INTERLOCK OF BEAM LOSS AT LOW-ENERGY PART OF J-PARC LINAC

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Abstract

The output beam power of the J-PARC linac has been improved by increasing the acceleration energy and peak beam current. The beam loss is getting serious along with increasing output beam power; however, the beam loss in the front-end region is difficult to detect because of the low energy of the radioactive emission. An interlock system using the beam current monitors has been developed to prevent significant material activation. In this system, an electrical circuit measures the beam transmission between the two beam current monitors. This study describes the design and performance of this electrical circuit and introduces the system configuration.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) linac can provide high intensity beams of peak current 50 mA, beam energy 400 MeV, pulse width 0.5 ms, and repetition rate 25 Hz using a radio frequency quadrupole linac (RFQ), three drift tube linac (DTL) cavities, 16 separation-type DTL (SDTL) cavities, 21 modules of annular coupled structure (ACS) cavities, and two beam transports, which have two ACS-type buncher cavities and debuncher cavities as shown in Fig. 1 [1, 2].

The J-PARC linac has a matching section between the RFQ and the DTLs, where 3-MeV beams are transported and measurements and beam profile matching are performed. An ion chamber-type beam loss detector has been employed for beam loss detection. The beam loss detector has a fast signal response; therefore, we have used this to develop an interlock system to stop beam operation when abnormal beam shots are detected. However, there is no beam loss detector in this section because the energy of radiation generated by 3-MeV beam is not sufficiently high to be detected.
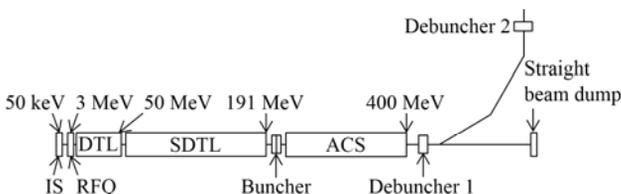

Figure 1: Schematic Layout of Present J-PARC Linac.

An interlock system that uses a new electrical circuit to measure the beam transmission between the two beam current monitors is proposed because of the large number of beam current monitors in the beam line.

In this study, a procedure for signal processing in the system and for processing waveforms in the processing unit is introduced. The waveforms obtained are also analyzed.

CIRCUIT DESIGN OF BEAM TRANSMISSION MEASUREMENT

The new interlock system, which uses beam current monitors, is named the beam transmission monitor (BTM) because the system compares beam currents detected by two independent beam current monitors. The signal design process is described below.

System Configuration

The schematic configuration of the system that uses the BTM is shown in Fig. 2. The system comprises two beam current monitors, and the signal processing circuit (BTM) shown in gray. Pre-amplifiers are usually used for continual beam operation and they are annually tuned to 0.10 V/mA of the beam current. The buffer amplifier has four channels per module, with two channels connected to the digitizer (one for both waveform outputs, 1 and 2) during operation, and the other two channels used by the BTM. The BTM circuit has six output terminals, as shown in Fig. 2.
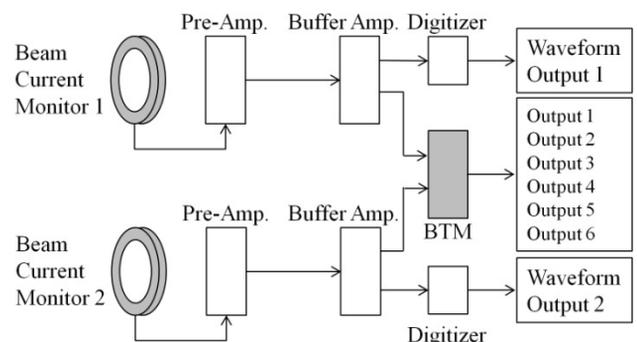

Figure 2: System Configuration of the Beam Transmission Measurement.

Process Flow

The signal processing flow in the BTM is shown in Fig. 3. It has two input terminals for the two signals coming from the two beam current monitors. Just after the signal input terminals, gain adjustment knobs amplify the input

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signals independently. These can be tuned by observing the low beam current signals (outputs 1 and 2). To detect small beam losses, the beam current signals are integrated with a gate signal that covers an entire beam pulse. The rise of the gate signal pulse plays a significant role in the trigger of the integration, whereas the flank plays a significant role in the reset of the integration. After integration, which can be observed in outputs 3 and 4, the difference, which should be small, is usually taken by the two integrated inputs. The difference can be observed at the output 5 terminal and it is integrated again into the circuit. The final integrated differential signal can be observed in output 6.
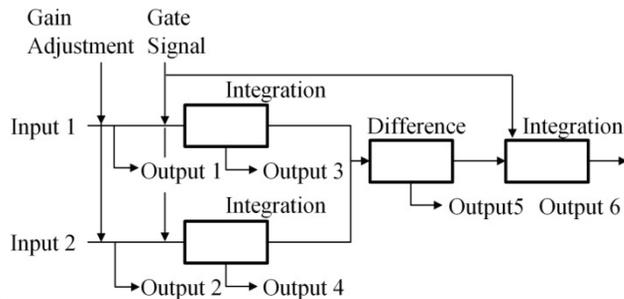

Figure 3: Block Diagram of the signal processing flow in the beam transmission monitor circuit.

Estimated Waveform

Figure 4 shows the estimated waveform at each output terminal. Two rectangular simulated beam input pulses are assumed with different wave heights at inputs 1 and 2. When input 1 is upstream from input 2 and the input gain is adjusted, the wave height of input 2 is smaller than that of input 1. After inputs 1 and 2 are integrated during the gate period, outputs 3 and 4 are obtained. The waveforms of outputs 3 and 4 are proportionally increased between beam-on and beam-off, and the highest peak is held ideally until the reset signal. The integrated signals are subtracted and the result is output 5. Furthermore, this signal proportionally increases in a beam period. The proportional difference is added over time, with the integrated difference being quadratically increased. After the beam has passed, the difference is proportionally increased until the reset signal.
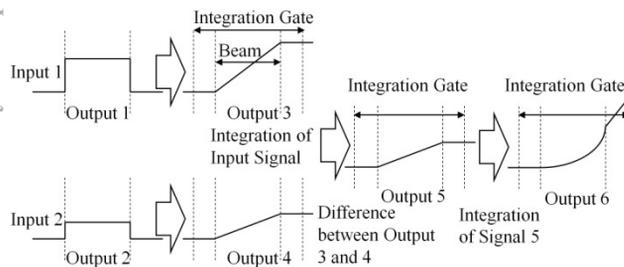

Figure 4: Waveforms during the signal processing.

SYSTEM TEST

Installation

There is a beam transport line between the RFQ and DTL, where the beam energy is 3 MeV, and there are five beam current monitors in this section. We assume that all the beams are lost in the DTL cavity, and we focus on the beam current monitors upstream and downstream of the DTL. Therefore, input 1 is occupied by the beam current signal from the last MEBT1 and input 2 is for the last DTL. In the test operation, we use a 30-mA peak beam current and a 100-μs pulse length. The integration gate covers the beam pulse preceding 50 μs from the beam pulse and having a width of 2 ms.

Test Results–Normal Operation

When the beam is operated with tuned beam lines, the beam loss in the DTL is assumed to be small. When the input currents are the same, the trends of inputs 1 and 2 as well as those of outputs 3 and 4are the same. Therefore, the subtraction of outputs 3 and 4 gives a value of zero for output 5, which will result in no signal in output 6.

For the beam test to use the ideal tuned beam line, inputs 1 and 2 were maintained with the same pulse height by using the gain adjustment knobs for the input signals. The waveforms of output 1 (raw output of input 1), 2 (raw output of input 2), 5 (difference of integration between 3 and 4), and 6 (final integration of the difference 5) are shown in Fig. 5. We used a pulse of 100 μs with a horizontal axis scale of 20 μs/div.

Figure 6 shows the waveforms of outputs 3 (integration of input 1), 4 (integration of input 2), 5, and 6 at time ranges of 40 μs/div along the horizontal axis. Integration of the input pulses, which started from the gate state, shows the same trends for outputs 3 and 4, with the difference between (output 5) of outputs 3 and 4 then being close to zero. Finally, the integration (output 6) of output 5 was shown to be almost zero.
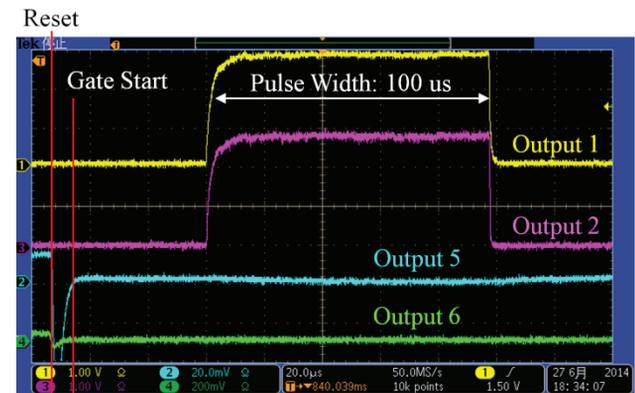

Figure 5: Waveforms of outputs 1, 2, 5, and 6 when pulses with same heights are input. The horizontal axis scale is 20 μs/division.
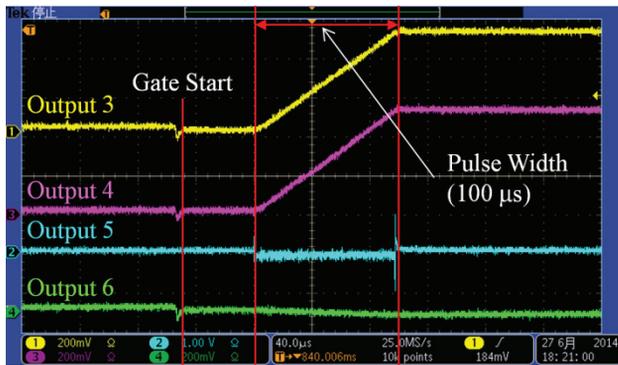
Figure 6: Waveforms of outputs 3, 4, 5, and 6. The horizontal axis scale is 40 μs/div.

Test Results–Beam Loss in the DTL Section

We assumed the entire beam to be lost in the DTL section. Input 1 remained; however, input 2 was suspended from producing any signals. Figure 7 show the waveforms of the outputs 1, 3, 5, and 6 at 400 μs/div along the horizontal axis. Output 3 is proportionally integrated and the difference of output 3 and input 2 (actually no signal input) was also proportionally integrated and the peak value was maintained until the reset signal. While the beam was passing, the proportional difference was integrated quadratically.
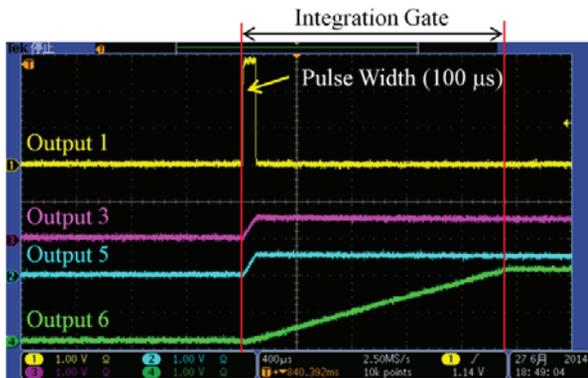

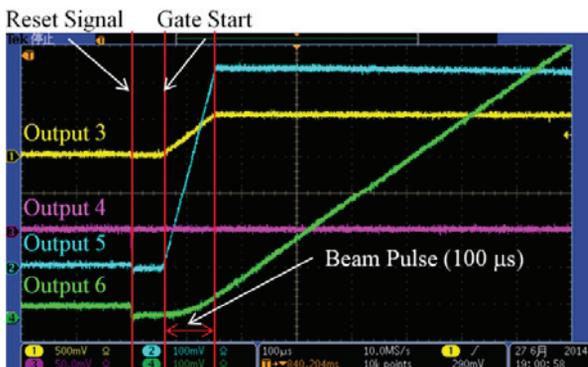Figure 7: Waveforms of outputs 1, 3, 5, and 6 for beam loss in the DTL section. The horizontal axis scale is 400 μs/div.

Figure 8: Waveforms of outputs 3, 4, 5, and 6 with beam loss in the DTL section. The horizontal axis scale is 100 μs/div.

After the beam had passed, the integration of the differential signal was proportionally increased due to the remainder of the peak value. Figure 8 shows the extensions of the waveforms of outputs 3, 4, 5, and 6 around the pulse duration. A quadratic increase of output 6 was observed.

We tested the beam loss detection system in the case of normal operation with beam loss occurring in the front-end section (DTL section). We confirmed that the signal outputs of all the terminals worked as estimated.

Thresholds for the Interlock

We confirmed the performance of the BTM by obtaining the maximum output of the integrated difference. In the interlock level, the worst case is that provides the maximum output from output 6. The reason for using output 6 is that it is sensitive to the small difference between outputs 1 and 2. We decided the threshold value as that which suspends the beam operation alarm. We are now using half of the maximum value, which implies that the alarm is triggered later than halfway through the pulse. The signal rise of output 6 is slow because it increases quadratically in the case of ideal beam loss. We can obtain a quicker response from output 5 than from output 6. Nevertheless, we plan to use both outputs 5 and 6.

This system can also be used for comparing two different signals. In the front-end of the beam line, an RF chopper system is used. As long as the RF chopping error is not sufficiently high to shift the beam away to the beam scraper, the beam remains in a beam line. Because this beam should not be injected into the downstream synchrotron, it is necessary to stop the beam after the chopper error occurs. We have attempted to use the system for detecting chopping errors using a beam current monitor and a beam scraper where the beam was irradiated by the chopper [3].

Operational Use

We continue to use the system for its usual operations. We experienced a triggering of alarm during beam operation when all the magnet setting parameters were lost due to a human error. The system was confirmed to be successful when used in actual beam operations.

SUMMARY

The J-PARC linac has a matching section between the RFQ and DTL, where 3-MeV beams are transported. We usually employ an ion chamber-type beam loss detector for beam loss detection in the linac beam line; however, there is no beam loss detector in the front-end section of the linac because the energy of radiation generated by the 3-MeV beam is not sufficiently high to be detected.

A new interlock system using beam current monitors is proposed. We developed an electrical circuit to measure

the beam transmission using two beam current monitors for the system. We established the new system and tested it using an actual beam in two typical cases. Based on the results obtained in all the cases of beam loss, we obtained the worst signal response, which will be used as a threshold for the interlock. We confirmed the performance of the BTM and its system as designed and decided on the operational threshold. We have been using this system continuously; however, the strategy of the threshold should be more serious if used for alarm timing.

REFERENCES

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Personnel Safety and Machine Protection