ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO107

PERFORMANCE EVALUATION OF THE RF REFERENCE PHASE STABILIZATION SYSTEM ON FIBER-OPTICAL LINK FOR KEK e-/e+ INJECTOR LINAC

N. Liu[†,1], T. Miura[1,2], T. Matsumoto[1,2], F. Qiu[1,2], D. Arakawa[2], H. Katagiri[2], Y. Yano[2], S. Michizono[1,2], B.T. Du[1], [1]SOKENDAI, Kanagawa 240-0193, Japan, [2]KEK, Ibaraki 305-0801, Japan

Abstract

The KEK e-/e+ injector is the 600 m J-shaped LINAC, which has 8 RF sectors. Stabilization of the RF phase reference for long distance transmission is necessary for stable RF operation. In the present system, single-mode fiber-optical links without feedback control are used from sector 2 to 5. The long-term phase drift of the reference phase at sector 5 was observed for more than 10° over 7 days. For SuperKEKB injector LINAC, the phase stability requirement is estimated to be 0.2° rms corresponding to 195 fs at 2856 MHz including short-term jitter and long-term phase drift. A more stable RF phase reference is necessary for the improvement of the phase stability. An RF reference phase stabilization system using a pair of wavelength division multiplexing (WDM) devices and a variable optical delay line (VODL) is constructed for the evaluation of the system's performance. The temperature and humidity characteristics of the electric and optical components, in addition to the phase stabilized optical fiber (PSOF) with different wavelengths are measured. In this paper, the performance of the proposed phase stabilization system will be evaluated.

INTRODUCTION

The KEK e-/e+ injector LINAC comprises of 124.8 m long and 488.3 m long straight beam lines, which consist of 8 sectors (sector A-C and 1-5) [1]. The Master Oscillator (MO, 571 MHz) system generates a 2856 MHz reference signal, which is delivered to sector A-C, 1 by coaxial cables and to sector 2 to 5 by optical links. During the long-distance transmission, the RF reference phase drifts due to the effect of temperature and humidity fluctuations on the propagation medium (coaxial cables and optical fiber) and the electric/optical components, especially for the S-band signal. The phase stability of the RF reference will contribute to the beam arrival jitter and influence the beam quality accordingly. In this paper, we focus on the phase stabilization system of the optical fiber link.

The phase stability of the RF reference depends on the short-term RF jitter and the long-term phase drift. The RMS jitter of the RF reference transmitted signal was found to be 100-200 fs for each sector [2]. In addition, the long-term phase drift of the reference phase at sector 5 was observed to be more than 10° for 7 days by the phase monitoring system, as shown in Fig. 1.

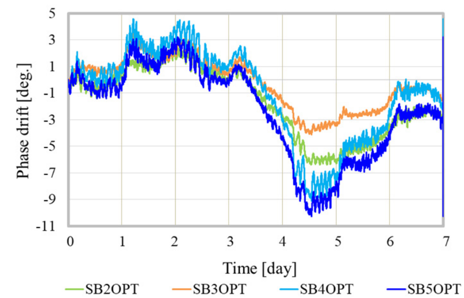

Figure 1: Phase drift of the optical link from sector 2-5 at injector LINAC.

In order to stabilize the RF reference phase, a phase stabilization system using a pair of wavelength division multiplexing (WDM) device and variable optical delay line (VODL) is implemented in the laboratory in order to evaluate the system's performance. In this paper, the temperature and humidity characteristics of the phase stabilized optical fiber (PSOF) are measured with different wavelengths (1310 nm, 1550 nm) and the performance of the phase stabilization system is evaluated.

OVERVIEW OF RF REFERENCE PHASE STABILIZATION SYSTEM

A similar feedback system to [3-5] is considered according to the current status of the injector LINAC. Figure 2 shows a schematic diagram of the proposed phase stabilization system for performance evaluation in the laboratory. The 2856 MHz electric RF signal is generated by a signal generator (SG) as the reference signal (REF). This signal is subsequently converted into an optical signal with a wavelength of 1310 nm (λ_1) using an optical transmitter (E/O). The optical signal is then transmitted by the single-mode phase-stabilized optical fiber (PSOF) and converted into an electrical signal (transmitted signal) by an optical receiver (O/E). In order to stabilize the transmitted signal, it is sent back using the same PSOF but at a different wavelength 1550 nm (λ_2) with a pair of WDM devices and another pair of E/O and O/E. All the S-band signals (REF, transmitted signal and returned signal) are down-converted to the intermediate frequency (IF, 14.28 MHz) by a local oscillator (LO, 2870 MHz). The phase difference (feedback phase) between the returned signal and REF is used for the feedback control. The transmitted signal is monitored in order to evaluate the performance of the feedback system.

† liuna@post.kek.jp

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO107

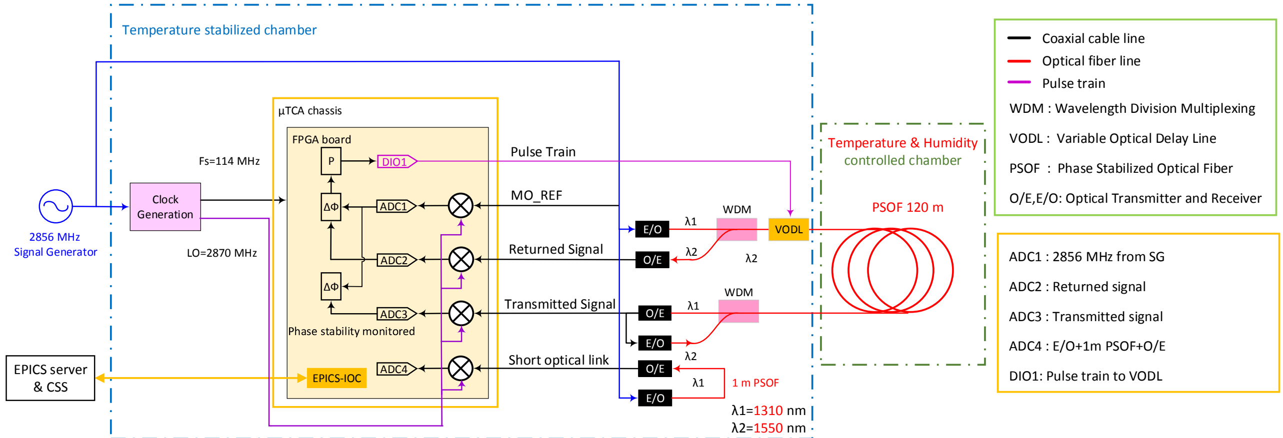

Figure 2: Schematic diagram of the phase stabilization system on the optical fiber for the performance evaluation.

Optical Transmitter and Receiver

The E/O (EOC-144) and O/E (OEC-1041), which operate at a wavelength of 1310 nm provided by TAMAGAWA Inc. are installed in sector 2-5 and the integral RMS jitter of a pair of E/O and O/E is 90 fs from 10 Hz to 10 MHz [6]. The specifications are also shown in Table 1. The same type of TAMAGAWA E/O and O/E with different wavelengths 1310 nm and 1550 nm are used in the test system. The electrical and optical components are necessary to keep inside the temperature-stabilized chamber.

Table 1: The Specification of EOC-144/OEC-1041

Items	EOC-144/OEC-1041
RF Input range	10 ~ 3000 MHz
Temperature range	+10 ~ +40 ºC
Temperature coefficient	-0.6154 ps/ºC
Humidity coefficient	-0.0382 ps/%RH

Variable Optical Delay Line

In order to compensate for the phase drift of the PSOF due to temperature and humidity fluctuations, a mechanical variable optical delay line (VODL) driven by a stepping motor is used. Figure 3 shows the feedback phase as a function of the pulse of the stepping motor. The feedback phase resolution of the VODL module is 2.15 mdeg/pulse and the phase range of the VODL module is more than 90°.

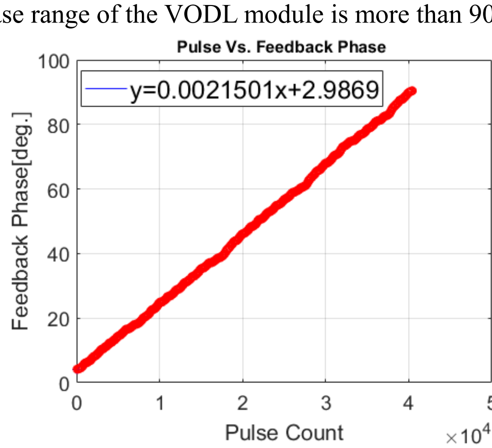

Figure 3: Measurement of the coefficient between the stepping motor pulse and the feedback phase.

PHASE-STABILIZED OPTICAL FIBER

The phase stabilized optical fiber is used to distribute the reference signal in the gallery of the injector LINAC. In the linac gallery, the temperature is stabilized to within ± 1 ℃ over a range of 24℃ ~ 27℃ and the humidity usually fluctuates between 10% RH and 50% RH from Sep. 2017 to Sep. 2018. The temperature and humidity characteristics of the PSOF will directly influence the phase stability. The PSOF was provided by Furukawa Inc. and the propagation delay temperature coefficient is 5 ps/km/℃ as provided in the specifications. It is important to note that, for the phase stabilization system, the wavelength of the transmitted signal and the returned signal should be different due to inherent requirements of the WDM technology. In order to study the effect of the wavelength difference on the feedback system, the temperature coefficient and humidity coefficient of both wavelengths (λ_1=1310 nm, λ_2=1550 nm) are measured using a network analyzer. The measurement system is explained in [6]. In order to guarantee the free extension of the PSOF, the fiber should be unbound. The fiber length is 120 m and this fiber will be used for the evaluation system.

Figure 4 shows the propagation delay temperature coefficient of the PSOF for different wavelengths. The temperature coefficient difference is 0.2 ps/km/℃. The distance from the MO station to sector 5 is 240 m long. Assuming the humidity is stable, the phase difference between the forward line (1310 nm) and the backward line (1550 nm) is less than 0.1 ps in the case of a temperature fluctuation of ±1 ℃. We started the humidity coefficient measurement from 30% RH at a stable temperature taking into consideration the control range of the humidity chamber. Figure 5 shows the transmission time delay difference of the PSOF from 30% RH to 50% RH, with the reference transmission time delay at 30% RH. The time delay difference between the two wavelengths depends on the different relative humidity values. Therefore, the humidity coefficient is difficult to estimate. The maximum difference is 5.38 ps/km at approximately 45% RH. If the humidity fluctuation is from 35% RH to 50% RH, careful attention should be paid to the wavelength difference. The performance of the phase sta-

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO107

bilization system is limited due to the wavelength difference of the forward and backward line in the phase stabilization system.

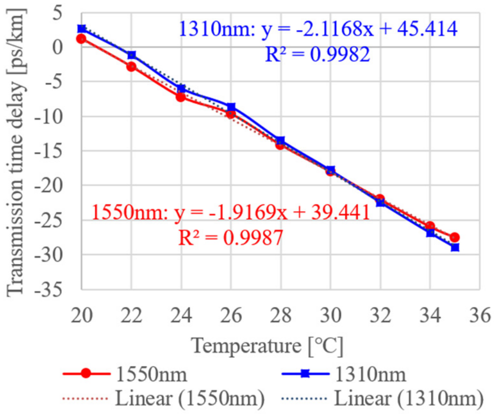

Figure 4: Transmission time delay temperature coefficient of PSOF.

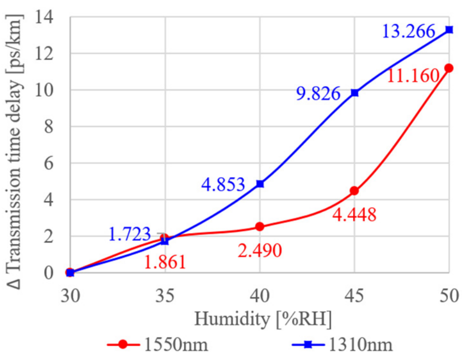

Figure 5: Transmission time delay difference of the PSOF from 30% RH to 50% RH.

FEEDBACK PERFORMANCE

In order to evaluate the performance of the phase stabilization system, a feedback test was performed in the laboratory. The same 120 m PSOF used for experimental measurement is used as the simulated transmission line. This PSOF is placed inside the temperature and humidity-controlled chamber (THC). All the feedback system including the VODL, WDM, E/O, and O/E are temperature stabilized in the chamber (TC). The temperature inside the THC was then decreased from 30 ℃ to 20 ℃ in 4 hours and the humidity was stabilized at 40% RH. The phase drift of the transmitted and returned signals depend on the temperature in the THC. Without feedback, the phase difference (feedback phase) between the returned signal and REF is 5.5°. Figure 6 shows the long-term phase stability of the returned signal with feedback control. It is observed that the feedback phase is compressed from 5.6° to 0.05° in the red solid box. However, some noise (in red dashed circle) appeared. To date, the origin of this noise in unknown and further study is necessary. Figure 7 shows the phase stability of the transmitted signal with feedback control. Although the feedback phase is controlled within 50 fs at 2856 MHz, the transmitted phase still depends on the temperature in the THC. Part of the residual phase drift of 0.25° might be caused by the wavelength difference of the PSOF.

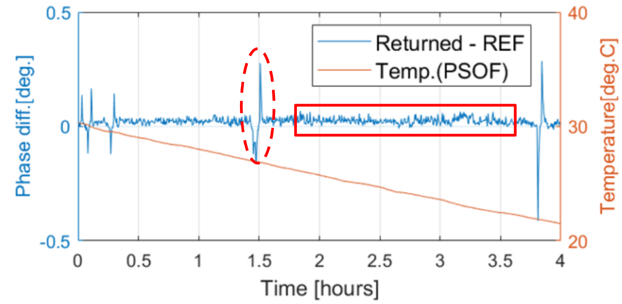

Figure 6: Long-term phase stability of the feedback phase with feedback.

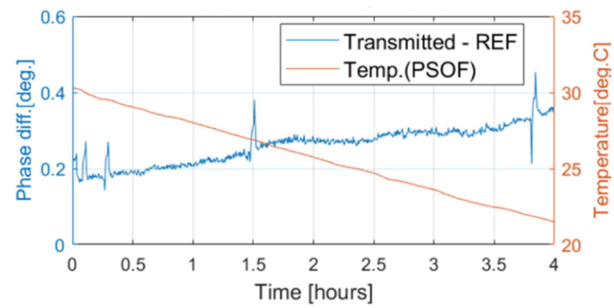

Figure 7: Phase stability of the transmitted signal.

CONCLUSION

The performance of the RF reference phase stabilization system was evaluated. The feedback phase was controlled within 50 fs for 120 m PSOF transmission. The phase drift of the transmitted signal depends on the temperature near the PSOF. This might be caused by the wavelength difference of the PSOF. A smaller wavelength difference between the forward line and backward line will be considered. The source of the noise in the feedback system will be investigated in the future in order to improve the phase stability.

REFERENCES

[1] M. Akemoto *et al.*, "The KEKB injector linac", *Prog. Theor. Exp. Phys.*, 03A002, 2013.

[2] N. Liu *et al.*, "Measurement of the RF Reference Phase Stability in the SuperKEKB Injector LINAC", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, BC, Canada, May 2018, paper THPML072, pp. 4815-4818, doi:10.18429/JACoW-IPAC2018-THPML073.

[3] T. Kobayashi *et al.*, "RF reference distribution system for J-PARC linac", *Nucl. Instr. Meth.*, vol. 585, pp. 12-19, 2008, doi:10.1016/j.nima.2007.11.006.

[4] T. Kobayashi *et al.*, "RF reference distribution system for the 400-MeV proton linac of the KEK/JAERI joint project", in *Proc. LINAC'02*, Gyeongju, Korea, Aug. 2002, paper MO463, pp. 187-189.

[5] T. Naito *et al.*, "Development of timing distribution system with femto-second stability", in *Proc. IPAC 2011*, San Sebastian, Spain, Sep. 2011, paper MOPC146, pp. 421-423.

[6] N. Liu *et al.*, "The consideration of RF phase reference distribution system for the injector LINAC of SuperKEKB", in *Proc. 14th Annual Meeting of the Japanese Society of accelerator (PASJ'17)*, Hokkaido, Japan, Aug. 2017, paper WEP065, pp. 1015-1018.