STATUS AND UPGRADE PLAN OF SLOW EXTRACTION FROM THE J-PARC MAIN RING

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Abstract

The proton beam from the J-PARC main ring is slowly extracted using a third integer resonance and delivered to the experimental hall for various nuclear and particle physics experiments. The slow extraction devices comprise two electro static septa, ten magnetic septa, four bump magnets, eight resonant sextupole magnets and their power supplies. We will report the extraction efficiency and spill structure obtained by the beam commissioning so far. We will also mention upgrade plans based on some ideas to aim at higher performance.

INTRODUCTION

One of the critical issues of the slow extraction is radiation caused by the beam loss. A high extraction efficiency is required avoiding irradiation in hands on maintenance and machine damage. Electrostatic and magnetic septa with thin septum thickness have been developed [1, 2]. The slow extraction scheme with a large step size and a small angular spread of the extracted beam enables a hit rate on the ESS of less than 1% [3]. In Jan. 2009, the first 30 GeV proton beam was successfully delivered to the fixed target. Quadrupole magnets and a DSP feedback control system to obtain a uniform beam spill structure were implemented in the 2009 summer shutdown period. Beam commissioning to achieve a high extraction efficiency was performed in Oct. 2009∼Feb. 2010 (RUN26∼30). Present large bending and quadrupole current ripples produce serious spikes in the spill time structure. The spill feedback and applying rf noises to the beam have been commissioned to improve such a spill structure. Upgrade plans to achieve a higher slow extraction performance have been proposed.

SLOW EXTRACTION SYSTEM

The J-PARC main ring with circumference of 1567.5 m has an imaginary γ_t. One section of three fold symmetry ring comprises a 406.4 m long arc section and a 116.1 m long straight section (LSS). The horizontal tune is ramped up to Qx=67/3 for the slow extraction by changing quadrupoles (48-QFN family) located in the ARC section. Eight sextupole magnets (RSX1∼8) to excite a third integer resonance are also located in the ARC section, which is fed by two sets of power supply. Two electric septa (ESS1∼2), low (SMS11∼12) , medium (SMS21∼24) and high field magnetic septa (SMS31∼34) and four bump magnets (SBMP1∼4) are located in the LSS connected to a high energy beam transfer line to the hadron experimental hall. Extracted beam profiles at each septum can be measured by the screen monitors. Quadrupoles (EQ1∼2 and RQ) for the spill feedback are located in the arc section upstream of the LSS. Parameters of the slow extraction devices are listed in Table 1. Fig. 1 shows the layout of the slow extraction devices.

Table 1: Parameters of slow extraction devices (30 GeV)

device name	**core length**	**septum thickness**	**field strength**	**p.s. output**
ESS1∼2	1.48 m	∼0.08 mm	4.2 MV/m	104 kV
SMS11	1.5 m	1.5 mm	0.071 T	3000 A
SMS12	1.5 m	3.5 mm	0.142 T	2×3000 A
SMS21∼24	0.838 m	8.5 mm	0.33 T	4×3000 A
SMS31∼32	1.14 m	35 mm	0.91 T	16×3400 A
SMS33∼34	2.28 m	64 mm	1.00 T	18×2800 A
SBMP1∼4	1.4 m	–	0.375 T	360 A
RSX1∼8	0.7 m	–	130 T/m^2	340 A
EQ1∼2	0.62 m	–	3.2 T/m^2	340 A ±260 V
RQ	0.62 m	–	0.89 T/m^2	±340 A ±300 V

BEAM COMMISSIONING

In the runs of Jan. and Feb. 2009 (RUN21∼22), the acceleration pattern for the slow extraction had a 0.7 s flat top. Typical spill length was 0.2 s. The 100∼200 W beam was delivered to the target. Fig. 2 shows the acceleration pattern in RUN26∼30, where the flat top was increased to 2.63 s and the spill length was extended to 1.5 to 2 s. The

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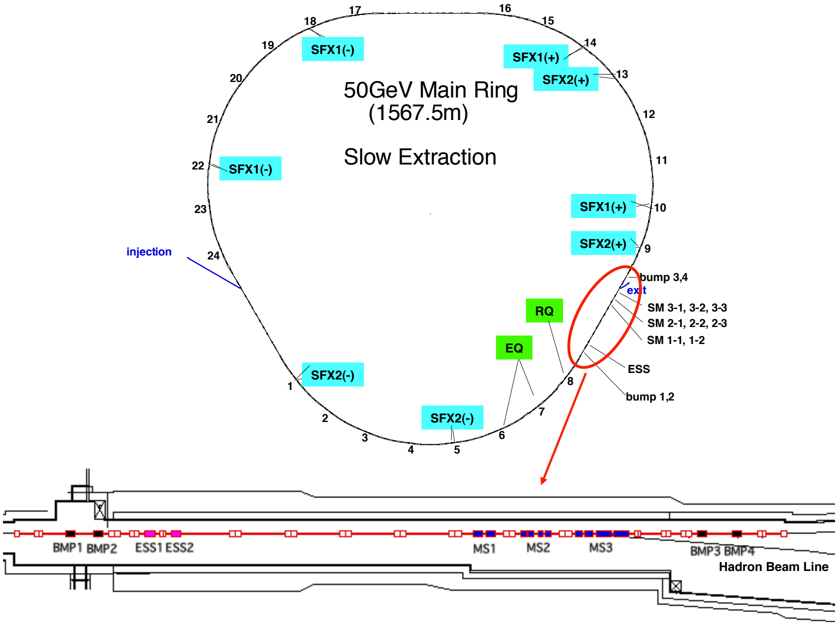

Figure 1: Layout of slow extraction device. SFX1 and SFX2 are family name of RSX.

extracted beam power increased to 1∼1.5 kW for users, and 2.5 kW-beam extraction was successfully demonstrated.

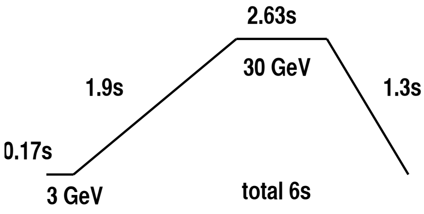

Figure 2: Present acceleration pattern.

Extraction Efficiency

Excitation of the extraction bump orbit made a large COD leakage outside the designed bump orbit in RUN21∼22. However the leakage became quite small in RUN26∼30, since the lattice quadrupole setting was modified so as to allow the design optics. Six horizontal steering magnets as well as the bump magnets were carefully tuned so as to reduce the beam loss monitor (BLM) counts. The horizontal septum position of the ESSs and SMS1 were adjusted to reduce the beam loss during the extraction. Radiation resistant stepping motors were used to change the septum position. Pulse drivers have been placed in the power supply building (D2) located 200 m far from the motors. The adjustment of the septa position drastically increased the extraction efficiency to 98.5% on average, where the extraction efficiency was derived from the BLM counts calibrated from the DCCT signal reduction corresponding to the beam loss generated by making local bump orbits. The evolution of the extraction efficiency is shown in Fig. 3.

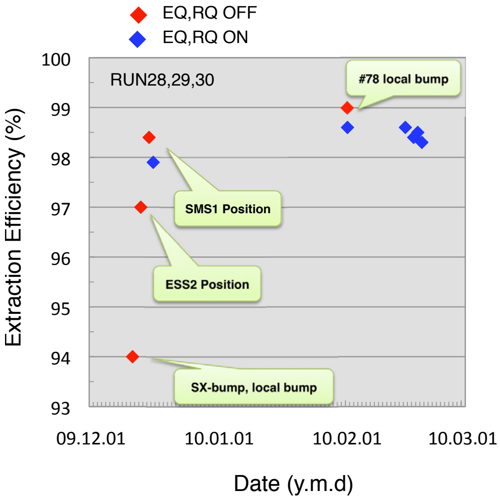

Figure 3: Evolution of the extraction efficiency.

Beam Spill

The beam spill intensity has a peak during extraction without the spill feedback. A flat beam spill intensity has been successfully obtained by the spill feedback using the EQ. The MR bending and quadrupole power supply has a large ripple even at 30 GeV energy. Corresponding tune ripple is estimated to be ±0.003. This causes serious spikes in the beam spill and brings accidental events for coincidence experiments. Trim coils are wound around poles of the lattice quadrupole magnets. Normally the trim coil terminal is open. In case the trim coil terminal was shorted, we expect the current ripple to bypass through the trim coil circuit and thus reduce the field ripple.

The spill duty factor D is defined as

$$D = \left[\int_{T_1}^{T_2} I(t)dt \right]^2 \Bigg/ \left[\int_{T_1}^{T_2} dt \cdot \int_{T_1}^{T_2} I^2(t)dt \right], \quad (1)$$

where $I(t)$ is spill intensity and T_1 and T_2 define the time range where the duty is computed. The beam spill was measured by the photomultiplier with a plastic scintillator. The measured duty factor for shorted trim coil terminal is 3% level without spill feedback. This was drastically improved to 11% level by spill feedback. In this feedback, the EQ is used to compensate low frequency spikes to help the RQ function [4, 5]. In order to improve the spill structure further, we applied the transverse rf field. This field was made by a horizontal exciter for the tune measurement. The rf field pushes the beams to the resonance by increasing the betatron amplitude. The rf frequency spectrum has a flat distribution over 1 kHz [6]. The carrier frequency was chosen to be 5.033877 MHz corresponding to a higher harmonics of the horizontal betatron frequency. The obtained duty factor except for the end of beam spill is 15%. Beam spill and its FFT spectrum measured at the case transverse rf ON are shown in Fig. 4. The EQ power supply tripped sometimes by a slight beam intensity burst due to the transverse rf. Optimization of the transverse rf parameters will be needed in the next run. Beam test using longitudinal rf noise to improve the spill structure was also performed [6].

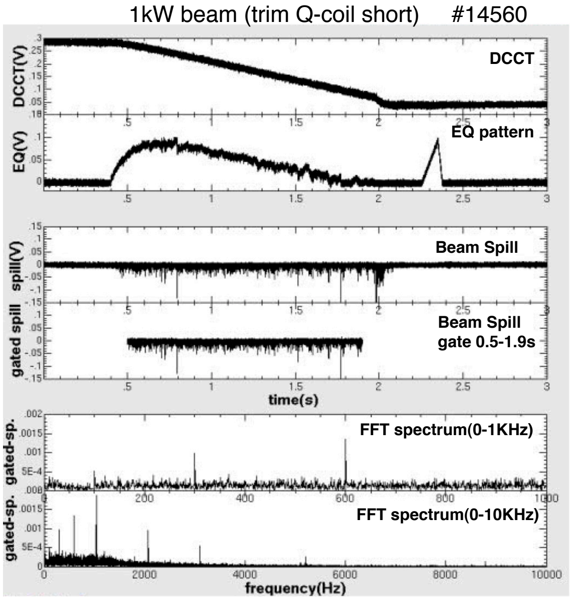

Figure 4: Beam spill at transverse rf ON. DCCT, EQ current pattern and FFT spectra of the spill are also shown.

UPGRADE PLAN

The following upgrades to improve slow extraction performances are planned or discussed;

- A dynamic bump scheme [3] will be tested in the next slow extraction run. The bump currents during slow extraction are uniquely defined by the bare horizontal tune which depends on the EQ and QFN current values. The bump current control signal is processed by dynamic bump DSP from real time EQ pattern and given QFN pattern. The dynamic bump system is expected to reduce the beam loss furthermore.
- Two beam collimators will be set downstream of the ESS2. Multiple-scattered protons with a large scattering angle can be absorbed in these collimators. This suppresses the residual radioactivity caused around downstream quadrupole beam ducts. These collimators are planned to be installed in the summer shutdown period next year.
- A titanium vacuum chamber reduces the residual radioactivity by factor of 5 compared to SUS316L ones for 30 days-beam cooling condition. We are discussing to replace SUS316L ones by titanium ones in a long shutdown period for linac energy upgrade from 180 to 400 MeV planned in 2014.
- Present spill feedback ability is limited by possible voltage of the RQ power supply. We have started a design study for a power supply with a higher voltage capacity.

SUMMARY

Obtained slow extraction efficiency amounted to be 98.5% which was obtained from calibrated BLM signals. The spill feedback control worked well and improved the spill structure. The preliminary transverse rf test shows a possibility to improve the spill structure further. We have discussed the upgrade schemes to achieve better performance with the slow extraction.

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