunnel is always kept within $\pm 1°C$. There are two kinds of sections between the LCRs: one is long sections of 750~775m and the other is short sections of 195~240m. The cables are connected in cascade between the eight LCRs along the ring. In addition to using the phase-stabilized cables, we further reduce the phase fluctuations on the cables with the phase stabilization system described below.

3 Phase stabilization system

To stabilize the RF phase between the LCRs, we employ a phase stabilization system shown in Fig. 2, which was used in the TRISTAN [6]. The system contains the control modules that form a phaselock loop (PLL). Using a transmitter (TX) module, the signal is sent to the next LCR located at a long distance. The signal is received with a receiver (RX) module and divided in two ways: one is used as a reference signal there and the other is converted to its second subharmonic and returned through the same cable to the TX. The returned signal is then converted back to the original frequency. The phase error relative to the reference is always measured and fed back to the two phase shifters placed at the forward and backward line of the signal. Symmetric phase shifts due to the variation of temperature are corrected within a residual error of the feedback loop of 1%. However, asymmetric phase shifts between the forward and backward line are reduced to a half of the phase difference between the two lines. One possible source of the asymmetry is a slightly different control voltage vs. phase shift property of one phase shifter from that of the other. It was corrected to be linear within 0.2 deg using a digital linearizer described later. The reference line is connected in cascade with the stabilization units. Figure 3 shows a typical reference system at the LCR. The system is assembled on two control racks at each LCR: the unit for the counter-clockwise line is set up to the right rack and that for the clockwise set up to the left. The all LCRs in KEKB except for D7 have the same arrangement of the modules and components.

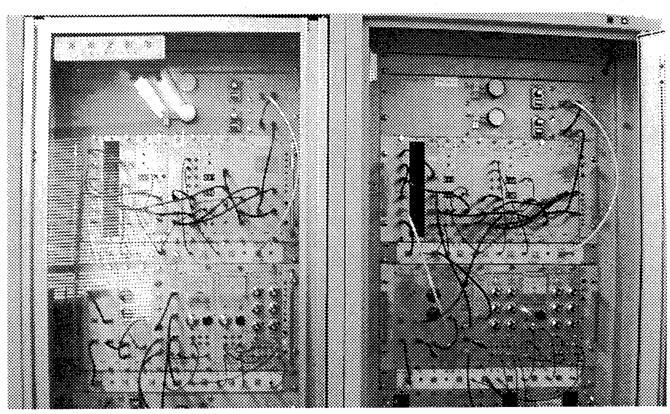

Fig. 3 Appearance of the reference line unit at the local control room.

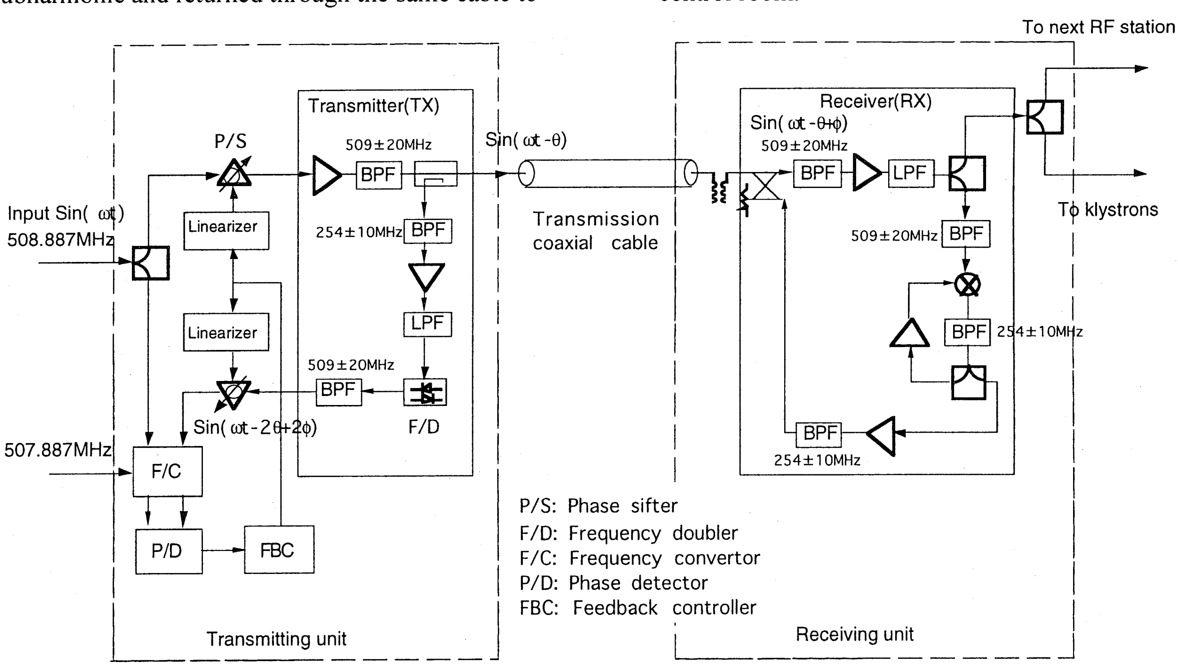

Fig. 2 Phase stabilization system

To obtain a better accuracy on the phase measurement in KEKB, we have improved the accuracy and the phase-temperature coefficient of the following modules used in the phase stabilization system.

Frequency converter; It is a down-converter from 508.887 MHz to 1MHz. Ferrite cores are formerly employed in inductors of a low-pass filter for eliminating harmonics of 1MHz. They have been replaced with air-core type inductors.

Phase detector; Using a signal generator of the direct-digital syntheseizer (DDS) type with two outputs, we precisely calibrated all the detectors. To improve the accuracy of the phase measurement, bandwidths of some detector were experimentally changed to 3kHz from 30kHz so that noise levels of the detector output were reduced to a quarter or less.

Phase shifter; Isolators with ferrites were inserted in the input and output line of the RF signal. As the isolators have plus phase-temperature coefficients, they partially compensate for the minus coefficient of the phase shifter.

Linearizer; Nonlinear response of the phase shifters to the control voltage has been corrected using a digital linearizer which has a resolution of ±0.1 deg in RF phase.

Coaxial cables; All cables used in the phase detection system and outside the feedback loop have been replaced with the phase-stabilized ones which have a stability of ~10ppm/°C.

4 Performance

The performance of the phase stabilization system was tested using a conventional cable (RG-213) of 100m which connected the TX to the RX module. The cable was placed inside the temperature controllable cabinet. Figure 4 shows the result of the phase response measurement, where the phase between the TX and RX modules was varied by changing the temperature of the cable. The insertion loss and VSWR of the cable were 16.2dB and 1.03 respectively. When the temperature was changed from 0°C to 32°C, the phase shift was ~125 deg. The returned phase in the figure means the output of the phase detector of the PLL and represents the residual error of the feedback loop. Because of a loop gain of 40dB, the error was very close to ~±0.6 deg when the phase shift in the cable was ±60 deg. It shows that the feedback loop works well. Meanwhile, the received phase in the figure is the one between the reference and the RX output and gives the phase error of the next station. In the test bench, we wound the cable of 100m into a bundle so that the RX module was placed close to the TX and consequently the received phase was precisely measured. As shown in Fig.4, the variation of the received phase was less than 0.4 deg when the phase shift in the cable was changed from –70 deg to +65 deg. In the KEKB reference line, we use a trombone-type phase shifter at the output of the TX and adjust the returned phase to around 0 deg to reduce the phase error of the feedback loop.

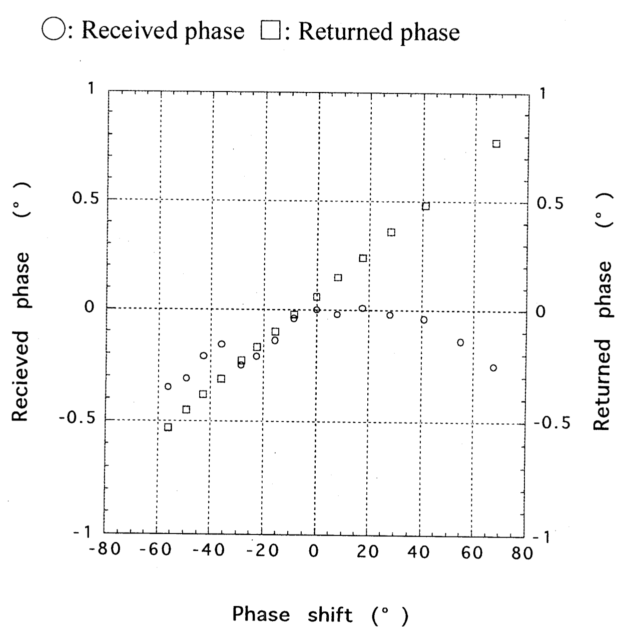

Fig. 4 Phase response property of the phase stabilization system .

At present, we are observing the phases of the clockwise relative to counterclockwise at the LCRs of D1 and D7. The phase in a half round of the ring measured at D1 varies within 1.3 deg and in a full round at D7 varies within 2.5 deg during a week. We are using the clockwise line at D8, D10 and D11 as the reference signal fed to the klystron and the cavity. While we are using the counterclockwise line at D5 and D4. The reference signal for D11, which is the farthest from D7, is sent via three cascaded stabilization systems, so the phase error of the D11 is estimated from the above measurement to be less than 1 deg.

Acknowledgement

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