DEVELOPMENT OF SPILL CONTROL SYSTEM FOR THE J-PARC SLOW EXTRACTION

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Abstract

J-PARC (Japan Proton Accelerator Research Complex) is a new accelerator facility to produce MW-class high power proton beams at both 3 GeV and 50 GeV. The Main Ring (MR) of J-PARC can extract beams to the neutrino beam line and the slow extraction beam line for Hadron Experimental Facility (HD-Hall). The slow extraction beam is used in various nuclear and particle physics experiments. A flat structure and low ripple noise are required for the spills of the slow extraction.

We are developing the spill control system for the slow extraction beam. The spill control system consists of the extraction quadrupole magnets and feedback control device. Here we report their construction status.

INTRODUCTION

The high intensity proton accelerator facility J-PARC is constructed in Tokai, Japan. The intense primary proton beam is slowly extracted to HD-Hall and used in the fixed target counter experiments for the nuclear and particle physics.

The beam spill, which is time structure of slow beam extraction, is required to be flat and low ripple to prevent pileup events in particle detectors or data acquisition systems. The spill control system provides the flat and stable beam to HD-Hall. It consists of the extraction quadrupole magnets and feedback device. The magnets consist of two kinds of quadrupole magnets, EQ (Extraction Q-magnet) which make flat beam and RQ (Ripple Q-magnet) which reject the high frequent ripple noise. The feedback device, which is using Digital Signal Processor (DSP), makes a ramping pattern for the EQ and RQ from spill signal.

The designed energy and power of the primary proton beam are 50 GeV and 750 kW, respectively. The energy of 30 GeV and the power of 270 kW are expected in phase 1 of the J-PARC construction. The first beam to the hadron experimental hall has been successfully extracted in January 2009. The spill control system for the slow beam extraction will be implemented in summer 2009, and operated in fall.

SPILL CONTROL

In physics experiment, the trigger rate or the counting rate of data acquisition system is limited by the hardware and software architecture. In some cases, the detectors cannot separate multiple events, due to collisions with too many particles and the target. In other cases, the data acquisition efficiency can be bad, due to a large dead time when too much beam is extracted. Therefore, the spill beam should be flat and stable sufficiently in extraction period.

The slow beam extraction of the J-PARC MR utilizes third integer resonance at Qx = 22.333. After acceleration of MR, the beam is extracted slowly by betatron tune ramping of main quadrupole magnets in the flattop period of about one second. By constant tune ramping speed, the spill structure of slow extraction beam is like Gaussian shape. In order to make flat spill structure, we control the horizontal betatron tune by using the EQ magnets via feedback system. On the other hand, the ripples of magnet power supply affect to spill structure by spike noise. We reject the ripple noise by RQ magnet. The spill control by EQ and RQ are shown in Figure 1.

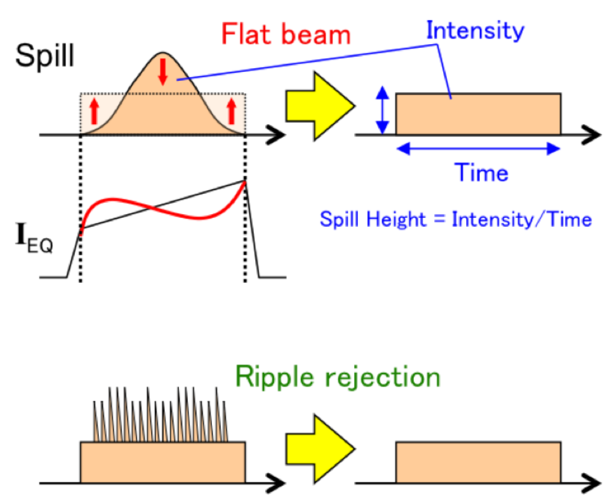

Figure 1: Spill control by EQ and RQ.

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MAGNETS

The spill structure can be controlled by fine adjustment of betatron tune ramping using quadrupole magnets in flat top region. We prepare extraction quadrupole magnets for spill control to assist the main quadrupole magnets. The extraction magnets consist of two EQs and one RQ.

The EQs make flat beam structure. The specification of the EQ is shown in Table.1. The maximum field gradient is 2.60 T/m and the core is the steel sheets of the 0.1mm thickness. The photograph of the EQ is shown in Figure 2.

Table 1: EQ Specification

Bore Radius	80 mm
Coil Turn Number	22 Turn/Pole
Core Material	ST-100 0.1 mm
Maximum Field Gradient	2.60 T/m at 301A
Magnetic Length	0.692 m
Inductance	8.8 mH
Resistance	80.3 mΩ at 20°C

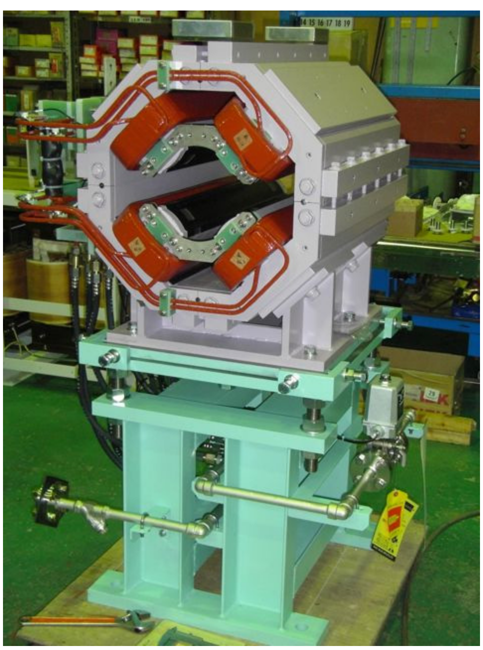
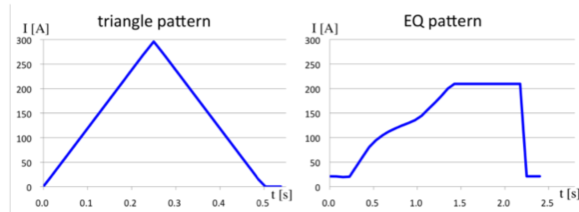


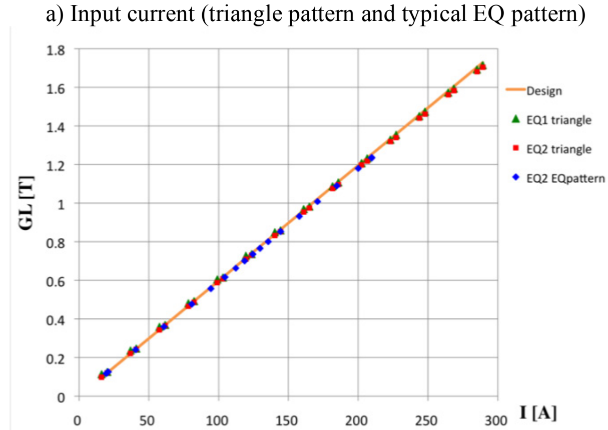
Figure 2: EQ magnet.

Two EQs and EQ power supply have been constructed and the performance has been tested. The dynamic field of EQs have been measured using a harmonic coil [1] with two kinds of input current pattern (Figure 3a).

The current dependence of magnet field gradient is shown in Figure 3b. The linearity of field gradient is well agreed with the design.



a) Input current (triangle pattern and typical EQ pattern)



b) x-axis: Input current [A], y-axis: Field Gradient [T]
Point: measured values, Line: design values

Figure 3: Linearity measurement of EQ.

The RQ compensates the high frequent ripple noise. The RQ is excited with high frequent sinusoidal like pattern up to few kHz. The field gradient is up to 0.94 T/m with 6 turn coils in order to get fast responsibility. The other spec of RQ is similar to EQ.

The RQ is under construction and both EQ and RQ will be installed to J-PARC MR in this summer.

FEEDBACK SYSTEM

The feedback system provides ramping pattern signals to EQ and RQ magnets. It is composed of circuit board for Digital Signal Processor (DSP), signal input/output (I/O) interfaces and LAN interface.

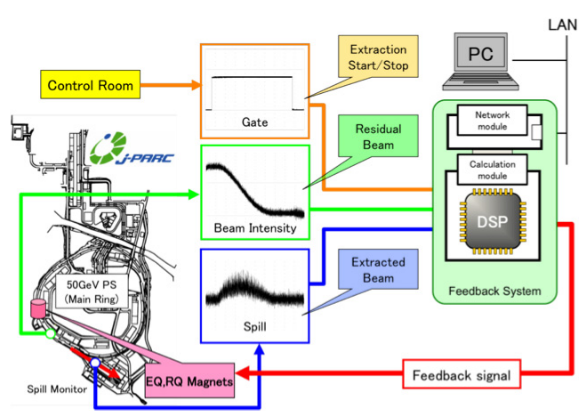


Figure 4: Signal flow of the feedback system.

The input signals consist of flattop gate, residual beam intensity and spill intensity of extracted beam. For the EQ feedback loop, the spill signal is compared with the reference level, which is proportional to the circulating beam intensity just before extraction. For high frequent ripple up to few kHz, the RQ feedback loop works to reduce the ripple noise by opposite phase signal. Figure 4 shows the signal flow of the feedback system.

From the experience on KEK-PS, the gain parameters of the feedback loop should be changed with extraction time. We have realized it by using the digital feedback with DSP [2]. The concept of parameter selection in feedback loop is shown in Figure 5.

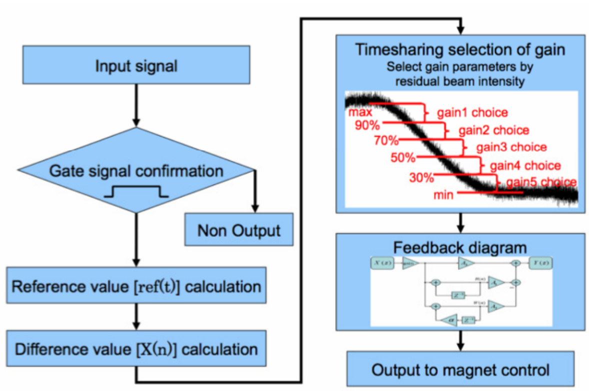


Figure 5: Flowchart of feedback loop.

The circuit board consists of two DSP cards (TMS320 C6713), dual port memories and FPGAs. Figure 6 shows the DSP feedback system. The two DSPs are in charge of spill feedback calculation and power spectrum analysis respectively. The dual port memory connects two DSPs and FPGAs to use sharing waveform data and changing parameter from power spectrum analysis.

The LAN board consists of Ethernet interface and CPU, which includes Embedding Linux system. We plan to develop the installing of EPICS in this board to use remote control.

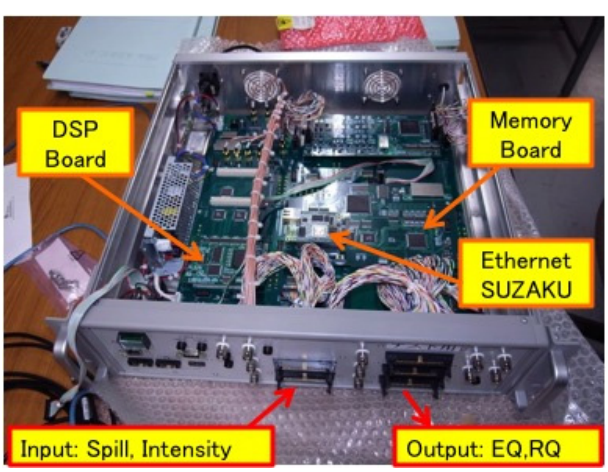


Figure 6: DSP feedback system.

BEAM STUDY

For the test of the feedback system, we took beam study by using HIMAC accelerator at NIRS, which has slow extraction beam line using third integer resonance.

The extraction quadrupole magnet (QDS) of HIMAC was controlled by DSP feedback system and the spill signal and residual beam intensity were measured [3,4]. Figure 7 shows the measured spill signal controlled by the feedback system.

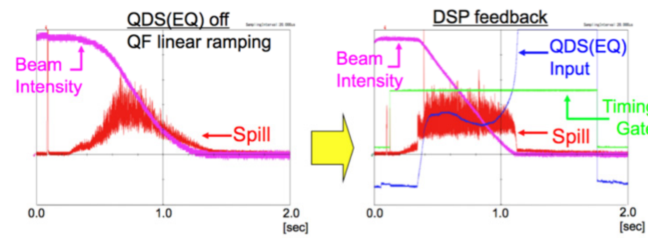


Figure 7: Results of beam test.

SUMMARY

For the spill control of the J-PARC slow extraction, EQ and RQ were constructed and the feedback system was developed. It was verified their performances and will be operated at J-PARC in fall 2009.

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