BEAM SPILL CONTROL FOR THE J-PARC SLOW EXTRACTION

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Abstract

The slow extraction beam from the J-PARC Main Ring (MR) to the Hadron Experimental Facility (HD-Hall) 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. The spill control system has been developed to make a flat structure and small ripple. It consists of the extraction quadrupole magnets and feedback device. The extraction 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 system, which is using Digital Signal Processor (DSP), makes a control pattern for EQ and RQ from spill beam monitor.

The extraction magnets and feedback device were installed in September 2009, and spill feedback study has been successfully started from the beam time in October 2009. Here we report the operation status of magnets and first study of beam commissioning with spill feedback system.

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 for the fixed target counter experiments of the nuclear and particle physics [1].

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.

In January 2009, the first 30GeV proton beam has been successfully extracted to the fixed target in HD-Hall. The spill control system has been implemented in September 2009. The spill control study at 30GeV, 1-2kW beam has been taken from October 2009 to February 2010.

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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 [2]. 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 [2]. The spill control by EQ and RQ are shown in Figure 1.

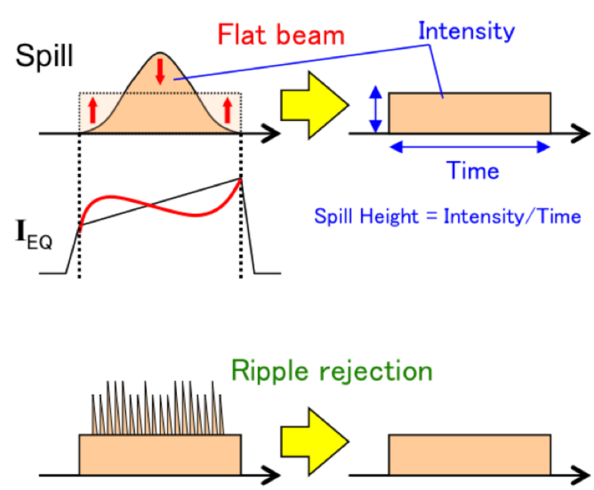


Figure 1: Spill control by EQ and RQ.

MAGNETS

The spill structure can be controlled by fine adjustment of betatron tune using quadrupole magnets in flat top region. We prepared extraction quadrupole magnets for spill control to assist the main quadrupole magnets. The extraction magnets consist of two EQs and one RQ. They were installed in September 2009. Figure 2 shows the photograph of EQ and RQ.

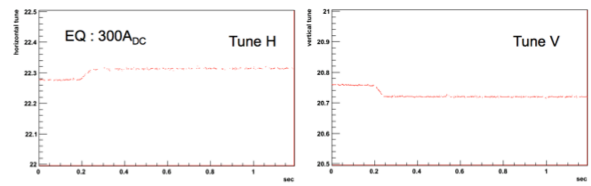
The EQs make flat beam structure. The field gradient of EQ is 2.60 T/m. The RQ compensates the ripple noise. It excited with high frequent sinusoidal like pattern up to few kHz. The field gradient of RQ is up to 0.94 T/m with 6 turn coils. In order to get fast responsibility, the core material is used the lamination steel of 0.1 mm thickness to reduce the effect of eddy current, the vacuum ducts are used the ceramics duct with RF shield. The coils for RQ consist of two conductor lines, which is transposition in each turn. The specification of the EQ and RQ are shown in Table 1.

Table 1: EQ and RQ specifications

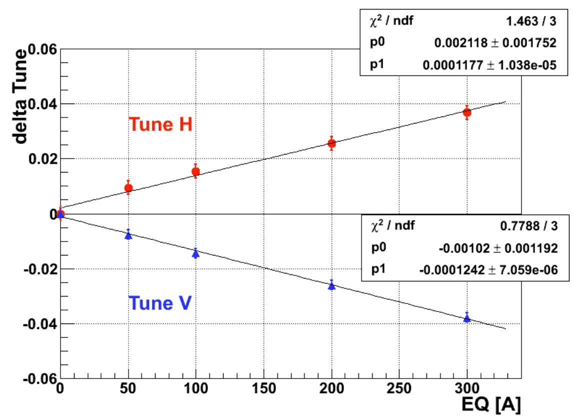
	EQ	RQ
Core Material	0.1mm thick lamination steel	
Bore Radius	80mm	80mm
Magnet Length	0.62m	0.62m
Coil Turn Number	22	6
Field Gradient	2.60T/m@301A	0.94T/m@400A
Inductance	8.8mH	0.65mH
Resistance	80.3mΩ	11.25mΩ

Figure 2: EQ and RQ magnets. (left: EQ1, right: RQ)

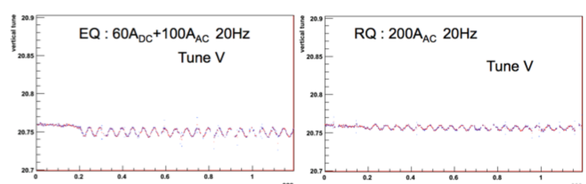
The performance of EQ and RQ magnets has been tested in beam commissioning with tune measurement. The EQ magnet operated with the DC or sinusoidal pattern in flattop period and we measured betatron-tune. Figure 3b shows the EQ current dependence of tune shift. The linearity of tune shift value well agreed with the design. The RQ was also tested by sinusoidal pattern.



a) Tune measurement with EQ 300A DC operation



b) x-axis: EQ current [A], y-axis: tune shift



c) Tune measurement with AC operation

Figure 3: Tune measurement with EQ or RQ.

FEEDBACK UNIT

The feedback unit [3] provides control patterns to EQ and RQ magnets. It is composed of circuit board for Digital Signal Processor (DSP), signal input/output interfaces and LAN interface. The circuit board consists of two DSP cards (TMS320 C6713), dual port memories and FPGAs. Figure 4 shows the DSP feedback unit. 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 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 5 shows the signal flow of the feedback system.

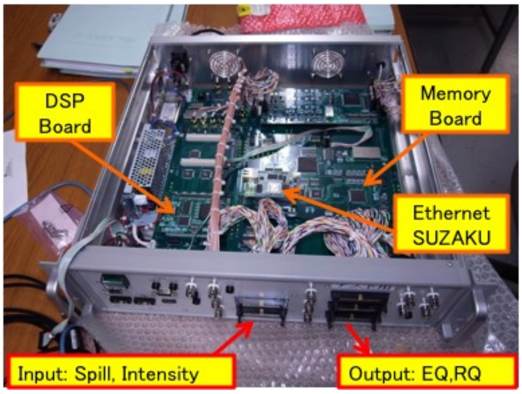


Figure 4: DSP feedback unit.

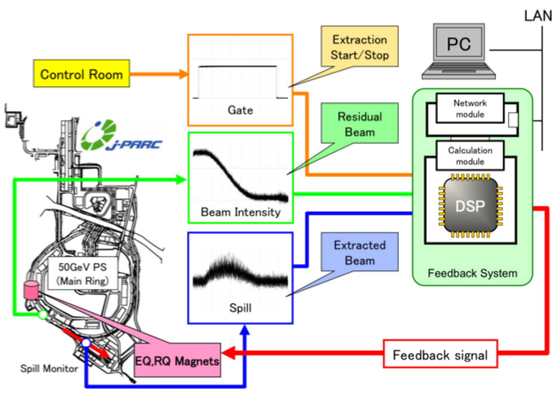


Figure 5: Signal flow of the feedback system.

BEAM COMISSIONING

The spill control system was installed in October 2009. The acceleration pattern for the slow extraction had a 2.63 sec flat top and the spill length was 1.5 to 2.0 sec.

The spill feedback study was successfully started from November 2009. The beam spill was measured by the photomultiplier with plastic scintillator, where is installed in slow extraction beam line.

The beam spill intensity has a Gaussian like shape without the spill feedback. A flat beam spill structure has been successfully obtained with the spill feedback using the EQ. The B and Q magnet power supplies of MR have a large ripple even at extraction period. It causes serious spikes in the beam spill and brings multiple events accidently in fixed target experiments.

The spill duty factor is defined as

$$Duty\ Factor = \frac{\left[\int_0^T I(t)dt\right]^2}{\int_0^T dt \cdot \int_0^T I^2(t)dt},$$

where *I(t)* is spill intensity and *T* is extraction time range. The measured duty factor is about 2~3% without spill feedback. It was drastically improved to 11~12% by spill feedback. In this feedback, the EQ works not only for macro-shaping control, but also for compensating low frequency spikes to assist the RQ function. Beam spill and its FFT spectrum are measured with and without feedback (Figure 6). It was verified that the spill feedback system is effective to improve the beam spill structure. For the user run of hadron experiment, we operated spill feedback with such condition.

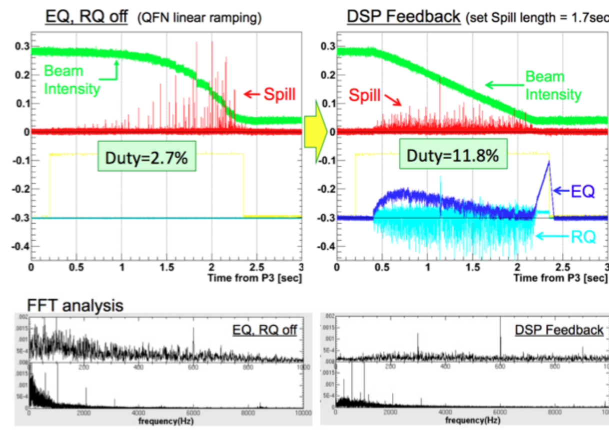


Figure 6: Beam spill structures and FFT results w/o and w/ feedback.

In order to improve spill structure further, we applied the transverse RF field [4]. Obtained duty factor is 15% for the most part of beam spill. Therefore, the EQ power supply tripped sometimes by a slight beam intensity burst by transverse RF. We will continue the transverse RF study.

SUMMARY

For the spill control for the J-PARC slow extraction, EQ, RQ and feedback system were constructed and implemented. The beam commissioning study with spill control has been taken successfully. The spill feedback control worked well and improved the beam spill structure.

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