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LOW LEVEL RF SYSTEMS FOR J-PARC LINAC 50-mA OPERATION

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Abstract

In the summer of 2014, lots of improvements were carried out at the J-PARC proton linac, including the ion source, the Radio Frequency Quadrupole linac (RFQ), and the medium-energy beam-transport line from the RFQ to the Drift Tube Linac (DTL) called as MEBT1. Firstly, the output beam current of the ion source was upgraded from 30 to 50 mA. Then the former 30-mA RFQ with two RF power input ports was also replaced by a newly developed 50-mA RFQ with one input port. Furthermore for the MEBT1, a new chopper cavity was developed to replace the former one, and the RF power of the solid state amplifiers for the RF cavities at the MEBT1 were upgraded; from 10 to 30 kW for both of the Buncher-1 and Buncher-2 cavities, and from 30 to 120 kW for the chopper cavity. Finally, the old scraper used as chopped-beam dump after the chopper cavity was also replaced by a new dump system using two scrapers; A new function of separating the chopped beam automatically to the two scrapers was developed by modifying the FPAG control program in the low level control systems. After those improvements, in the September 2014 the J-PARC linac was successfully upgraded for 50-mA beam operation. The details of the improvements, especially for the low level RF systems, will be reported in this paper.

INTRODUCTION

The 400-MeV proton linear accelerator at the Japan Proton Accelerator Research Complex (J-PARC) consists of 324-MHz low-β and 972-MHz high-β accelerator sections, and the J-PARC linac is operated at a repetition rate of 25 Hz with a beam pulse width of 500 µs. From October 2006 to May 2013, only the 324-MHz low-β accelerator section was in operation with beam energy of 181 MeV. In the summer of 2013, the J-PARC linac was upgraded by installing the 972-MHz high-β accelerator section, and the proton beam was successfully accelerated to 400 MeV in January 2014. Then in the summer of 2014, the upgrade of the front end of the J-PARC linac, including the ion source, RFQ, and MEBT1, were successfully carried out for the 50-mA beam operation. An outline of the RF systems and RF cavities of the upgraded J-PARC 400-MeV linac is given in Fig. 1. In the 324-MHz low-β section, there are 23 RF stations, including one RFQ, two bunchers, one chopper, three DTLs (Drift Tube Linacs), and 16 SDTLs (Separated DTLs). In the 972-MHz high-β section, there are 25 RF stations. At each station, there is one ACS (Annular Coupled Structure) cavity. Among the 25 ACS cavities, there are 2 bunchers, 21 acceleration cavities, and 2 debunchers. Therefore, for the 400-MeV J-PARC linac, there are 48 RF stations and 64 cavities in total. The length of the J-PARC linac is approximately 300 m.

UPGRADED RFQ RF SYSTEM

In the summer of 2014, the RFQ was upgraded for the 50-mA beam operation. In the former 30-mA RFQ, called as RFQ-I, there were two RF power input ports. The RF power from the klystron was divided by a high-power hybrid divider, and forwarded to the two input ports of the RFQ-I through two waveguide systems. The RFQ-I was replaced by a newly developed 50-mA RFQ, called as RFQ-III. For the RFQ-III, there is only one input port. Thus, the hybrid divider in the waveguide systems will not be used, and it was removed in the summer of 2014 for the upgraded RFQ RF system, as shown in Fig. 2. The RF power from the klystron will be directly forwarded to the RFQ cavity.

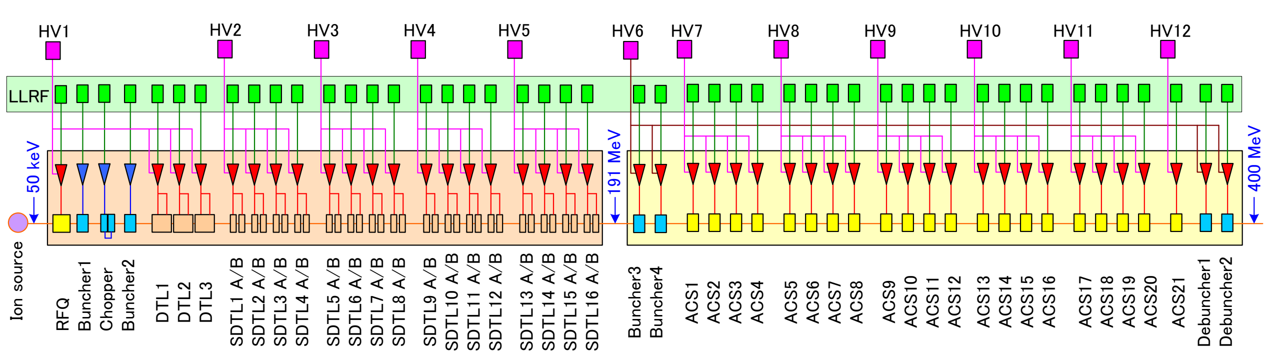

Figure 1: Outline of RF systems and RF cavities of the upgraded J-PARC 400-MeV linac.

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For the new RFQ-III, there are two directional couplers near the RFQ cavity in the input waveguide, which are used for detecting the input and reflection power of the RFQ cavity. Besides, there are 23 signal pickups in the cavity, as shown in Fig. 3. Two of them are used in the feedback control system, which are carried out by an FPGA (Field-Programmable Gate Array)-based digital feedback system installed in a compact PCI (cPCI) [1-4]. Another pickup is used for the phase monitor system. The other 20 pickups are used for field monitor system. After carrying out all the necessary LLRF setting and calibration, the RFQ-III was successfully applied to the operation of the J-PARC linac.

Figure 2: Waveguide system for the upgraded RFQ with one input port.

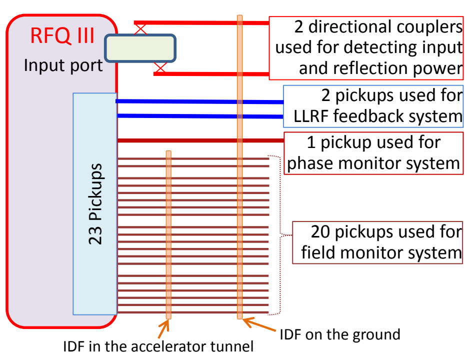

Figure 3: Directional couplers and signal pickups for the upgraded RFQ RF system.

UPGRADE OF RF AMPLIFIERS FOR MEBT1 RF CAVITIES

The upgrade for the MEBT1 was also successfully carried out in the summer of 2014. A new chopper cavity was developed to replace the former one. And for the RF systems of the MEBT1, the solid state amplifiers were upgraded with RF power from 10 to 30 kW for both of the Buncher-1 and Buncher-2 cavities, and from 30 to 120 kW for the chopper cavity. Figure 4 shows the 30 kW amplifier made by the NEC company for the Buncher-1 cavity. Figure 5 shows the 30 kW amplifier made by the TOMOCO company for the Buncher-2 cavity. And Figure 6 shows the 120 kW amplifier made by the R&K company for the chopper cavity. Now, all of these amplifiers are working very well. After beam study for the upgraded J-PARC linac, the output power of amplifiers for the Buncher-1, Buncher-2, and chopper cavities, are usually set as 8.1, 8.0, and 108 kW, respectively, for the 30-mA beam operation; or 8.7, 11.5, and 112 kW, respectively, for the 50-mA beam operation.

Figure 4: NEC 30 kW amplifier for the Buncher-1 cavity.

Figure 5: TOMOCO 30 kW amplifier for the Buncher-2 cavity.

Figure 6: R&K 120 kW amplifier for the chopper cavity.

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FPGA PROGRAM UPGRADE FOR NEW BEAM-CHOPPING SYSTEM

For the beam-chopping system at the MEBT1 before the summer of 2014, only one scraper was used as a chopped-beam dump after the chopper cavity. However, with the proton beam current increasing from 30 to 50 mA, and the chopped-beam power will be over the limitation of the scraper. Thus in the summer of 2014, two scrapers were installed after the chopper. And a function of separating the chopped beam automatically to the two scrapers was realized by using FPGA program in the LLRF control systems. Figure 7 shows the schematic diagram of one chopper with two scrapers at the J-PARC linac. In this system, a way of separating beam by intermediate-pulse of chopping signal is used.

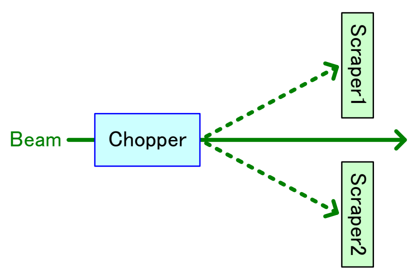

Figure 7: Schematic diagram of one chopper with two scrapers at the J-PARC linac.

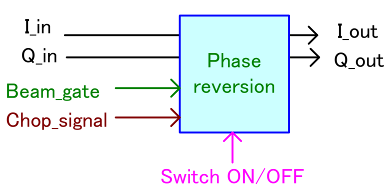

Figure 8: Phase-reversion function block inserted in the FPGA output circuits.

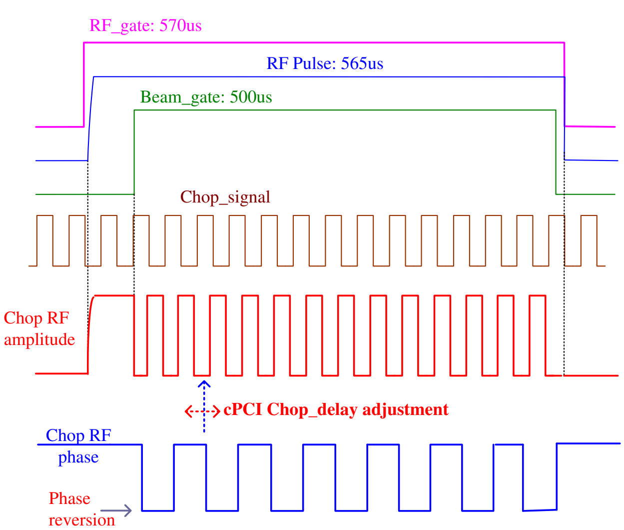

Figure 9: Schematic view of timing signals for the chopper station and output RF amplitude and phase for the chopper cavity.

In order to realize the function of separating beam, a phase-reversion function block is inserted in the FPGA output circuits for the FPGA program as shown in Fig. 8. In Fig. 8, for the phase-reversion function block, there are two input timing signals, "Beam_gate" and "Chop_signal". By detecting these two signals in the FPGA, the output RF phase will be reversed and the beam will be separated to the two scrapers by the intermediate-pulse of chopping signal. Furthermore, a switch set by the touch panel (TP) of the PLC (Programmable Logic Controller) of the LLRF control system is available for turning this function ON or OFF.

Figure 9 shows a schematic view of timing signals for the chopper station and output RF amplitude and phase for the chopper cavity. In the FPGA program, the phase reversion of the I and Q output signals is carried out in real time tracking the input signals including the chopping signal. And the RF phase reversion can be easily taken out by using $I_{\_out}$=- $I_{\_in}$, and $Q_{\_out}$=-$Q_{\_in}$. Thus, the beam will be chopped to a revered direction so that the beam is separated to the two scrapers by intermediate-pulse of chopping signal. Of course, we need to adjust the chopping-signal delay once before applying this system to the beam operation in order to assure that the timing of the phase reversion is carried out at the bottom of the RF amplitude. Finally, this control system had been applied to the practical 50-mA beam operation successfully, and it worked very well.

CONCLUSION

The front end of the J-PARC linac had been successfully upgraded by applying a 50-mA ion source, a 50-mA RFQ, a new chopper cavity, three upgraded RF amplifiers for the MEBT1 cavities, and two scrapers as chopped-beam dump. After these improvements, the J-PARC linac was successfully upgraded for the 50-mA beam operation in the September 2014.

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