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Slow extraction from the J-PARC main ring using a dynamic bump

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ABSTRACT

A dynamic bump under the achromatic condition has been applied for third integer slow extraction from the Japan Proton Accelerator Research Complex main ring. This dynamic bump scheme has drastically reduced beam loss rate for slow extraction compared to that for a fixed bump mode. The low beam loss rate for slow extraction has been retained for high power operations. A beam power of 41−44.4 kW was achieved for physics runs using the slow extraction by applying the dynamic bump scheme. The beam profile measured just upstream of the target indicates that the beam spot at the target does not travel over the entire extraction time. This behavior is advantageous for experimental data acquisition.

1. Introduction

The accelerators of the Japan Proton Accelerator Research Complex (J-PARC) comprise a 400 MeV linac, 3 GeV rapid-cycle synchrotron (RCS) and 30 GeV main ring (MR) [1]. An imaginary transition γ_t lattice has been adopted for the MR [2]. A high-intensity proton beam accelerated in the 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. 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. In January 2009, the first 30 GeV proton beam was successfully slow-extracted and delivered to the hadron experimental hall [3]. One of the critical issues in slow extraction of a high intensity proton beam is an inevitable beam loss caused by the extraction process at septum devices. A design with a low beam loss rate (high extraction efficiency) is required to reduce machine damage and radiation exposure during hands-on maintenance. Slow extraction from J-PARC MR has unique characteristics that can be used to obtain a low beam loss rate [4,5]. Devices with electrostatic septum (ESSs) and magnetic septum (SMSs) are placed in the long straight section with zero dispersion. The separatrix for the third-integer resonance is independent of the momentum at the septa when the horizontal chromaticity is set to zero. The resulting beam has a large step size and small angular spread, enabling a low hit rate of the beam on the septum of the ESS1. Under these conditions, a dynamic bump scheme has been applied to reduce the beam loss further. This scheme has drastically reduced the beam loss at the SMSs as well as the ESSs. The beam position on the target is maintained without any other beam tuning in the hadron beam line by applying the dynamic bump scheme. In this paper, we briefly review an outline of slow extraction from the MR. We explain the dynamic bump scheme, including the beam simulation, and show the beam performance achieved by applying the scheme.

2. Design and simulation of efficient slow extraction

2.1. Overview of the slow extraction from J-PARC main ring

The MR has a circumference of 1567.5 m and a superperiodicity of 3. Each period has a 406.4 m arc section and a 116.1 m long straight section (LSS) as shown in Fig. 1. An imaginary transition γ_t lattice has been adopted in the MR. The arc section has eight modules, each consisting of three DOFO cells with four quadrupole families (QFN, QFX, QDN, and QDX) and a bending family (BM). To produce negative dispersion, the center cell of each module has no bending magnet. Sextupole families (SFA, SDA, and SDB) for correcting the chromaticity are located in the center cell [1]. The lower part of Fig. 1 shows the LSS for slow extraction, which branches to a beam transfer line (hadron beam line) in the hadron experimental facility. The LSS has a short section located between the two focusing quadrupoles QFT and QFP, with the Courant-Snyder lattice function parameter β_x of 40 m, which is the largest in the ring. This section is a suitable location for the

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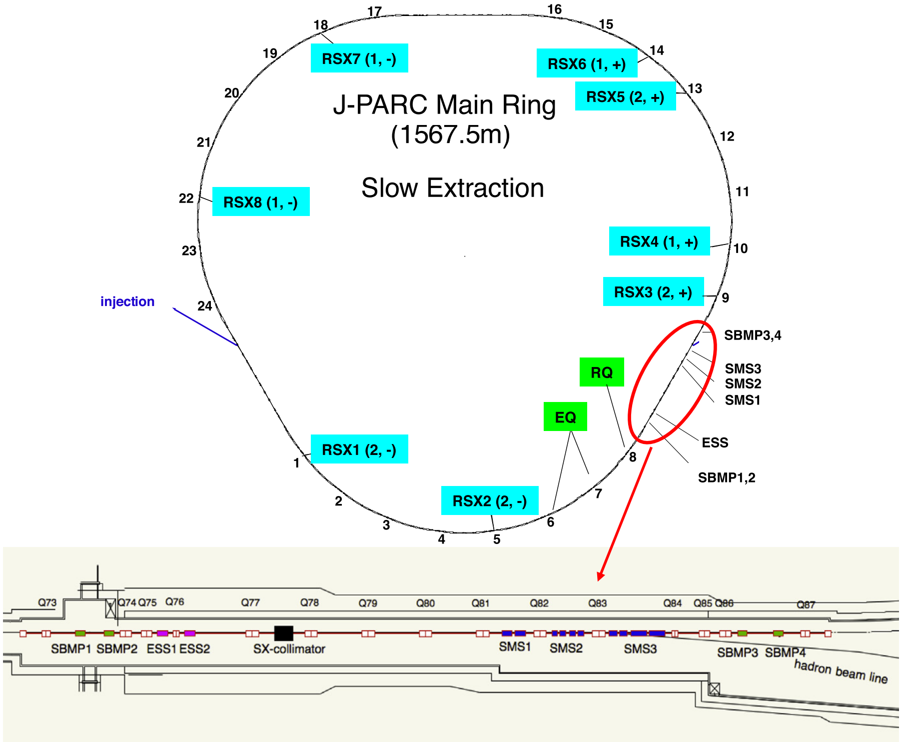

Fig. 1. Locations of slow extraction devices in the main ring.

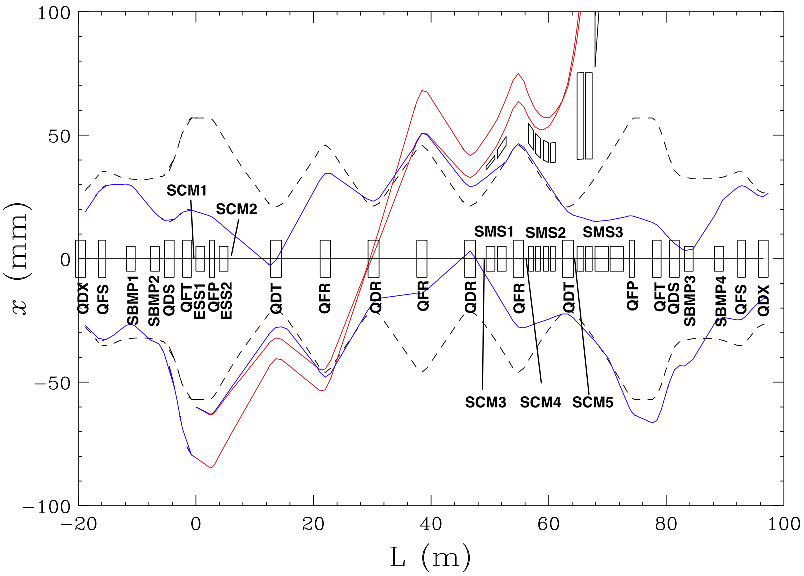

Fig. 2. Envelopes of the extracted (red lines), circulating (blue lines) and injection (broken lines) beams. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

first septum device, as described in Section 2.2. Two ESSs (ESS1 and ESS2), low field SMSs (SMS11 and 12), medium field SMSs (SMS21–24), high field SMSs (SMS31–34) and bump magnets (SBMP1–4) are located in this LSS. The horizontal betatron phase advance from the ESS1 to SMS11 is 250°, which is near the condition, $90+180\cdot n$ (n:integer), giving the largest spatial separation between the extracted and the circulating beams. A beam entering the electric field region of the ESSs is kicked inside, goes to the outside because of a betatron oscillation, and is then kicked out by the SMSs. Fig. 2 shows a beam envelope, which is obtained from the separatrices obtained using an analytical approach [6,7]. We have enough free space between the ESSs and the first SMS that we can apply collimators for protons scattered through the ESS, radiation shielding, and additional diagnostics. The horizontal tune is ramped to a $\nu_x = 67/3$ resonance by adjusting the 48 QFNs distributed in the arc section. The tune ramping does not affect the extracted beam orbit because it does not change the quadrupole strength in the LSS. The tune diagram for the MR operation area is shown in Fig. 3. The MR parameters specific to slow extraction operation are listed in Table 1.

The ESSs, (ESS1 and ESS2), are placed at the locations shown in Fig. 1. To improve the robustness of the septa, we employed tungsten ribbons [8] with 26% rhenium, instead of the more popular plain tungsten wires. The ribbons are 1 mm wide and 25–30 μm thick, and are attached to a 1.5-m-long C-shaped frame made of stainless steel (SUS) at every 3 mm of pitch. The circulating beam passes through the