PULSE-BY-PULSE SWITCHING OF BEAM LOADING COMPENSATION IN J-PARC LINAC RF CONTROL

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Abstract

For the J-PARC linac low level RF system, a new function that switches the feed-forward control parameters in every pulse was installed into the digital accelerating-field control system, in order to compensate beam-loading change by pulses in the operation of 25-Hz repetition.

The linac provides a 50-mA peak current proton beam to a 3-GeV rapid-cycling synchrotron (RCS). Then the RCS distributes the 3-GeV beam into a following 50-GeV synchrotron (main ring, MR) and the Materials and Life Science Facility (MLF), which is one of the experimental facilities in the J-PARC. The 500-us long macro pulses from the ion source of the linac should be chopped into medium pulses for injection into the RCS. The duty (width or repetition) of the medium pulse depends on which facility the RCS provides the beam to the MR or MLF. Therefore the beam loading compensation needs to be corrected for the change of the medium pulse duty in the 25-Hz operation.

INTRODUCTION

J-PARC will be one of the highest intensity proton accelerators, which consists of a 181 or 400-MeV Linac, a 3-GeV rapid-cycling synchrotron (RCS) and a 50-GeV synchrotron (main ring, MR) [1]. The beam is applied to several experimental facilities, for example, the Materials and Life Science Facility (MLF), the Hadron Physics Facility and the Neutrino Facility (See Fig. 1). The MLF is aimed at promoting materials science and life science using the world highest intensity pulsed neutron and muon beams which are produced using 3-GeV protons with a current of 333micro-amps and a repetition rate of 25 Hz.

The beam commissioning has progressed steadily, since the linac beam commissioning was started in October 2006. Then the first neutron production was succeeded at the MLF, and in the MR the 3-GeV beam was captured by RF and extracted to the beam dump after 1000 turns in this year. Now more detail beam sturdy is in progress.

As described in above, the RCS has to distribute the beam to the MLF and the MR. This switching of the beam destination (MLF or MR) influences the beam intensity of the linac. Therefore the parameters of the beam-loading compensation need to be switched due to the destination of the beam in the 25-Hz pulse operation. Accordingly, a new function that switches the feed-forward control parameters in every pulse was installed into the digital accelerating-field control system.

For high quality and high intensity beam acceleration,

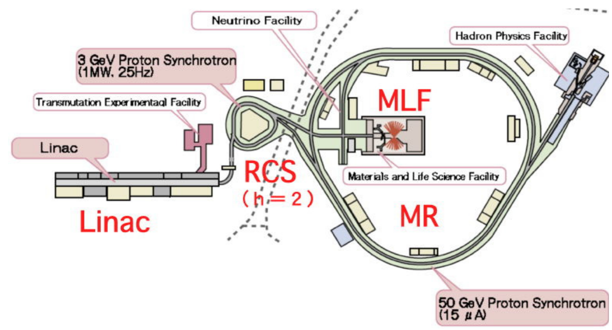

Figure 1: Layout of J-PARC accelerator.

the stability of the accelerating field is one of the most important issue. Because the momentum spread (Δp/p) of the RCS injection beam is required to be within 0.1%, the accelerating field error of the linac must maintained within ±1% in amplitude and ±1 degree in phase. To realize this stability, a digital feedback (FB) control is used in the low level RF (LLRF) control system, and a feed-forward (FF) technique is combined with the FB control for the beam loading compensation [2]. In the 181-MeV acceleration of the linac, the 24 LLRF systems are operated in a frequency of 324 MHz and the stability of ±0.2% in amplitude and ±0.2 degree in phase is achieved including the beam loading [3]. This RF stability makes high reproducibility of the injection beam and then contributes to the steady commissioning progress of the J-PARC.

BEAM STRUCTURE AND RF SYSTEM

The beam structure of the J-PARC linac is shown in Fig. 2. Maximum peak current will be 50 mA. Macro-pulses of 500-μs widths are accelerated in 25-Hz repetition. The macro-pulse is chopped by a RF-chopper into medium pulses as synchronized with the RCS RF

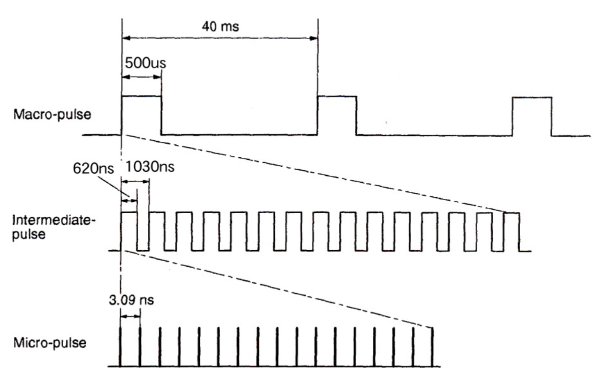

Figure 2: Beam Structure of the J-PARC linac.

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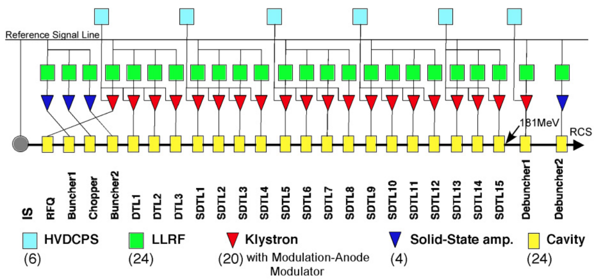

Figure 3: Overview of the J-PARC linac RF system.

frequency of about 1 MHz. In the linac commissioning the macro-pulse beam is 50-μs width and 30-mA peak current.

The harmonic number of the RCS is 2 (h = 2). The medium pulses shown in the Fig. 2 correspond to two-bunch (full bucket) acceleration in the RCS. In this case, the beam is distributed to the MLF. On the other hand, when the beam is distributed to the MR, the RCS operation changes to the one-bunch acceleration. In the case of the one-bunch acceleration, the train of the medium pulses of the linac is alternative; the macro pulse is chopped in about 500 kHz.

The overview of the J-PARC linac RF system and cavities is shown in Fig. 3. There are totally 24 cavity units including bunchers/debunchers, and the 24 LLRF systems control the each cavity field. An accelerating frequency is 324 MHz, and the RF pulse width is 650 μs. Twenty 324-MHz klystrons are used for the 181-MeV acceleration. One DC high-voltage power supply drives four klystrions.

The RF chopper is located between two bunchers in the medium energy beam transport line (MEBT). It is driven by a 30-kW solid-state amplifier and it chops the macro pulse beam into the medium pulse beam [4]. The LLRF for the chopper drive generates the chopped RF pulse as synchronizing with the RCS injection RF signal, which is received from the RCS through an optical link. This chopping frequency (1 MHz or 500 kHz) depends on the beam destination (the MLF or the MR). Accordingly, the beam loading changes twice when the beam is distributed to the MLF.

FB CONTROL SYSTEM AND BEAM LOADING COMPENSATION

For stabilization of cavity field, a digital feedback (FB) control system, which acts on a cPCI crate system, is applied. The FB control is programmed on a FPGA as shown in Fig. 4. The cavity filed monitor signal (324 MHz) is down-converted into a 12-MHz IF signal by a 312-MHz LO; The 312-MHz optical signal is received by an O/E in the cPCI as the phase reference. The I and Q components of the field are obtained by sampling the IF signal in 48 MHz with 14-bit ADC on the FPGA. The I/Q

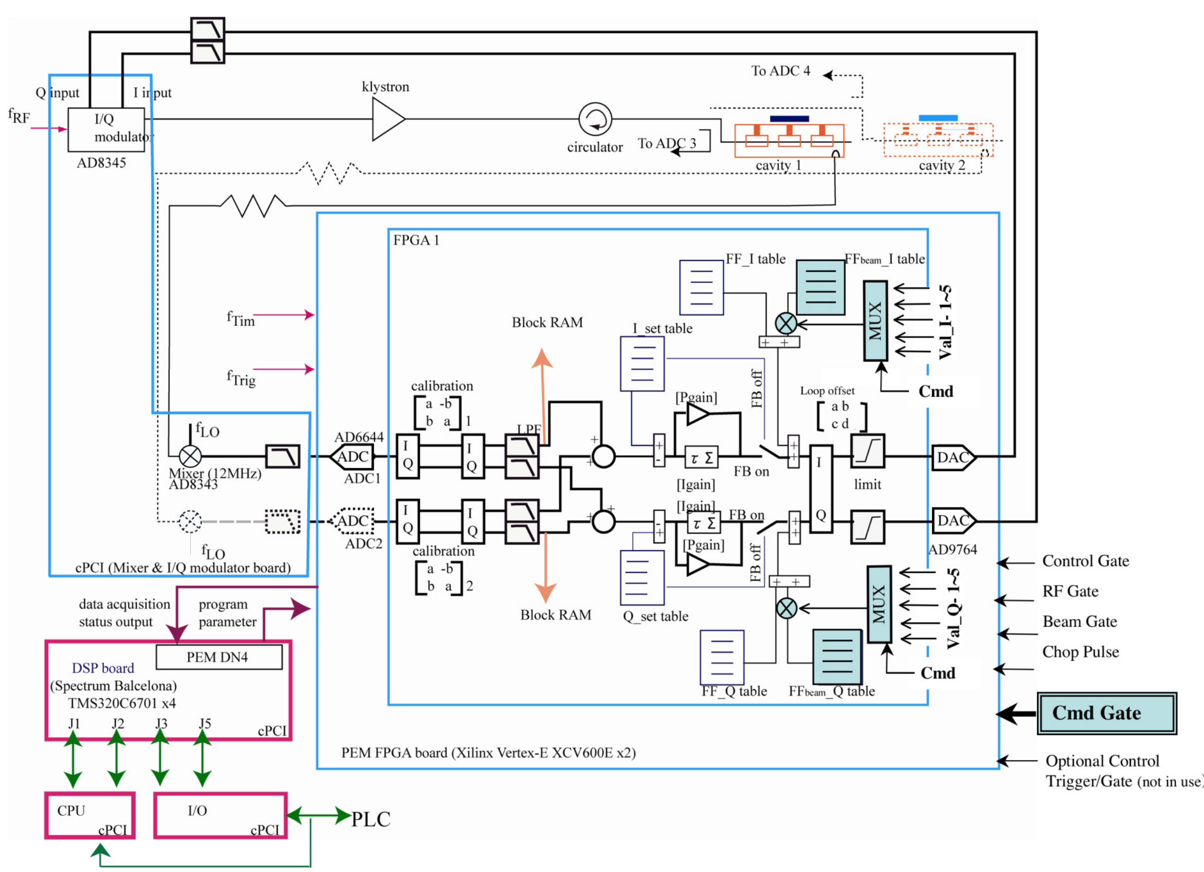

Figure 4: FPAG block diagram of the digital FB and FF control system for the J-PARC linac LLRF.

components are controlled to be set values by PI control and output to an IQ-modulator through a DAC.

Cavity-tuners are controlled from the cPCI by way of a program logic controller (PLC) [2], and the auto-recover sequence from the fault down is processed by the PLC.

The beam-loading ripple at the rising/falling of macro beam pulse could not be compensated enough by only the FB control. Therefore FF control is combined with the FB control for the beam loading compensation. FF-control values are added to the I/Q-component outputs during the external beam gate (See Fig. 4). As shown in Fig. 5, by using the FF control with FB, the field change due to the beam loading (26-mA peak current and 50-μs width) was vanished almost perfectly. If the FF control is not adopted, the amplitude and phase change due to the beam loading is about ±3% and ±1.5 degrees, respectively. The beam current decay of about 3% was observed in 181-MeV acceleration without the FF control. By applying the FF control to all cavities, the current decay and the energy dispersion in the macro pulse decrease obviously [5].

For the FF-control, it is necessary to adjust a timing of a beam-synchronized gate signal in precision of 0.1-µs. Furthermore, optimum values of the FF amplitude and phase depend on beam intensity, therefore the FF parameters are need to be changed with beam intensity changes. As described above, the beam intensity changes due to the destination of the RCS extraction beam. Therefore a function that can switch the feed-forward control parameters in every pulse is required. In addition, when the beam is stopped due to some faults, the FF control has to be stopped in order to prevent the cavity from being damaged by overloading.

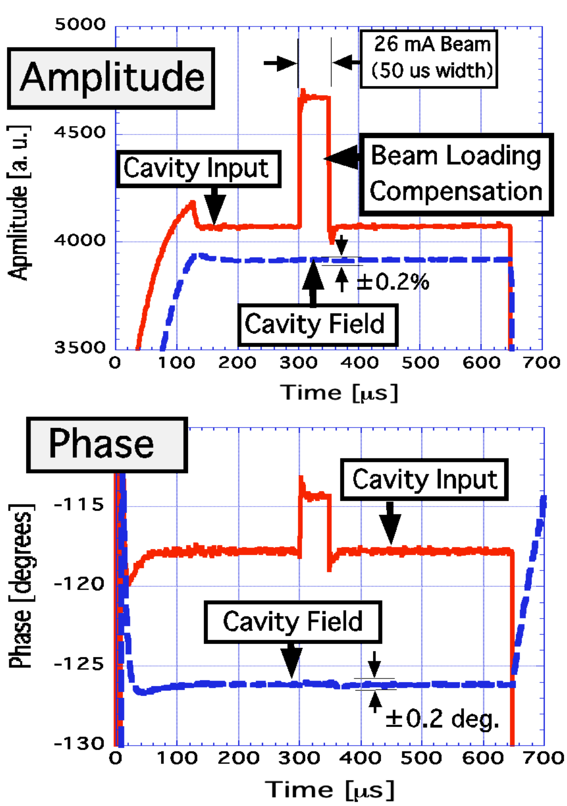

Figure 5: Beam Loading Compensation

PULSE-BY-PULSE SWITCHING OF BEAM LOADIN COMENSATION

The FPGA program was modified, and the new function for pulse-by-pulse switching of the beam-loading compensation parameters is installed into the LLRF control system. As shown in the Fig. 4, FF-control preset values of the I/Q component are switched by an external command gate signal. The width of the command gate controls selection of the preset values as shown in Table 1. This command gate signal is generated by the timing system of the J-PARC and it is switched automatically in accordance with the operation mode. This switching command affects an immediate RF pulse in 25-Hz repetition. Presently, 5 sets of the preset value are available as shown in the Table. One set of the preset values is set zero, so that the beam loading compensation is to be stopped when the beam is stopped.

The operation test for the new function was performed and it was succeeded in low power operation. This new function in planned to be used from December 2008 for the J-PARC.

Table 1: Preset values for the FF control switching.

Gate Width		Preset Value	
5	(04～06)	Val1_I, Val1_Q	I and Q = 0
10	(09～11)	Val2_I, Val2_Q	I and Q = 1024
15	(14～16)	Val3_I, Val3_Q	
20	(19～21)	Val4_I, Val4_Q	
25	(24～26)	Val5_I, Val5_Q	

SUMMARY

Because the linac beam intensity changes depending on the destination of the RCS beam extraction, a new function that can switch the beam-compensation parameters in every pulse was installed into J-PARC linac LLRF control system. The test operation was succeeded, and this new function will be used from December 2008 for the J-PARC.

REFERENCES

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