STABLE RF DISTRIBUTION SYSTEM FOR THE S-BAND LINAC

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Abstract

The phase stabilization of the RF distribution is key issue for the stable linac operation. An RF distribution system with femto-second stability has been developed for S-band linac using optic fiber links. The system uses a phase stabilized optical fiber (PSOF) and an active fiber length stabilization. The phase stability is 0.02 degree (20fs) for 6 hours observation. In this paper, we present the test results of the system stability and the evaluation of the existing RF reference line by using this system.

INTRODUCTION

The Accelerator Test Facility(ATF) [1] in KEK is a test accelerator for developing future accelerator technologies, especially focus on the International Linear collider(ILC). The ATF consists of a 1.3GeV S-band linac, a damping ring(DR) and an extraction line. The ATF2 [2] experiment to produce 37nm of the vertical beam size is in progress at the end of the extraction line. The stable operation of the S-band linac is a significant factor to supply the stable beam to the ATF2 beam line. The energy drift of the S-band linac comes from the phase drift of each klystron, which resulted the unstable beam condition in the DR. The reference signals of the klystrons are transferred using optical links and the phase stabilized optical fibers(PSOF). The PSOF has a low thermal expansion coefficient, 5ps/$°C$/km, comparing the normal fiber [3]. The length of the fiber is about 100m, however, there is no temperature control at the klystron gallery. The phase drift of the reference signal is not negligible even the PSOF is used.

The high accuracy reference signal is required for not only for the ATF linac, but also for future accelerators and experiments. In the case of ILC, the reference signal of the acceleration frequency(1.3GHz) needs to have 0.1 degree(0.2ps) of the stability over 30km long. The synchronization between the beam and the laser system of the pump probe experiment at energy recovery linac(ERL) requires less than 50fs stability.

We have been developed the active fiber length stabilization system [4]. Wavelength Division multiplexing(WDM) is used for the signal multiplexing and the signal isolation of the round trip signal in a single fiber. The fiber stretcher using piezo actuator compensates the fiber length. The phase stability depends on the temperature of the control circuit and the optical transmitter/receiver. The error of these components can not compensate by the feedback loop. We fabricated a double layer temperature control box to make the stable temperature, which has the temperature stability less than 0.02 $°C$. The phase stability achieved to 0.02degree(20fs) for S-band frequency by using the temperature control box.

This paper describes the system configuration and the evaluation of the phase stability of the existing linac reference line by using this system.

SYSTEM DESCRIPTION

The conceptual layout is shown in Figure 1. The phase at the receiving end, ϕ_1 , is expressed as $\phi_1 = \phi_0 + \phi$, where ϕ_0 is the input phase and ϕ is the phase delay in the transmission line. When the phase change, $\Delta\phi$, in the optical fiber is exist, the phase at the receiving end is expressed as,

$$\phi_1 = \phi_0 + \phi + \Delta\phi.$$

The round tripped signal goes through same optical fiber. The phase change, $2\Delta\phi$, can be detected at the sending end. When the fiber length feedback is applied to the fiber,

$$\phi_1 = \phi_0 + \phi + \Delta\phi - 1/2(2\Delta\phi) = \phi_0 + \phi.$$

The relation of the phase between the sending end and the receiving end can be kept at the same phase.

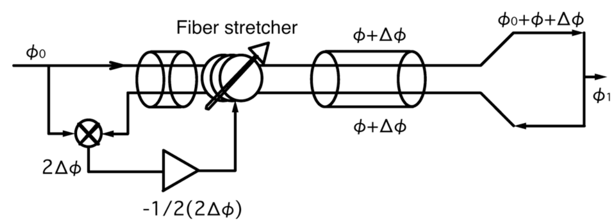

Figure 1: Conceptual layout of the fiber length stabilization.

The layout of S-band RF distribution system is shown in Figure 2. A pair of WDM is used for the signal multiplexing and diving. The RF signal is sent as an optical signal using a wavelength(1552.52nm). The transmitted optical signal is converted to the RF signal at the receiving end. The RF signal is converted to optical signal again using a different wavelength(1551.72nm). The round trip signal goes through same fiber. The phase of the round tripped RF signal is compared to the sending phase. The detected phase deviation is feed backed to the fiber stretcher(FST-001, General Photonics Co.) [5], which has 11ps of the control range. The piezo-driven fiber stretcher keeps the fiber length to constant.

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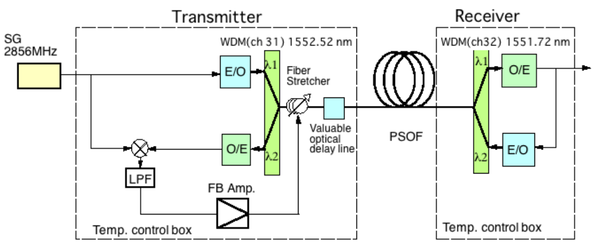

Figure 2: The layout of S-band RF distribution system. E/O:electrical/optical converter, O/E:optical/electrical converter, WDM: wavelength division multiplexing, PSOF: phase stabilized optical fiber.

An optical delay line is installed to adjust the fiber stretcher position. All of the components of the transmitter and the receiver are set in the temperature control box. The phase stability of these components exactly affects the stability of the feedback system. The devices are selected, which has low temperature coefficient. The cables of the RF signals are connected as shorter as possible.

TEMPARATURE CONTROL

Usually, only the temperature of the key component is stabilized using the peltier cooling unit. However, this system needs to stabilize the many components, E/O, O/E, WDM, mixer, coaxial cable, etc. The coaxial cables inside of the transmitter/receiver has a temperature coefficient, for example, SUCOFORM(SUHNER) has 100fs/$^\circ C$/m. It is not negligible to realize less than 20fs of the stability.

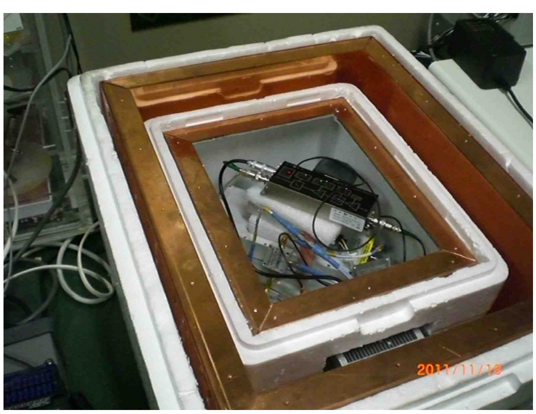

Figure 3: Picture of the fabricated double layer temperature control box.

We fabricated a double layer temperature control boxes for the transmitter/receiver. Two temperature control boxes are nested and each temperature control box has 80W peltier cooling device. The temperatures are controlled individually. The picture of the fabricated double layer temperature control box is shown in Figure 3. The outside of each box is made by insulator to isolate the temperature change. The inside of the each box is made by copper to keep the controlled temperature at whole area. The temperature stability is shown in Figure 4. The blue line shows the room temperature, which changes about 1$^\circ C$. The green line shows the first layer of the temperature control box, which keeps the temperature about 0.1$^\circ C$. The red line shows the second layer of the temperature control box, which realized less than 0.01$^\circ C$ of the stability over 1 hour. The achieved temperature stability depends on the room temperature. The system could keep the temperature stability less than 0.02$^\circ C$ for a long time measurement.

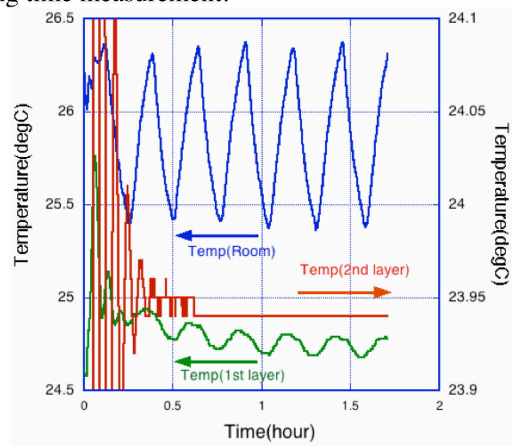

Figure 4: Temperature stability measurement of the temperature control box.

PHASE STABILITY MEASUREMENT

The phase stability of Figure 1 was measured at the test bench. The transmitter and receiver are connected using test fiber(20m long). The phase between the input of the transmitter and the output of the receiver was measured by the phase detector. The phase detector is set in the temperature control box to avoid the phase drift. The measured result is shown in Figure 5. The red line shows the time difference by the fiber length change, which is estimated from the control voltage of the fiber stretcher. The thermal expansion of the test fiber was 0.6ps for the room temperature change. The blue line shows the time difference with the fiber length feedback. The stability is achieved until less than 20fs.

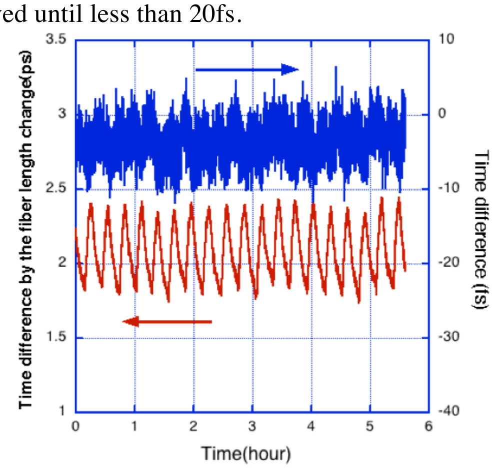

Figure 5: Feedback stability measurement.

EVALUATION OF THE EXISTING REFERENCE LINE

We measured the stability of the linac reference line by using this system. The measurement was done at KEKB linac. The reference line has about 300m long from the start section of the injector to the end [6]. The reference line is go through in the klystron gallery, which is usually temperature controlled. The PSOF is used for the reference signal transmission. The stability is estimated less than 2ps for the temperature coefficient of the PSOF. But we do not yet confirmed the stability. The stable reference line with fiber length feedback is connected in parallel and compared the time difference at the end.

The measurement result is shown in Figure 6 and Figure 7 for the air conditioner of the klystron gallery is on and off case, respectively. The blue line shows the time difference, the green line shows the temperature of the start section and the red line shows the temperature of the end section. In the case of Figure 6, the time difference is 1.2ps. The temperature of the end section was very stable and the time difference changed according to the temperature of the start section. In the case of Figure 7, the time difference is 7ps. The temperature of the end section changed 2 °C and the time difference changed according to the temperature of the end section. The time difference almost depends on the temperature change of the klystron gallery.

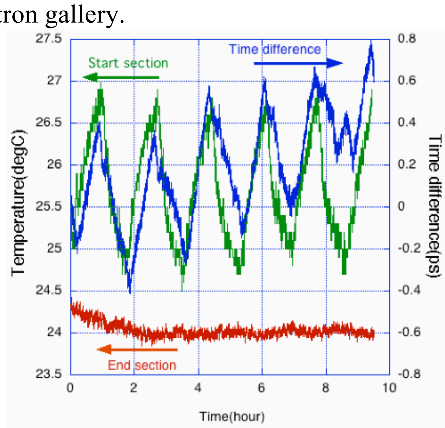

Figure 6: Reference line measurement at the condition of the air conditioner of the klystron gallery is on.

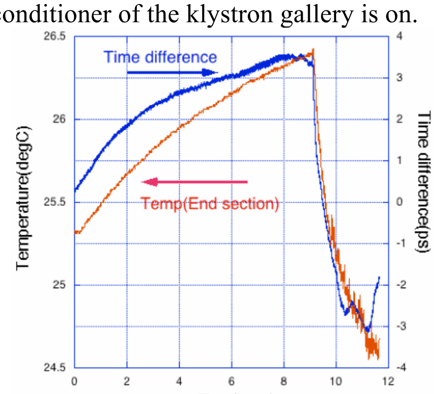

Figure 7: Reference line measurement at the condition of the air conditioner of the klystron gallery is off.

SUMMARY AND FUTURE PLAN

We developed a stable S-band RF distribution system. The stability is achieved until less than 20fs. The temperature stabilization is effective to realize the stability. The stability of the linac reference line was measured. The time difference was 1.2ps and 7ps for the air conditioner of the klystron gallery is on and off case, respectively. The temperature of the klystron gallery should keep less than 1 °C or the reference line needs to use the active feedback to keep less than 1ps of the time difference.

This system will be installed to the ATF S-band linac to improve the phase drift. This system also can be applied to the long distance signal transfer. The reference line of the ILC main linac(1.3GHz) will be designed by using this system.

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