RF REFERENCE DISTRIBUTION USING FIBRE-OPTIC LINKS FOR KEKB ACCELERATOR

T.Naito, K.Ebihara, M.Suetake, E.Ezura, KEK, Tsukuba, Japan

Abstract

The KEKB accelerator is a 3 km circumference double-ring collider which has six RF accelerating stations and will have two station for crab cavities. Each station is 800 m from the other. A stable RF phase reference is necessary for stable RF cavity operation. Coaxial cables with phase locked loops are used for the present system. A more stable RF phase reference is required for the crab cavity luminosity improvement project.

An RF phase distribution system using single-mode fiber-optic links has been tested for improvement of the phase stability. The system uses a phase stabilized optical fiber and a phase-locked loop circuit with a wavelength division multiplexed device (WDM). This paper describes the circuit and its performance.

1 INTRODUCTION

The KEKB accelerator has eight RF accelerating stations located along the collider ring tunnel. The total loop cable length is ~4 km. Stabilization of the RF phase reference is one of the key issues for a very large scale accelerator like KEKB. The acceleration frequency is 508.887 MHz with desired phase stability tolerance of 1 degree. The present KEKB RF phase reference system, an improved version of that used for TRISTAN[1][2] uses coaxial cables and a phase feedback system. For the project reported here, we tested an optical fiber link with phase feedback. Optical fiber links have many advantages compared to coaxial cables for long distance signal transmission: lower transmission losses, smaller electrical noise, reduced cable cost, etc. An optical fiber link with phase was employed at LEP[3]. The LEP system used ordinary fibers which have poor temperature stability. A newly developed phase-stabilized fiber (PSOF) fabricated by Sumitomo Electric Ind., Ltd, was used, without phase feedback, at TRISTAN[4][5]. The PSOF has excellent stability against temperature changes. Since its introduction at TRISTAN, the PSOF was used at LEP[6], Spring8[7], KEKB[8] and KEK-ATF[9] (also Fermilab and SLAC). All clock and trigger signals at KEKB are distributed using PSOF, but not the RF phase reference signal. The PSOF for KEKB was manufactured by Furukawa Electric Ind., Ltd. And is similar to that made by Sumitomo.

A phase feedback system is needed to compensate for residual errors in the propagation delay of the PSOF. A phase feedback system in an optical link is difficult because of forward and reverse signal mixing. The phase feedback system developed at LEP[3] used a signal chopping method in order to avoid mixing of forward and reverse signals. In order to avoid the complexity and difficulty associated with pulsed phase sampling, we use a wavelength division multiplexing device (WDM). WDM has high directivity and low signal loss. With WDM, we employ a bi-directional link in a single fiber with two wavelengths.

2 PHASE STABILIZED OPTICAL FIBER (PSOF)

An ordinary optical fiber has a 6 ppm/°C propagation delay temperature coefficient. In order to reduce the thermal expansion coefficient, PSOF is coated with liquid crystal polymer which has a negative thermal expansion coefficient. The resultant thermal expansion coefficient of PSOF is 0.4 ppm/°C in the range of -10 to 30 °C. Figure 1 shows the measured thermal dependence of the propagation delay of a sample PSOF. The slope of the thermal behavior changes sign over the temperature range

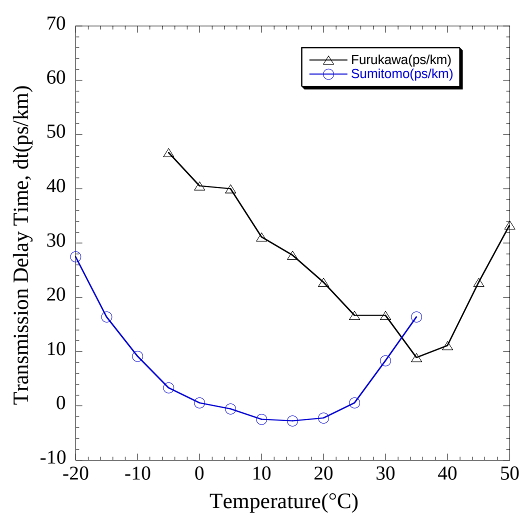

Fig. 1 Temperature dependence of the transmission delay time

of interest. It is difficult to keep a zero thermal coefficient over the entire range.

2 PHASE FEEDBACK

The schematic diagram of the phase feedback using PSOF and WDM is shown in Fig.2. The reference RF passes through the first phase shifter and is converted to a optical signal by the optical transmitter. The pair of optical links consists of a round trip optical signal transmission through PSOF and WDM. In one direction the wavelength of the optical signal is 1.3μm and in the other it is 1.5μm. Wavelength separation in each direction is done by the WDM. The returned rf signal passes through a second phase shifter and the phase detector detects the total phase change. The amplified phase deviation, with gain G, is applied to the control voltage of the phase shifters. If the phase shift of the both phase shifters, shown as θ, is the same, the phase change of the PSOF, shown as ϕ, is reduced to 1/G. In order to minimize the feedback error, each component has to have good stability. The characteristics of each component is

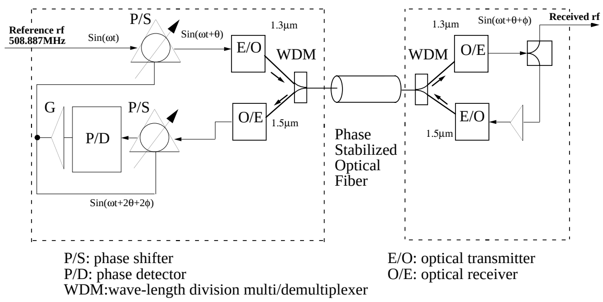

Fig.2 Schematic diagram of phase feedback

described below.

2.1 WDM

WDM is an optical coupler which has a wavelength selectivity. This device was developed for multiple data transmission in optical fiber communication networks. Multiple optical signals or bi-directional optical signals can be multiplexed/demutiplexed using this device. It is produced by several companies. The specification supplied by Showa Electric Wire & Cable Co., Ltd., used at the test, is sown in table1. The temperature stability of the WDM modules is less than 0.2° at the room temperature range, 26+/-2°C.

Table 1: Specification of WDM

	WD-SMF(SWCC)
Operation Wavelength	1.310μm/1.550μm
Band width	60nm
Insertion loss	<1.5dB
Isolation	>50dB
Directivity	>50dB

2.2 E/O, O/E

The distributed feedback laser transmitters and photo diode receivers are used for 1.3μm and the 1.5μm wavelength linear communication. The specifications of the modules are summarized in table 2. The modules are made by Lucent Technologies Inc..

The temperature stability of the modules is 0.1°/°C with 0.3~0.4° long term phase drift coming from two mechanisms, first from the temperature expansion of the fiber connecting the semiconductor and the connector (ordinarily optical fiber) and second from drift of the semiconductor current.

Table 2: Specifications of Transmitter/Receiver modules

Model #	**Wave-length**	**Optical Power**	**DC Photo Responsi-bility**	**Freq.**
Transmitter 3740A	1310nm +/-30nm	7mW		0.1 - 4GHz
3540A	1550nm +/-30nm	4mW		0.1 - 5GHz
Receiver 4518B	1.3/ 1.5μm		>0.7A/W	0.1 - 10GHz

2.3 Phase Detector

The 508.887MHz frequency signal is down converted to 1MHz by using a 507.887MHz local oscillator and a mixer. A comparator is used for detecting the phase of 1MHz signal. The calibration of the phase detector was carefully done using a direct digital synthesizer. The stability of the phase detector is 0.2° within the room temperature range, 26+/-2°C.

2.4 Phase Shifter

The electronically controlled phase shifter uses varactor diodes which have a non-linear control voltage response and a strong temperature dependence. The stability of the phase shifter used in the low level RF control of KEKB is under 1° at the room temperature range, 26+/-2°C. It has a drift of ~1°. We developed a temperature stabilized phase shifter. All of the components of the phase shifter are in a temperature controlled oven (44+/-1°C). The relative phase difference of the two phase shifters makes feedback error for our application. A pair of phase shifter is installed in one module to keep same temperature. The stability of the temperature stabilized phase shifter is 0.5° and 0.2° for the absolute phase change and the relative phase change, respectively, within the temperature range of 10°C to 30°C.

3 PERFORMANCE TEST

In order to check the feedback system, a performance test was done. The feedback phase measurement was done when the propagation delay of the transmission line was changed by a thermal extension of an ordinarily optical fiber in a test oven. Two hundred meters of ordinarily optical fiber was used as simulated transmission line. Figure 3 shows the phase shift of the received signal as a function of a phase shift of a pair of phase shifters. The measured points are shown as circles in the plot and the solid line shows the linear fit. We call “received phase” the phase of the received signal and “feedback phase” the phase shift of a pair of phase shifters. The phase shift of a pair of phase shifters correspond to the phase shift of the fiber expansion. The loop gain of the feedback was set to 100 and the measured loop gain was 106, in good agreement with the expected loop gain. The deviation from the fitted line was less than +/-0.1° which mainly comes from the room temperature change, 26+/-1° .

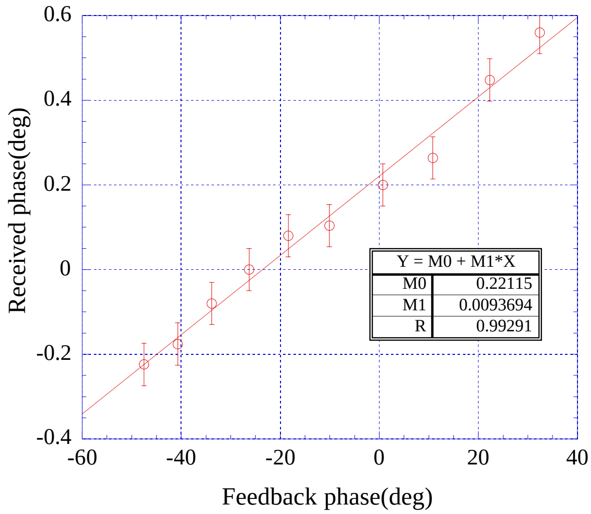

Fig3 Received phase as a function of Feedback phase

A performance test using an actual fiber cable was made. Six 800 m long PSOF fiber cablse were installed between local control rooms of KEKB. Phase stability was measured by the round trip signal transmission. The optical signal at the opposite side end is directly connected to the return signal. Table 3 shows the phase stability of the round trip signal, 2 times of round trip signal and 3 times round trip signal in one day. The phase change of the feedback phase and the received phase were 4.3° and 2.1° at the 4.8km signal transmission, respectively. The feedback gain was small compared to the previous test. The phase change was mainly from the temperature change of the control devices from changes of ambient temperature. Optical fibers in E/O, O/E were especially sensitive to the temperature change. This will be reduced by replacing the connecting fibers with PSOF. The feedback gain also depends on the signal modulation level of E/O. If the modulation is shallow, the demodulated RF signal of O/E has a high S/N ratio. We need to carefully adjust the amplitude level.

Table 3: Phase stability of the round trip signal transmission in one day

Cable length	**Feedback phase**	**Received phase**	**Temperature change in control room**
1.6km	1.1°	0.36°	3.0°C
3.2km	3.3°	1.5°	3.5°C
4.8km	4.3°	2.1°	3.5°C

4 CONCLUSION

The RF phase distribution using PSOF with feedback system was tested. The phase stability was 2.09° at 4.8km signal transmission. This value will be reduced by replacing the ordinarily fiber with PSOF and carefully control of the ambient temperature. This system will be used for the RF phase distribution for KEKB as an upgrade. This technology will also be extended for a large scale accelerator like the linear collider.

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6 REFERENCES

[1] H.Hayano et. al., “The RF reference line for TRISTAN", PAC'87, Washington, D.C., USA, Mar. 1987.
[2] K.Ebihara et. al., “RF reference line for KEKB", The 12th Symposium on Accelerator Science and Technology, Wako, Japan, Oct. 1999.
[3] E. Peschardt et. al., “Phase Compensated Fiber-optic Links for the LEP RF Refernce Distribution", PAC'89, Chicago, Mar. 1989.
[4] T.Kakuta et. al., “LCP coated fiber with zero thermal coeficient of transmission delay time", International Wire & Cable Symposium, 1987.
[5] S. Tanaka et. al., “Precise Timing Signal Transmission by a New Optical Fiber Cable", KEK Report 90-5, May 1990
[6] L. de Jonge et. al., “RF reference distribution for the LEP energy upgrade ", EPAC'94, London, Jul. 1994.
[7] H.Suzuki et. al., “Characteristics of RF Reference Signal Distribution for Spring8", The 9th Symposium on Accelerator Science and Technology, Tsukuba, Japan, Oct. 1993.
[8] T.Naito et. al., “Performance of the Timing System for KEKB", ICALEPCS'99, Trieste, Italy, Oct. 1999.
[9] T.Naito et. al., “Timing System of the ATF", ICALEPCS'97, Beijing, Nov. 1997.