CHOPPER OPERATION FOR THE TANDEM SCRAPERS AT THE J-PARC LINAC

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Abstract

In the J-PARC linac, the energy upgrade to 400 MeV by the installation of Annular-ring Coupled Structure (ACS) cavities was successfully achieved in 2013. In the next stage, we schedule the current upgrade by improving the front-end in this summer. Then, the heat load of a scraper to irradiate the kicked beam by the RF deflector increases and its surface is predicted to be damaged. Therefore, we are preparing the tandem scrapers to suppress the heat load. The half of the kicked beam leads to a scraper and the residual is to the other. Its chopping operation will be achieved by rotating the phase of the RF deflector in the periodic cycles by the low-level RF (LLRF) system. We are preparing the device for the phase rotation and the MPS unit. This will be investigated this system on October and utilized from the user operation of 50 mA on April, 2015.

INTRODUCTION

In the J-PARC linac, the energy of the injection beam to RCS was upgraded from 181 MeV to 400 MeV by the installation of 25 additional ACS modules and 25 new 972-MHz RF systems in the shutdown of 2013 [1]. The 400-MeV acceleration was successfully achieved on January 17th, 2014 and the user operation with the 400 MeV injection energy started from February 17th [2, 3].

In the next step, the upgrade of the beam current is scheduled in order to achieve the design power of 1 MW by improving the front-end, an ion source, a RFQ and a 3 MeV Medium Energy Beam Transport (MEBT1), in the summer shutdown of 2014. The beam current after this upgrade is supposed to be 50 mA and it is three times than that of the present. One of grave concerns for this upgrade is the thermal durability of a scraper to stop the wasted beam for the increment of the heat load. The present scraper had a dent of 1 mm on the surface caused by merely the operation of 17 mA [4]. Therefore, we are preparing the tandem scrapers to reduce the damage as shown in Fig. 1. The half of the kicked beam leads to a scraper and the residual is to the other. Its chopping operation will be achieved by rotating the phase of the RF deflector in the periodic cycles by the LLRF system.

The beam of 50 mA is predicted to irradiate the beam pipe by the simulation of the beam dynamics [5]. Therefore, the chopper cavity with an expanded gap and beam pipes was developed and installed [6]. Additionally, since the beam halo is predicted to spread longitudinally to increase the current, the deflected field by the present RF source, 30 kW, does not have enough to dissipate the remaining beam [7].

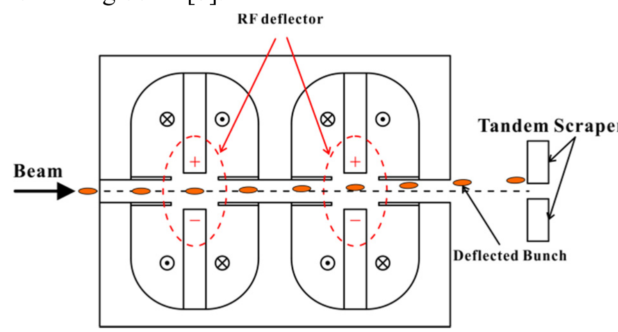

Figure 1: A RF deflector and tandem scrapers. The phase of the RF deflector is quickly rotated by 180 degrees to guide the wasted beam to each scraper.

DESIGN CONCEPT

We are preparing two methods of the phase rotation, by a macro-pulse with 25 pps and by an intermediate-pulse with 1.227 MHz.

The phase rotation in the period of macro-pulses will be realized using the IQ modulator in cPCI. When a phase-rotated trigger of $25/2 = 12.5$ Hz is inputted to the IO module of cPCI, the phase of the DAC output is rotated by the software. This method is convenient and hardly causes the problems. On the other hand, the less effect to suppress the transitional temperature's increment of scrapers is expected in comparison with that of the phase rotation by an intermediate-pulse.

For the phase rotation in the period of intermediate-pulses, two approaches are prepared. One is implemented through the introduction of hardware, which is called a "chopper controller", as shown in Fig. 2 (a). In this case, the chopper controller has two functions, producing the chopping RF with the comb-like structure and rotating the phase, when inputting the normal pulsed RF. The development of new chopper controller with the function to rotate the phase by an intermediate-pulse is required for us. Although there is a lack of the flexibility, this approach inhibits the possibilities of some problems like a rotated-timing error. The other's principle is shown in Fig.2 (b). It is achieved using the IQ modulator of cPCI as same as the rotation by a macro-pulse. In this approach, we do not have to develop hardware since we just improves the software of the LLRF system. Because the phase is rotated in cPCI and the chopping RF is produced in the chopper controller, we have to tune the timing in both instruments. We are slightly concerned this instrument's difference causes a critical trouble.

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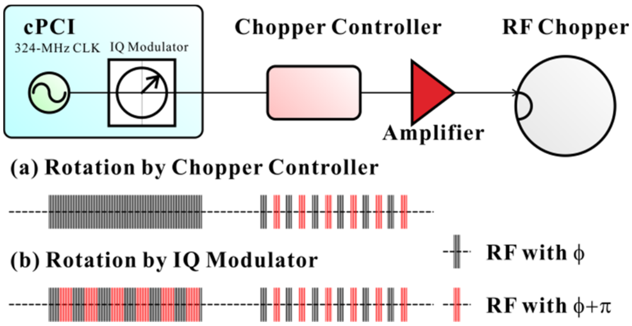

Figure 2: Principle of the phase rotation in the period of intermediate-pulses (a) using the chopper controller and (b) using the IQ modulator of cPCI.

PRESENT STATUS

Phase Rotation by an Intermediate-Pulse

A prototype of the new chopper controller, which was produced by CANDOX System Inc., was developed. The results of the phase rotation are shown in Fig. 3. Here, the frequency of the intermediate-pulse was change to 0.2 MHz and the duty was 50% easily to identify. It can be confirmed to rotate the phase and to have the same amplitudes in the normal phase and the rotated. However, the phase difference was obtained to 162 deg. but not just π. As the principle of the phase rotation, there are two lines with the phase difference in the chopper controller and the RF path is quickly switched. Therefore, the rotating phase is determined from the accuracy of the phase difference between two lines. The timing of the phase rotation is fixed to 200 nsec after RF-OFF. Therefore, we cannot use the intermediate-pulses with the narrower width than 200 nsec, which was sometimes utilized in the beam commissioning until the present.

We are developing another chopper controller improved for the accuracy of the phase rotation and its timing. This new chopper controller will be installed for the user operation of 50 mA from April, 2015.

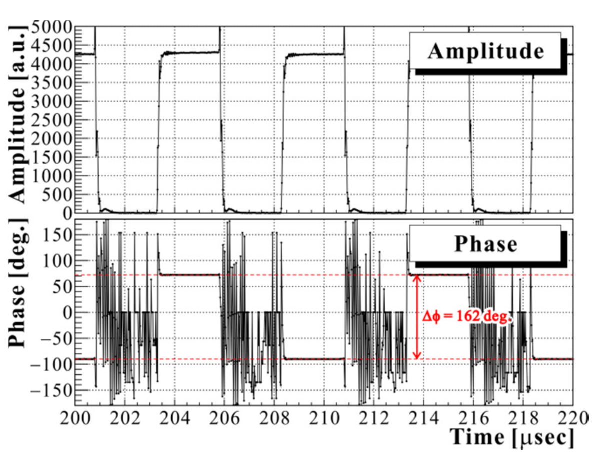

Figure 3: Result of the phase rotation using the chopper controller.

For the method using the IQ modulator in cPCI, the software is being improved in the digital feedback (FB) system. The working goes to the final stage and will be finished at the begging of this September. We will investigate the performance of this system using the beam on October.

Phase Rotation by a Macro-Pulse

The improvement of the software in cPCI will be prepared together with the method by an intermediate-pulse. This system will also be checked on October.

MPS Module

We developed and installed the phase-rotation monitor to stop the beam in the non-rotation of the phase. This module is basically the similar to the cavity phase monitor for a 324-MHz cavity in Fig. 4 [8]. The RF signals and the local oscillator (LO) signal of 312 MHz are inputted from the front panel. The RF signal with 324 MHz is down-converted to the intermediate frequency (IF) signal of 12 MHz by the mixers using the LO signal. The IF signal is measured with 14-bit ADCs by the 48-MHz sampling. Herewith, the IQ components can be obtained and the phase is calculated from IQ components. The sampling value can be visualized in the front panel. If the phase is not rotated, the MPS signal is generated and transmitted for the beam stop as an interlock of the scraper's protection. As may be necessary, the RF stop signal can also be used. Two channels of an input RF are prepared for the parallel system. The timing of the measurement can be set by the external trigger and the internal delay to detect the chopping RF signals. The three modes, the two phase-rotation methods and the mask deflecting the beam to one scraper, can remotely be selected. In addition, when the mode of the phase rotation by a macro-pulse is selected, the health of the phase-rotated trigger can be monitored and included as an interlock.

The accuracy of the phase measurement by this MPS module was obtained to less than 0.3 deg. without average. This is enough to judge the rotation or not. The response time after the events corresponding to MPS was less than 3 μsec.

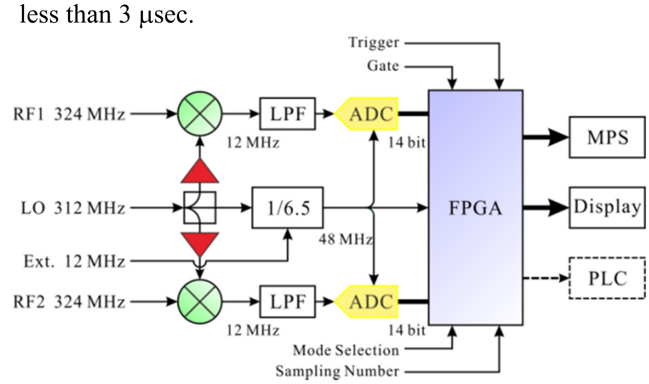

Figure 4: Schematic view of the phase-rotation monitor.

Other Monitoring System

In the J-PARC linac, the RF stabilities are controlled and monitored using cPCI to measure the IQ components of IF (12 MHz). This system is unfit to monitor the fast variation like this case with the structure of an intermediate-pulse. Therefore, we prepare another phase detector consisting of the double-balanced mixers (100 MHz in IF) and the exclusive-OR logic gates in order to change to the voltage signal from the phase (10 mV/deg.). This signals with the phase information can be detected by the DPO7354C oscilloscope produced by Tektronix Co. and the Wave Endless Recorder (WER) with 200 MS/s of Nichizou Electronic & Control Corp. This will enable the operators and the shift leader to confirm the operating status of the phase rotation at the Central Control Room (CCR).

SOLID-STATE AMPLIFIER

We prepared a new solid-state amplifier with the class-AB operation mode to satisfy the required RF power. Figure 5 shows the photograph of this amplifier produced by R&K Co. Ltd. The maximum output power in the frequency of 324-MHz is 120 kW in the pulse width of 600 μsec, the repetition of 50 pps, and the duty of 3%. As the feature, the band frequency is reasonably large (324±5 MHz) to supress the half-kicked beam in the transient pulse-rising and falling.

Figure 5: Photograph of a new solid-state amplifier with the output power of 120 kW.

The higher stabilities are required to the RF system of the chopper station including an amplifier, because the digital FB system cannot be used for the extremely-rapid cycles of RF-ON and OFF (1.227 MHz). In the both conditions of the pulse period and the long term, the stabilities were about ±3% in amplitude and less than ±1 deg. in phase. The rising and falling times were obtained to 16.0 nsec in 10-90% and 15.5 nsec in 90-10%, respectively. The rising time of a cavity with Q_L for a rectangular RF are ideally expressed by:

$$A(t) = A \times \exp(-\frac{\omega}{2Q_L}(t - t_0)) .$$

Here, A, t_0, and ω indicate an amplitude of RF, time of RF-ON, an angular frequency, respectively. When the frequency and the rising are assumed to $f = 2\pi\omega = 324$ MHz and $t_{10-90\%} = 16.0$ nsec, the calculated Q_L value is estimated to 7.4. Because this value is sufficiently-smaller than the preliminary results of the new chopper cavity, $Q_L = 11.6$, the property of this amplifier against the transient time is enough.

SUMMARY

In the J-PARC linac, the upgrade of the front-end is scheduled by increasing the beam current in order to achieve the design power of 1 MW. Then, the heat load increases on the surface of the scraper. Therefore, we are preparing the tandem scrapers to suppress the damage. The half of the kicked beam leads to a scraper and the residual is to the other. The chopping operation will be achieved by rotating the phase of the RF deflector in the periodic cycle at the LLRF system. We are preparing two methods for the phase rotation, by a macro-pulse and by an intermediate-pulse. The hardware so-called "chopper controllers" and the software in the LLRF system have been developed and will be installed until March 2015. In addition, the MPS system and other hardware were prepared and those performances were confirmed. We will use and study a part of this system in the beam commissioning of this October and utilize this chopping operation in the user operation of 50 mA from April, 2015.

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