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SIMULATION OF DEBUNCHING FOR SLOW EXTRACTION IN J-PARC MR

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Abstract

The J-PARC MR delivers a proton beam for nuclear physics experiments with slow extraction. The beam is debunched at flat top to obtain a coasting beam by turning off the rf voltage. The beam loading effect can disturb the uniformity of the debunching at the flat top. We describe the results of the particle tracking simulation including the beam loading effect.

INTRODUCTION

The J-PARC Main Ring (MR) receives a high intensity proton beam of 3 GeV from Rapid Cycling Synchrotron (RCS) and accelerates it up to 30 GeV [1]. The beam is slowly extracted and delivered to a hadron experimental hall for the nuclear physics [2]. The beam is debunched at the flat top by turning off the rf voltage for the slow extraction. The beam commissioning of the slow extraction has been performed and the beam power of 23.8 kW has been successfully obtained so far.

Furthermore, the beam power should be increased to 100 kW next step. One of the issues is the beam loading effect during the debunching. Since the rf voltage is turned off at the flat top, a wake voltage caused by the cavity impedance becomes the main component. Since the slippage factor at the flat top is small, even the small wake voltage can disturb the debunching. We have investigated the debunching process by a particle tracking simulation.

ACCELERATION

The number of the particles to be accelerated in the MR is 1.25×10^{14} ppp for 100 kW slow extraction with the repetition period of 6 s. The harmonic number h is 9 and 8 bunches are filled in the rf bucket. The acceleration voltage of 280 kV is generated by 8 rf cavities.

The MR receives the RCS bunches which have the longitudinal beam emittance of 5 eVs. The emittance is enlarged by a phase modulation method to mitigate the microwave instability. The phase modulation is performed using a high frequency cavity [3], and the emittance becomes 10 eVs.

After the emittance is enlarged, the beam is accelerated up to 30 GeV during 1.9 s. The beam loading effect is compensated by a multi-harmonic feedforward method [5], and the compensation harmonics are $h = 8 \sim 10$. The beam emittance and the bunch shape calculated through the RCS and the MR acceleration process are shown in Fig. 1. The horizontal axis corresponds to the MR ring circumference. This is the initial distribution of the debunching simulation.

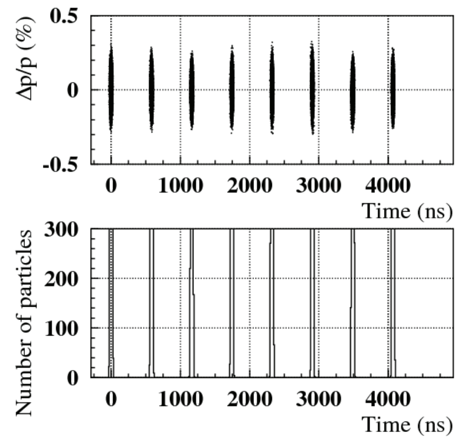

Figure 1: The simulation result of the beam emittance and the bunch shape before the debunching.

DEBUNCHING

The debunching starts when the acceleration voltage is turned off at the flat top, and the slow extraction starts 0.3 s later. The simulation has been performed until 0.5 s from the debunching start. Figure 2 shows the calculation result without any beam loading effect. The beam is smoothly debunched in this case.

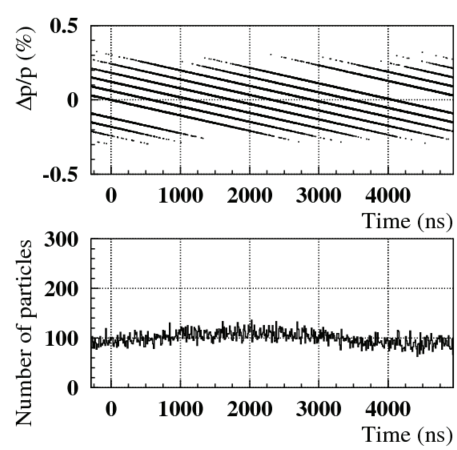

Figure 2: The simulation result during the debunching without any beam loading effect.

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Next, the beam loading effect is considered. The MR cavity has 3 accelerating gaps and each gap has a shunt impedance of $\sim 1100\ \Omega$ [4]. The quality factor is ~ 22 and the resonant frequency is ~ 1.72 MHz. Figure 3 shows the cavity impedance where the 3 gaps are connected in parallel. The black line is the case that the cavity is regarded as an ideal parallel LCR resonant circuit. First of all, we have calculated the debunching for this ideal cavity impedance.

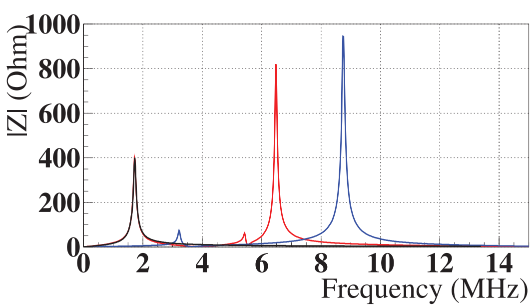

Figure 3: The cavity impedance. The black line is the ideal case, the red one is the measurement result of the real cavity, and the blue one is the measurement result with a gap short relay.

Ideal avity Impedance

Figure 4 shows the calculation result with the ideal cavity impedance. Since the beam loses the energy by the beam loading effect, the beam distribution is biased below $\Delta p/p = 0$. The bunch shape is also not uniform.

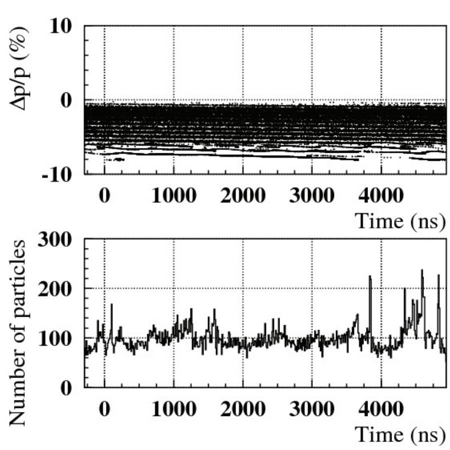

Figure 4: The simulation result during the debunching with the beam loading effect. The ideal cavity impedance is assumed, and the beam loading is not compensated.

Figure 5 shows the calculation result where the beam loading effect is compensated for the harmonics of $h = 8 \sim 10$, which is the same method as applied in the acceleration stage. Although the energy loss is recovered, the compensation is not enough because the beam distribution still has structure.

Figure 6 shows the case that the compensation is done for the harmonics of $h = 6 \sim 10$. The compensation harmonics are added until the bunch shape becomes almost uniform.

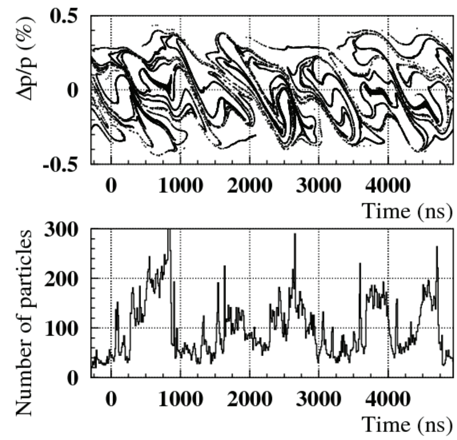

Figure 5: The simulation result during the debunching with the beam loading effect. The beam loading is compensated for the harmonics of $h = 8 \sim 10$.

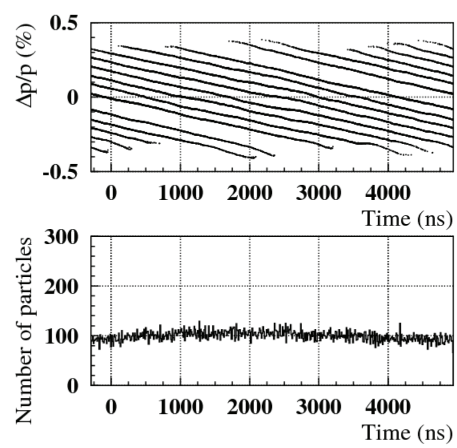

Figure 6: The simulation result where the compensation is done for the harmonics of $h = 6 \sim 10$.

Since the compensation for the harmonics of $h = 6, 7$ is not equipped in the present MR rf system, it should be considered for the 100 kW debunching.

Parasitic esonance

The simulation results indicate that the beam loading compensation for the harmonics around the main resonance makes the debunching uniform in the ideal cavity impedance case. However, the real cavity has parasitic resonances. The red line in Fig. 3 is the measurement result of the real cavity impedance. The real cavity has a large parasitic resonance around 6.5 MHz ($h = 34$) and a small one around 5.4 MHz ($h = 28$).

Figure 7 shows the calculation result including the parasitic resonance. Although the beam loading effect is compensated for the harmonics of $h = 6 \sim 10$ in the same

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way in Fig. 6, the energy loss is caused by the parasitic resonance.

Figure 8 shows the result where the compensation is done for the harmonics of $h = 6 \sim 10$, $27 \sim 29$ and $32 \sim 35$. The uniformity of the debunching is restored by compensating for the harmonics around the parasitic resonances. However, the large number of the harmonics should be compensated in this case. If the parasitic resonances can be suppressed by adding some damper circuit at the cavity, the beam commissioning of the compensation will be relieved.

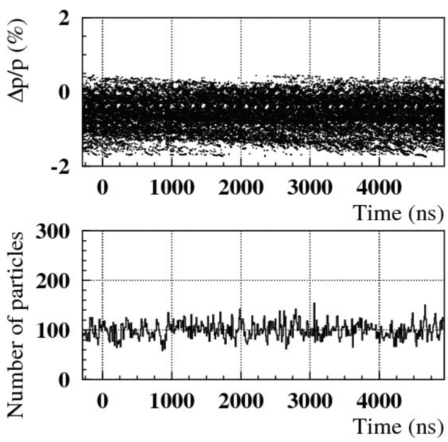

Figure 7: The simulation result where the cavity has the parasitic resonance. The beam loading effect is compensated for the harmonics of $h = 6 \sim 10$.

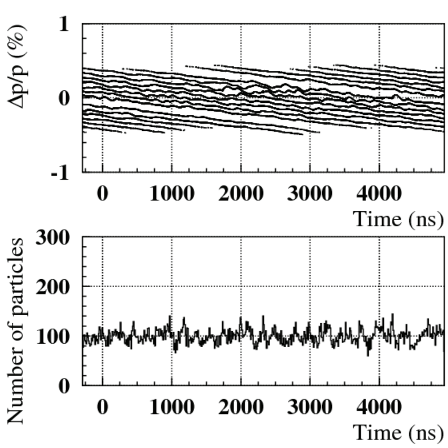

Figure 8: The simulation result where the cavity has the parasitic resonance. The compensation is done for the harmonics of $h = 6 \sim 10, 27 \sim 29$ and $32 \sim 35$.

Gap short relay

One way to reduce the cavity impedance seen by the beam is using a vacuum relay at the cavity gap. It is activated after the acceleration voltage is turned off.

If the gap is shorted completely, the cavity impedance seen by the beam becomes zero. However, the cavity impedance with the gap short relay also has a parasitic resonance as shown in Fig. 3. The blue line is the measurement result of the cavity impedance with the gap short relay, and there is a large parasitic resonance around 8.7 MHz ($h = 46$). This parasitic resonance also disturbs the debunching, but the beam loading compensation can not be used in this case because the cavity gap is shorted.

Figure 9 shows the calculation result in the case that the gap short relay is activated. The beam loading effect is not compensated. The energy loss is caused by the parasitic resonance, and the beam distribution is not so uniform. This means the parasitic resonance should be removed when the gap short relay is used. Furthermore, since there is a time lag of 20 ms to activate the gap short relay, the energy loss can not be avoided during this period.

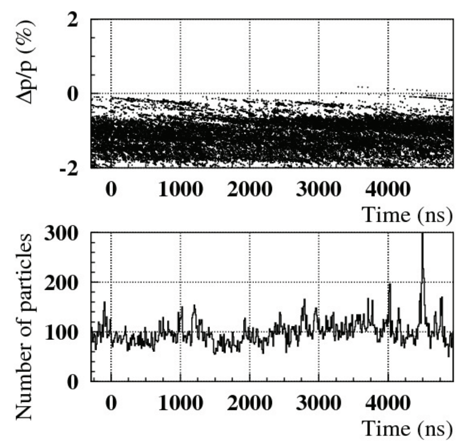

Figure 9: The simulation result during the debunching with the beam loading effect. The gap short relay is activated.

SUMMARY

We have investigated the debunching at the J-PARC MR for the 100 kW slow extraction where the beam loading effect disturbs the debunching. The beam loading compensation method should work well when the all harmonics around the resonances are cured. The gap short relay method has the issue of the parasitic resonance. It should be suppressed if the gap short relay is used.

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