LONG-TERM BEAM POSITION AND ANGLE STABILITIES FOR THE J-PARC MAIN RING SLOW EXTRACTION

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Abstract

A 30 GeV proton beam accelerated in the J-PARC Main Ring (MR) is slowly extracted by the third integer resonant extraction and delivered to the hadron experimental hall. A unique dynamic bump scheme for the slow extraction has been applied to reduce the beam loss. The current extraction efficiency is very high, 99.5%. However, the dynamic bump scheme is sensitive to the beam orbit angle at the first electrostatic septum (ESS1). The orbit angle of the dynamic bump must be sometimes readjusted to keep such a high efficiency. A long term stability of the orbit depending to momentum has been investigated.

INTRODUCTION

A high-intensity proton beam accelerated in the J-PARC main ring (MR) is slowly extracted by the third integer resonant extraction and delivered to the hadron experimental hall to drive various nuclear and particle physics experiments [1]. Most of the proposed experiments are best performed using a coasting beam without an RF structure and a uniform beam intensity during the extraction time. One of the critical issues in slow extraction (SX) of a high intensity proton beam is an inevitable beam loss caused by the extraction process at septum devices. A unique dynamic bump scheme for the slow extraction has been applied to reduce the beam loss [2]. The layout of J-PARC MR Slow extraction devices is shown in Fig. 1.

The beam power of 30 GeV slow extraction has achieved to 51 kW at 5.2s cycle in current physics runs. The extraction efficiency is very high, typically 99.5%. However, the dynamic bump scheme is sensitive to the beam orbit angle at the first electrostatic septum (ESS1). The orbit angle of the dynamic bump must be sometimes readjusted to keep such a high efficiency. A long-term stabilities of the orbit and the relative momentum have been investigated in this paper. The work in this paper is useful for a diffuser [3] and/or a silicon bend crystal [4] to achieve further high slow extraction efficiency introduced in future. They could be more sensitive to the orbit and momentum shifts.

CURRENT SLOW EXTRACTION PERFORMANCES

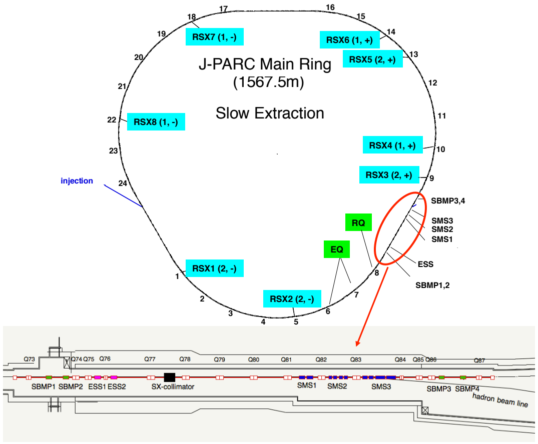

Figure 1: Layout of J-PARC slow extraction devices.

The momentum pattern of the current slow extraction is shown in Fig. 2. The repetition cycle is 5.2 s, in which the flat top length is 2.61 s. The proton number per cycle is 5.6×10^{13} ppp corresponding to 51 kW. The extraction efficiency is very high, 99.5% [5,6]. The typical spill length and spill duty factor is 2 s and 50%, respectively [6]. In the current beam power, the transverse instability during the debunch process to obtain an uniform time structure is serious. To solve this problem, the beam is injected to the RF buckets with phase offset of 50−60 degree [5]. The resultant momentum width is spread to ~0.5% in full width at the flat top.

The dynamic bump orbit tuning associated with the position and angle of the electrostatic septa (ESS1 and ESS2) and the magnetic septa (SMS1 and SMS2) is the most important to obtain a high extraction efficiency. Figure 4 shows extraction efficiency as a function of the bump orbit angle at the entrance of the ESS1. The bump orbit angle is for the end of extraction and the actual bump orbit angle is shifted so as to superimpose the extraction arms from the separatrices

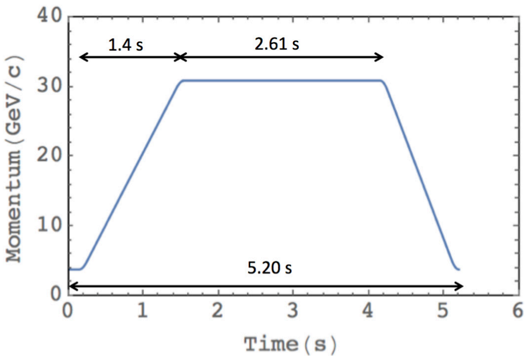

Figure 2: Momentum pattern of MR slow extraction operation.

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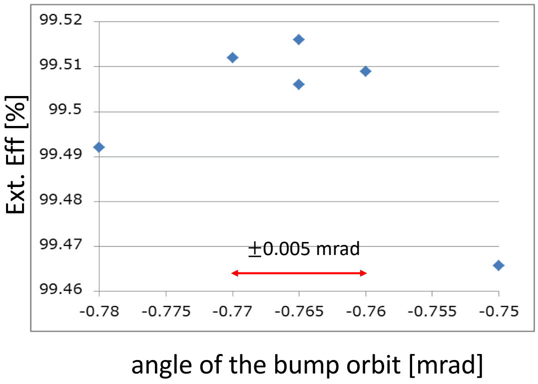

Figure 3: Measured extraction efficiency and the bump orbit angle at the ESS1 entrance.

during the extraction. The extraction efficiency is sensitive to the bump orbit angle, and must be tuned with an accuracy of 5 μrad to optimize the extraction efficiency (Fig. 3).

ORBIT ANGLE AND MOMENTUM SHIFTS

The orbit angle x' and the position x at the ESS1 entrance are derived from the beam positions measured by beam position monitors (BPMs) located just upstream and downstream of the ESS1 and so-called Twiss parameter β_x, α_x and phase advance at the three locations. The straight section where the ESSs is located is dispersion free. The 24 BPMs with large dispersions in the arc sections are chosen to derive the shift $\Delta p/p$ for the reference momentum defined by the bending field and the RF frequency. The COD in MR is corrected by the steering magnets at any acceleration timing in typical rms COD of ~0.5 mm. The beam position x_i of the i-th BPM is written as

$$x_i = \eta_i \cdot \frac{\Delta p}{p} + \delta x_i, \tag{1}$$

where η_i and δx_i are dispersion and COD, respectively. Then the momentum shift $\Delta p/p$ can be expressed as

$$\frac{\Delta p}{p} \sim \frac{1}{24} \sum_{i=1}^{24} \frac{x_i}{\eta_i}. \tag{2}$$

The COD term δx_i in Eq. (2) can be approximately canceled in the summation. The observing timing for plots shown in next section is at the flat top start just before debunch and exciting the bump orbit. The bump orbit is actually incorporated in the actual orbit angle during slow extraction.

LONG TERM STABILITIES OF EFFICIENCY, ORBIT ANGLE AND MOMENTUM SHIFT

Figure 4 shows trends of slow extraction efficiency, orbit position x and angle x' at the ESS1 entrance and momentum shift. The extraction efficiency can be derived from the beam loss monitors (BLMs) around the ESSs and SMSs area (see Fig. 1). The horizontal axis shows accumulated shot numbers (one shot is 5.2 s MR cycle). In this figure, the data derived from the BPMs are plotted every 10 shots. The interesting oscillation pattern can be seen in the $\Delta p/p$ trend. The oscillation pattern has a half-day cycle. The orbit angle at the ESS1 entrance also has a pattern synchronized with the $\Delta p/p$ oscillation pattern. The extraction efficiency seems to have a similar oscillation, though it is not so clear.

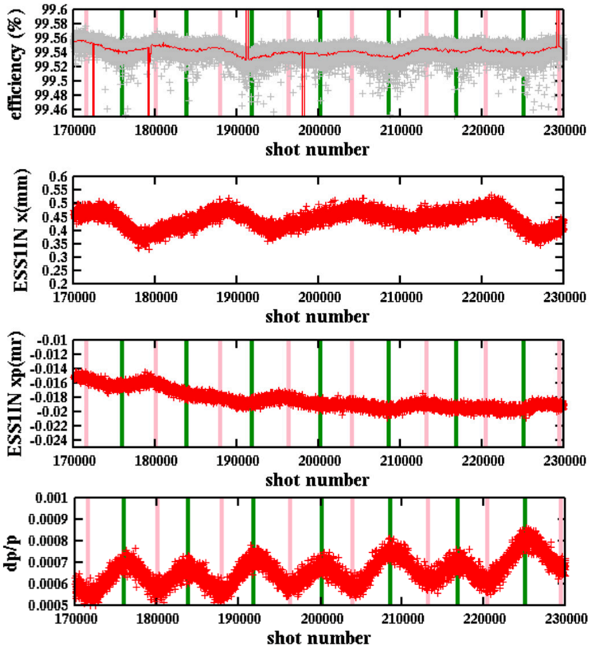

Figure 4: Trends of extraction efficiency, horizontal position x, angle x' and $\Delta p/p$.

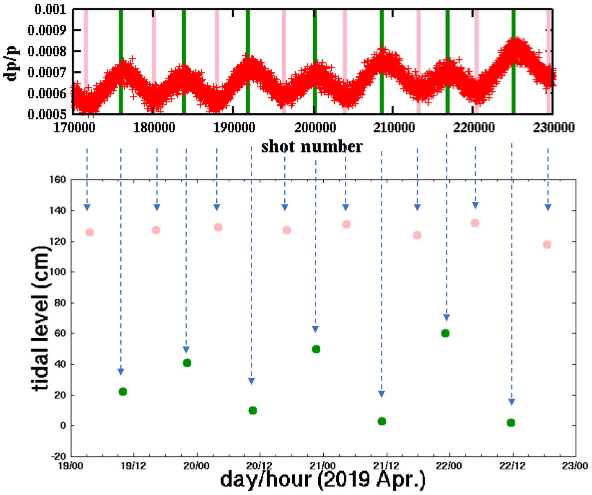

Figure 5: Relation between $\Delta p/p$ trend and tidal level in Oarai coast.

Figure 5 shows the relation between the $\Delta p/p$ pattern and tidal level in Oarai coast [7]. Oarai coast is located at 20 km far from J-PARC cite as shown in Fig. 6. Low and high tides are shown in green and pink in Figure 5, respectively. The $\Delta p/p$ peaks coincide with the low tides, on the other hand, the $\Delta p/p$ valleys coincide with the high tides. The

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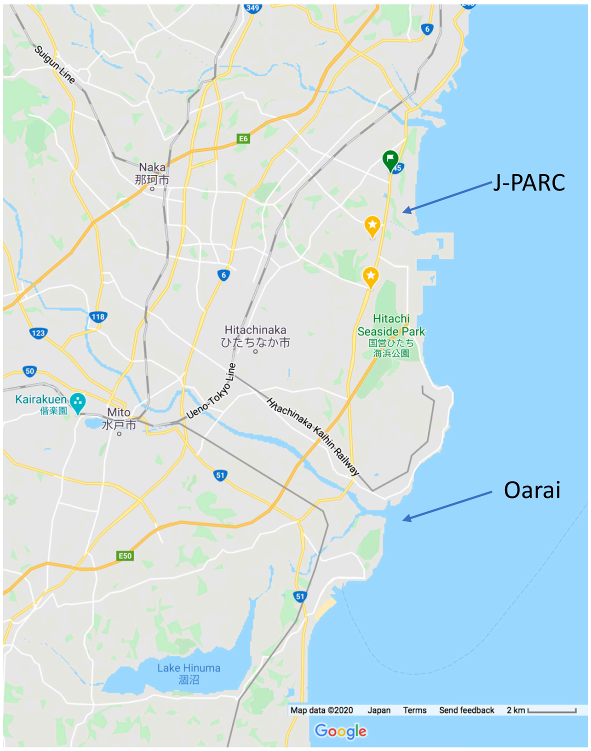

Figure 6: Location of J-PARC and Oarai coast.

peaks have large and small amplitudes alternately, which corresponds to the strong and week low tides. The valleys are also similar. The $\Delta p/p$ oscillation pattern is estimated to be generated by the circumference change of the ring due to the tidal force. If RF frequency and bending field are constant, $\Delta p/p$ can be written as

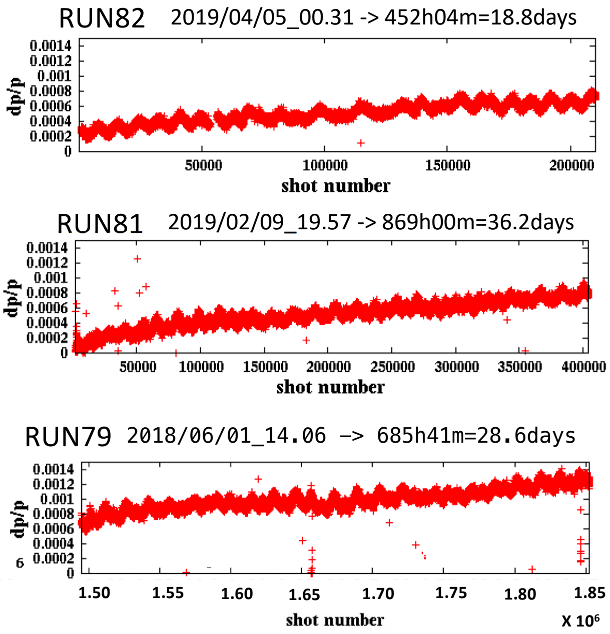

Figure 7: Long term $\Delta p/p$ shifts for three runs.

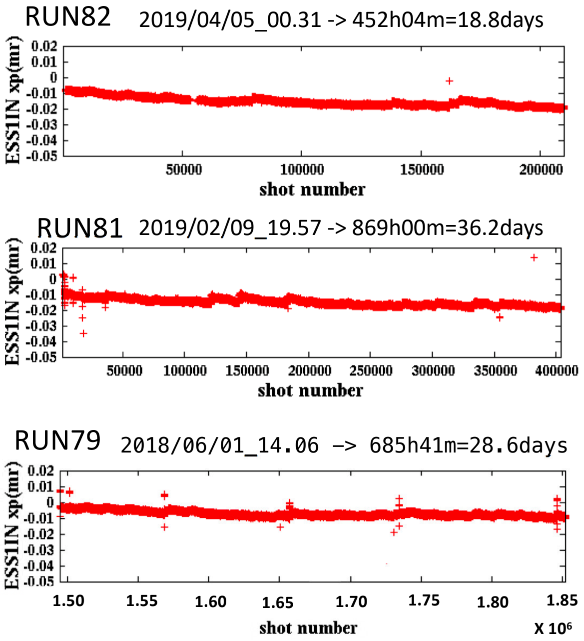

Figure 8: Long term shifts of x' at ESS1 entrance corresponding to Fig. 7.

$$\frac{\Delta p}{p} = \gamma^2 \cdot \frac{\Delta C}{C}, \tag{3}$$

where, γ and C are Lorentz factor and the ring circumference, respectively [8]. From Eq. (3), when $\Delta p/p$ increases by 0.0001 at 30 GeV, the corresponds C expansion becomes 0.144 mm (= ΔC).

Figure 7 shows a longer term stability of orbit angle at the ESS1 entrance and $\Delta p/p$, three different run cases are plotted. The $\Delta p/p$ increases monotonically in the long period at any run (0.002~0.003/100days). The long term $\Delta p/p$ shifts is rather larger than the oscillation amplitude by the tide. On the other hands, the orbit angle at the ESS1 entrance shifts monotonically in the long period at any run (-0.05~-0.03 mrad/100 days). Temperature in the MR tunnel has been controlled by air conditioners in three machine buildings connected to the MR tunnel. The air temperature in the SX operation is roughly 4 degree higher than the air temperature in the machine maintenance period. The tunnel concrete may expand gradually by the air temperature increase of 4 degree during the slow extraction operation.

CONCLUSION

A 30 GeV proton beam accelerated in the J-PARC Main Ring (MR) is slowly extracted by the third integer resonant extraction and delivered to the hadron experimental hall. A unique dynamic bump scheme for the slow extraction has been applied to reduce the beam loss. We have achieved 51 kW stable operation at 5.2s cycle in the recent physics run. The extraction efficiency is very high, typically 99.5%. However, the dynamic bump scheme is sensitive to the beam orbit angle at the first electrostatic septum (ESS1). The orbit

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angle of the dynamic bump must be sometimes readjusted to keep such a high efficiency. A long-term stabilities of the beam position and angle at the ESS1 and $\Delta p/p$ have been investigated. We observed an oscillation synchronized with tides in Oarai coast. We also observed a monotonical $\Delta p/p$ increase in the long period at any run. They are estimated to be caused by the tunnel expansion.

ACKNOWLEDGMENT

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REFERENCES

[1] Accelerator Group, JAERI/KEK Join Project Team, "Accelerator Technical Design Report for J-PARC", KEK Report 2002–13, 2002, p.204.

[2] M. Tomizawa *et al.*, "Slow extraction from J-PARC main ring using a dynamic bump", *Nucl. Instr. and Methods*, A902, 2018, pp.51–61, `doi:10.1016/j.nima.2018.06.004`

[3] B. Goddard *et al.*, "Reduction of 400GeV/c slow extraction beam loss with a wire diffuser at the CERN Super Proton Synchrotron", *Phys.Rev.Accel.Beams*, 23, 2020, 2, 023501, `doi:10.1103/PhysRevAccelBeams.23.023501`

[4] F.M. Velotti, *et al.*, "Septum shadowing by means of a bent crystal to reduce slow extraction beam loss", *Phys.Rev.Accel.Beams*, 22, 2019, 093502, `doi:10.1103/PhysRevAccelBeams.22.093502`

[5] M. Tomizawa *et al.*, "Status and Beam Power Ramp-Up Plans of the Slow Extraction Operation at J-Parc Main Ring", in *Proc. 61st ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams (HB'18)*, Daejeon, Korea, Jun. 2018, pp. 347–351. `doi:10.18429/JACoW-HB2018-THA1WD03`

[6] R. Muto *et al.*, "Current Status of Slow Extraction from J-PARC Main Ring", *IOP Journal of Physics Conference Series*,1350, 012105, `doi:10.1088/1742-6596/1350/1/012105`

[7] Oarai Tide Table, Japan Meteorological Agency, `https://www.jma.go.jp/jma/index.html`

[8] C. Bovet *et al.*, "A selection of formula and data useful for the design of A.G. synchrotrons", CERN/MPS-SI/Int. DL/70/4, 23 April, 1970.