PERFORMANCE OF RESONANT SLOW EXTRACTION FROM J-PARC MAIN RING

M. Tomizawa*, Y. Arakaki, T. Kimura, S. Murasugi, R. Muto,
H. Nakagawa, K. Okamura, Y. Shirakabe, H. Sato, T. Toyama, E. Yanaoka, M. Yoshii,
KEK, Oho 1-1, Tsukuba, Ibaraki, Japan
A. Schnase, JAEA/J-PARC, Shirane Shirakata 2-4, Tokai, Ibaraki 319-1195, Japan
K. Mochiki, Tokyo City Univ., Tamazutsumi 1-28-1, Setagaya, Tokyo 158-8557, Japan
D. Horikawa, the Graduate University for Advanced Studies (Sokendai),
Shonan Village, Hayama, Kanagawa 240-0193, Japan

Abstract

A proton beam accelerated by the J-PARC main ring (MR) is slowly extracted by a third integer resonant extraction and delivered to the hadron experimental hall. A low beam loss (high extraction efficiency) operation is required to reduce the machine damage and radiation exposure during hands-on maintenance. A very high extraction efficiency has been already achieved. A new collimator for the slow extraction has been installed. We have improved serious spiky beam spills by applying some schemes.

INTRODUCTION

A proton beam accelerated by the J-PARC main ring (MR) with an imaginary γ_t lattice is slowly extracted by a third integer resonant extraction and delivered to the hadron experimental hall. One of the critical issues in the slow extraction from the MR is an inevitable beam loss caused at septum devices in the extraction process. A design and operation with the low beam loss (high extraction efficiency) is required to reduce machine damage and radiation exposure during hands-on maintenance. Our extraction scheme has a large step size and a small angular spread which reduce the beam loss on developed thin septum devices [1, 2]. Since the first 30 GeV proton beam was successfully delivered to the experimental hall in January 2009, a very high extraction efficiency of 99.5% has been achieved by moving the bump orbit dynamically during the extraction. A serious spiky spill structure caused by large current ripples from the power supplies for the bending and quadrupole magnets has been rather improved by the spill feedback system and the transverse RF system.

SLOW EXTRACTION SYSTEM

The J-PARC main ring with circumference of 1567.5 m has an imaginary transition (γ_t) lattice. 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 $Q_x = 67/3$ for the slow extraction by changing quadrupoles (48-QFN family) located in the ARC section. Eight sextupole magnets (RSX1∼8) to excite the 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. Quadrupoles (EQ1∼2 and RQ) for the spill feedback are located in the arc section upstream of the LSS. A layout of the main slow extraction devices are shown in Fig. 1.

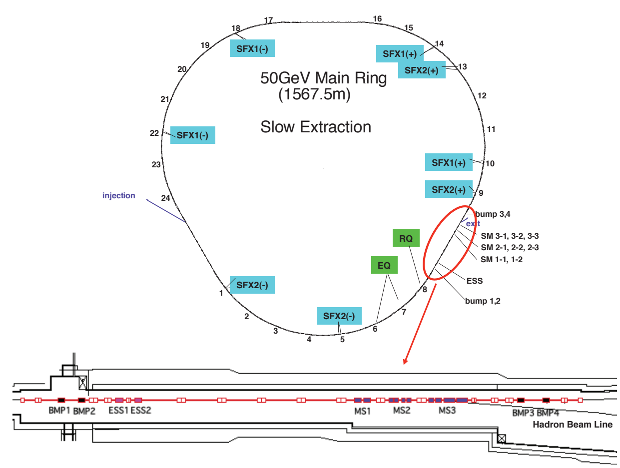

Figure 1: Layout of slow extraction device. SFX1 and SFX2 are family name of RSX.

BEAM PERFORMANCES

In the run of January 2012 (RUN40) after the earthquake, the acceleration pattern for the slow extraction had a 2.93 s flat top. Typical spill length was 2 s. The 3.5 kW beam was delivered for user runs, and 10 kW beam extraction was demonstrated.

* masahito.tomizawa@kek.jp

ISBN 978-3-95450-115-1

Figure 2: Photographs of the collimator for the slow extraction.

A bump orbit for the slow extraction must be finely adjusted to obtain a high extraction efficiency. The bump orbit by setting the values predicted from the optics produced a COD leakage outside the bump orbit. The MICAD algorithm was utilized to correct the bump orbit leakage. The horizontal septum position of the ESSs and SMS1 were adjusted so as to minimize the beam loss during the extraction. The adjustment of the septa position increased the extraction efficiency to 98.5% level. The extraction efficiency was derived from the BLM counts calibrated from the DCCT signal reduction due to the beam loss generated by making a local bump orbit.

A dynamic bump scheme has been proposed [3] and actually introduced in the past runs. The optimum bump condition during the slow extraction is uniquely defined by the bare horizontal tune which depends on the EQ and QFN current values. The bump current control signal is processed by a dynamic bump DSP from the real time EQ pattern and given QFN pattern. The extraction efficiency is increased to 99.5% at 3.5 kW beam by applying the dynamic bump scheme. The dynamic bump scheme worked well for user runs.

Collimator

A beam collimator was installed downstream of the ESS2 in a long shutdown period after the earthquake. The collimator has one horizontally-moved and two vertically-moved 40 cm long blocks made of tungsten alloy (W:95, Cu:3, Ni:2%). A beam halo generated by hitting on the ESS can be absorbed in the collimator blocks. These blocks does not interfere in the circulating beam. A beam pipe and separation wall to reduce the coupling impedance are attached in the vacuum chamber. The tungsten alloy blocks can be moved in cut areas of the separation wall with rf contacts. The vacuum chamber is covered by 10 cm thick marbles and surrounded by 30-70 cm thick iron shields. In the RUN40, the collimator reduced the residual radioactivity on the downstream-quadrupole duct from 900 to 150 μSv/h on contact after 4 hours cooling time in the same 7×10^{17} protons extraction.

Deceleration Observation During Debunch

An RF voltage in the acceleration cavities are turned off just after finishing acceleration to obtain a coasting beam. However, the average beam energy decreases by longitudinal coupling impedances in the ring during an debunch process over several hundreds of millisecond. The deceleration continues till a complete coasting beam is formed. The momentum shift is estimated from position informations from the beam position monitors (BPMs) placed at finite dispersion regions. The BPMs signals becomes more inaccurate as the debunch proceeds. We plan the measurement by an ion profile monitor (IPM) placed at a finite dispersion region. Present major impedance source is believed to be the RF cavities. The acceleration gaps will be shorted by mechanical switches after turning off the gap voltage. The influence due to the injection and extraction kickers and resistive wall impedances would be also checked.

Beam Spill

The beam spill (time structure of the extracted beam intensity) is obtained by detecting secondary particles from a thin foil placed at the beam transfer line to the target by a photomultiplier with a plastic scintillator.

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 a spill intensity and T_1 and T_2 define the time range where the duty is computed. D=100% shows an ideal flat beam intensity over the extraction time.

The spill has a mountain shape during the extraction time without the spill feedback. A flat beam spill intensity has been successfully obtained by the spill feedback by the EQ. The MR bending and quadrupole power supply have large current ripples which make tune ripples. This causes serious spikes in the beam spill and brings accidental events in the experiments. Trim coils wound around poles of the lattice quadrupole and bending magnets were shorted to bypass the current ripples through the trim coil circuit and to reduce the magnetic field ripples. The duty factor measured for the shorted trim coils was 3.5% level without spill feedback. This was improved to 17% by the spill feedback system (EQs and RQ). In this feedback, the EQ is also used to compensate low frequency spikes to help the RQ function [4, 5]. In order to improve the spill structure further, we applied a transverse RF field to the circulating beam during the slow extraction. The transverse RF field was generated by a horizontal stripline kicker for the tune measurement. The RF field pushes the beam to the resonance by increasing the betatron amplitude. The transverse RF with 49.9576 MHz carrier frequency and a flat noise spectrum over 2 kHz [6] was applied to the circulating beam. The duty factor is improved to 32% at 3.3 kW beam power. The feedback current for the EQs and RQ, beam spill and its FFT spectrum measured in the case the transverse rf was turned on are shown in Fig. 3. An original power supply for the spill feedback (RQ) is a current-controlled type. We have developed a prototype of a voltage-controlled type power supply with a better frequency response. Two output amplifiers are series-connected to obtain double output voltage capacity. In the beam test using this prototype, we achieved the duty factor of 43% under the transverse RF operation at 3.3 kW-beam power.

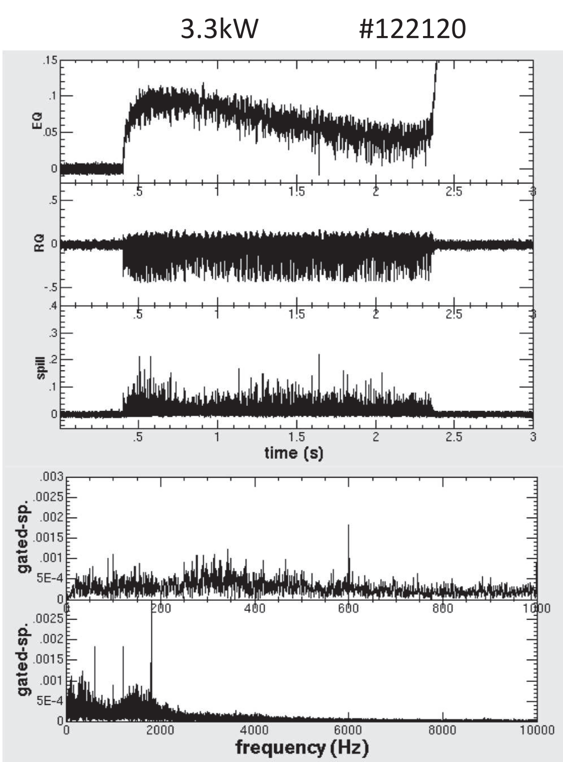

Figure 3: The spill feedback EQ and RQ currents, spill, and FFT spectrum. The transverse RF is turned on.

FUTURE PLANS

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

- A titanium vacuum chamber is expected to reduce the residual radioactivity by a several factor compared to the SUS316L ones. We have a plan to replace the SUS316L ones by the titanium ones in a long shutdown period for the linac energy upgrade in 2014.
- The spill feedback for the ripple compensation is limited by the capacity of the RQ power supply. We have started the design study of the power supply with three times higher current capacity.
- We have started R&D for robust carbon wires for the septum of the ESS [7]. We expect this development brings very low beam loss and reduce the residual radioactivity around the ESS area.

SUMMARY

We have achieved 99.5% extraction efficiency by applying the dynamic bump scheme. A collimator installed downstream of the ESS worked well and reduced the residual radioactivity. The beam spill structure has been drastically improved by applying the spill feedback and the transverse RF. We have plans to achieve higher performances on the slow extraction.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. K. Satou who calibrated the BLM signal to derive the extraction efficiency. We also would like to thank Dr. F. Tamura for fruitful discussion on the beam wake of the RF cavities.

REFERENCES

[1] Y. Arakaki *et al.*, “Electrostatic Septum for 50 GeV Proton Synchrotron in J-PARC ”, Proc. of IPAC’10, p. 3900.

[2] R. Muto *et al.*, “Construction and Operation of the Magnetic Septa for the Slow Beam Extraction from the J-PARC 50-GeV Synchrotron”, to be published in IEEE Trans. Appl. Supercond.

[3] M. Tomizawa *et al.*, “Design of Slow Extraction from 50 GeV Synchrotron”, Proc. of EPAC’02, p. 1058.

[4] A. Kiyomichi *et al.*, “Beam Spill Control for the J-PARC Slow Extraction ”, Proc. of IPAC’10, p. 3933.

[5] S. Onuma *et al.*, “The Spill Feedback Control Unit for J-PARC Slow Extraction ”, Proc. of IPAC’10, p. 2776.

[6] A. Schnase *et al.*, “Application of Digital Narrow Band Noise to J-PARC Main Ring ”, Proc. of IPAC’10, p. 1446.

[7] D. Horikawa *et al.*, “Study of Electric Septum by Low-Z Material for High Intensity Proton Beam ”, These proceedings.

ISBN 978-3-95450-115-1