PERFORMANCE OF CAVITY PHASE MONITOR AT J-PARC LINAC

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Abstract

The amplitude and the phase stabilities of the RF system play an important role on the operation of a high intensity proton accelerator due to the suppression of the beam loss. In the J-PARC linac, the accelerating amplitude and the phase stabilities in the RF systems are required to be less than 1% and 1 deg., respectively. The stabilities of ±0.2% in amplitude and ±0.2 deg. in phase had been achieved including the beam loading in a macro pulse. Additionally, the cavity phase monitors, which can measure the phase difference between any two cavities, were installed as the external monitor in the summer of 2011. The monitors have the three difference types, which are for the present 324-MHz RF system, for the 972-MHz RF system and for the combined system of 324-MHz RF and 972-MHz RF. The phase monitor for the 324-MHz RF has been in the operation since Dec. 2011 and the phase stability of ±0.3 deg. in the phase difference of the neighbor cavities by this monitor was almost achieved with the beam condition. We would like to introduce the phase monitor and show the phase stability and momentum stability at J-PARC

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is one of the highest intensity proton accelerator facilities in the world. It consists of a 400-MeV H^- linac[1], a 3-GeV rapid cycling synchrotron (RCS), and, a 50-GeV main ring synchrotron (MR)[2]. The accelerated beam is provided for the wide-ranging applications such as materials and life science, particle and hadron physics, and so on [1, 2].

The linac is composed of a 50-keV negative hydrogen ion source, a 3-MeV radio frequency quadrupole linac (RFQ, number of cavities: 1), 50-MeV drift tube linacs (DTLs,3), 191-MeV separated-type drift tube linacs (SDTLs,16), 400-MeV annular-coupled structure linacs (ACSs,21), and 3- and 191-MeV medium energy beam transports (MEBTs,3+2). In the present linac on phase I, the beam is accelerated to 181 MeV using the cavities from RFQ up to 15th SDTL, which are operated at the frequency of 324 MHz. The upgrade of the injection beam energy by installing ACS cavities with the resonant frequency of 972 MHz is scheduled in the summer of 2013.

The beam quality in a proton linac strongly depends on the accelerating fields inside each cavity. In the J-PARC linac, the momentum spread of the injection beam has to be within ±0.1% in $\Delta p/p$ due to the acceptance of RCS [2]. Then, the accelerating amplitude and the phase stabilities in the RF systems are required to be less than 1% and 1 deg., respectively. Therefore, the low level radio frequency (LLRF) system using a compact PCI (cPCI) with the digital feedback (FB) and feed-forward (FF) system In addition, the optical RF reference distribution system were utilized to satisfy of those requirements [3, 4].

The new phase detectors, which is called ”cavity phase monitor”, were installed to the 19’ LLRF racks in 2011. Those were used to measure and monitor the phase difference of the neighbor cavities. We would like to introduce this cavity phase monitor and show the performance of the phase stability in the J-PARC linac.

CAVITY PHASE MONITOR

Design

The cavity phase monitor, which is 482×88.1×450 mm, is used to measure the accelerating phase with high precision. The two RF pick-up signals from the neighbor cavities are inputted and the phase difference between both cavities is calibrated. The information about each amplitude and phase of two input signals, the ratio of two amplitudes, and the phase difference is displayed in the front panel of this monitor as shown in Fig.1 Those are outputted through two 40-pin flat cables and recorded on EPICS with the VME module. There are three types in those monitors by the frequency of two input signals, the dedicated 324 MHz system, the dedicated 972 MHz system, the combined system of 324 MHz and 972 MHz. Figure 2 shows the block diagrams of the cavity phase monitors.

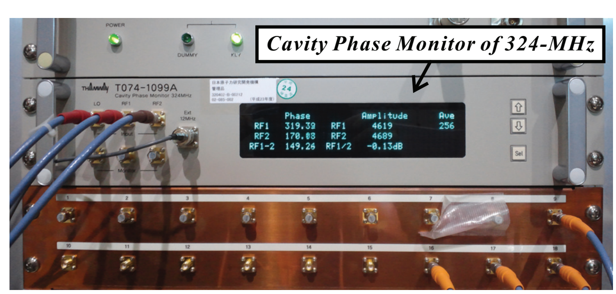

Figure 1: Photograph on the front of the cavity phase monitor.

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[1] The present energy of the linac is 181 MeV.
[2] The present energy of MR is 30 GeV.

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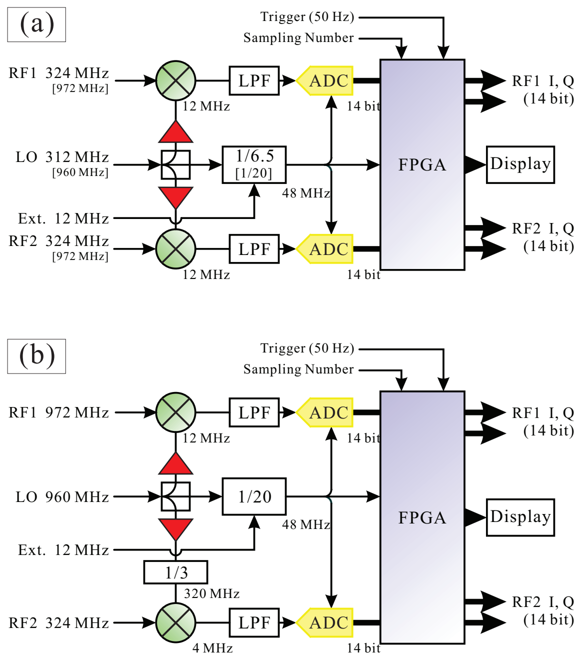

Figure 2: Block diagrams of the cavity phase monitors. (a) shows that for the dedicated 324-MHz [972-MHz] cavities. (b) represents that for the combined system of 324 MHz and 972 MHz.

A block diagram of a cavity phase monitor for two RF inputs with the same frequency, 324 MHz-324MHz and [972 MHz-972 MHz], is shown in Fig. 2 (a) [3]. The monitor systems are fundamentally the same as the those of each cPCI on the LLRF of the J-PARC linac. The two pick-up RF signals, 324 MHz [972 MHz] are inputted from front panel. The local oscillator (LO) signal of 312 MHz [960 MHz] from the output of the RF&CLK board on cPCI are also inputted as the reference signal. The LO signal is divided and the 48 MHz sampling frequency is generated. The each RF signal with 324 MHz [972 MHz] is down-converted to the intermediate frequency (IF) signal of 12 MHz by the mixer using the LO signal (312 MHz [960 MHz]). IF signal is measured with 14-bit ADC by the 48 MHz sampling and IQ components can be obtained. The amplitude and the phase against the input are transformed from IQ components and the amplitude ratio and the phase difference are calculated.

A block diagram of a cavity phase monitor for the combined system of 324 MHz and 972 MHz is shown in Fig. 2 (b). In the system of this cavity phase monitor, the frequency of LO is 960 MHz. As same as the cPCI system, the RF pick-up signal of 972 MHz are down-converted to 12-MHz IF signal and sampled by 48-MHz ADC. On the other hand, the inputted LO signal of 960 MHz is one-third divided to 320 MHz on the signal line of the 324-MHz pick-up. The pick-up signal is down-converted to the IF signal of 4 MHz by the mixer using the divided 320-MHz LO. Although IF signal is sampled by the 48-MHz sampling, the one-third data is actually used to obtain IQ components [4].

Specification of Stability

- The temperature characteristics at the output of the mixer are less than 0.1 deg./°C in phase and less than 0.1%/°C in amplitude.
- The ratio of harmonic signal level is under −60dB on the 12-MHz IF signal.
- The measurement deviations after the averaged data are less than ±0.2 degrees in phase and less than ±0.2% in amplitude.

Installation

The cavity phase monitors are basically used to measure and monitor the phase difference of the neighbor cavity.

Twenty two cavity phase monitor of the 324-MHz system were installed at the present 324 MHz stations. Exceptionally, the phase difference on the cavities of the 3-MeV MEBT1 line (buncher1, 2, and chopper1) and DTL1 are measured against the pick-up signals of RFQ. The cavity phase monitor on the chopper2 station is used for the phase tune and monitor between chopper1 and 2. The RFQ station do not have this monitor because of the front end of the RF cavity.

The monitor for the combines system of 324 MHz and 972 MHz will be used in the buncher3 station on the MEBT2 line, which is the frequency jumping point from 324 MHz to 972 MHz. The phase of the buncher3 will be compared with that of last 324 MHz cavity, SDTL16.

The cavity phase monitor of 972 MHz are installed in twenty four 972 MHz stations (buncher4, twnety one ACS, and debuncher1, 2) except for the buncher3 station. Those will be operated after the energy upgrade of linac under the shutdown in 2013.

PHASE STABILITY

The trend chart of the phase difference over 3rd Apr. to 12th Apr. was obtained with the cavity phase monitor installed on (a) DLT1, (b) DFTL3, (c) SDTL3, and (d) SDTL13 as shown in Fig. 3. The phase stability of ±0.3 deg. was almost achieved with the beam condition. As the results, the deviation of the phase stability of DTL was better than that of SDTL. It may caused that two cavities in the SDTL station are derived in parallel and the vector sum of two pick-up signals is controlled by one LLRF system.

MOMENTUM SPREAD

Figure 4 shows the trend chart of the momentum spread on the L3BT section over about 1 week. It was calculated using the time of flight method between the upstream

[3] The brackets in the figure and the text mean the specification for the 972 MHz system.

[4] It is actually the same as the 16-MHz sampling.

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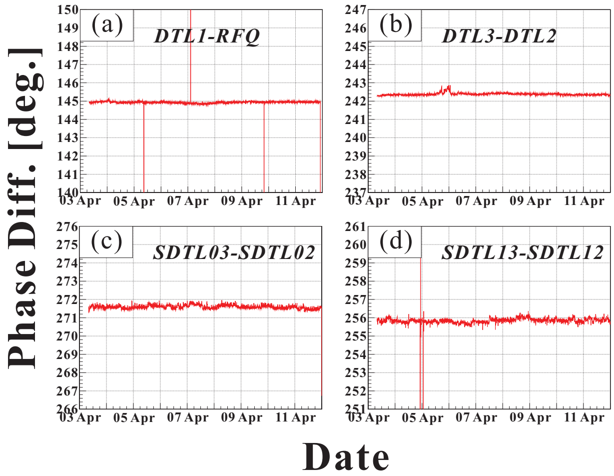

Figure 3: Trend Chart of the phase stability by the cavity phase monitors.

and the downstream FCTs (Fast Current Transformers) of the 324-MHz debuncher2 cavity. Here, the flight length is about 4.1 m and the kinematic energy of the beam is 181 MeV. The momentum spread was confirmed to be ±0.07% at the peak-to-peak value[5]. It satisfied the requirement from the momentum acceptance of RCS.

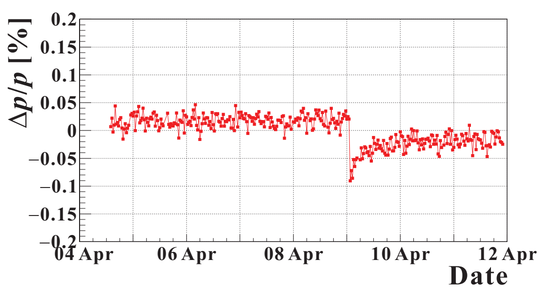

Figure 4: Trend chart of the momentum spread with FCTs. It was calculated from time of flight around the debuncher2 cavity.

TROUBLE OF PHASE SHIFT

The transceiver electrical/optical (E/O) module (RPN-471, REPIC Corp.) was broken on 24th May, 2013. It distributed a 12 MHz signal, a 50Hz trigger, and a type code signal to SDTL13, SDTL14, and SDTL15 stations. The broken module was replaced by a spare one and the beam operation was immediately restarted. However, the beam could not be delivered to the neutrino facility so that the interlock of the beam loss in the 3-50BT section was activated. In addition, the increment of the beam loss in RCS could be confirmed. It was the cause the relative phases in the SDTL13-15 sections were shifted, because the timing of the 12 MHz signal to the cPCI module was changed. The timing change is to prompt the discrete phase shift by about 13.8 degrees. Unfortunately, that phase shift caused by the timing change is predicted to be blinded in the measurement of a cPCI ADCs as shown in Fig. 5 (b). It is the reason that not only the phase of 324-MHz RF but also that of 48-MHz ADCs sampling were shifted. On the other hand, the phase shift could be confirmed with the cavity phase monitor to compare the phase of SDTL13 with that of SDTL12 (Fig. 5 (a)). The cavity phase monitor is clearly beneficial tool against the measurement of the relative phase.

[5] Here, temperature characteristic of FCT is not small. Its value was thought to be the over-estimation.

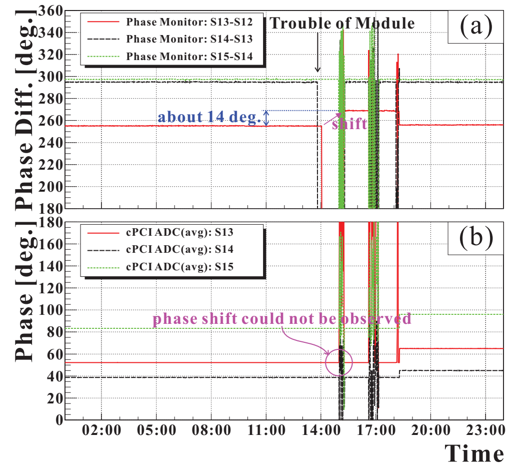

Figure 5: Recorded data for the SDTL13-15 sections in 24th May, 2013. The phase shift could not be seen with the measurement of (b) cPCI ADCs, but could be confirmed with that of (a) the cavity phase monitor.

SUMMARY

We installed the cavity phase monitors to measure the phase difference between any two cavities in the summer of 2011. The phase monitor for the 324-MHz RF has been operated since Dec. 2011. The phase stability of ±0.3 deg. by this monitor was almost achieved with the beam condition. In addition, it played an important role on the trouble of the phase shift. The cavity phase monitors for the 972-MHz cavity and the combined type between 324 MHz and 972 MHz will be operated after the energy upgrade of the J-PARC linac in 2013.

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