LONGITUDINAL BEAM DYNAMICS ON 3 GEV PS IN JAERI-KEK JOINT PROJECT

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Abstract

Longitudinal beam emittance should be controlled to alleviate space charge effects and also to provide various types of bunched beam to the experimental hall and MR by rf manipulations at 3 GeV proton synchrotron in JAERI-KEK Joint High Intensity Proton Accelerator Project [1]. Furthermore, heavy beam loading is a severe problem, and it should be compensated by feedforward method for stable acceleration. About these themes, the scenario will be described with particle tracking simulations.

1 INTRODUCTION

Since the 3 GeV Rapid Cycle Synchrotron (RCS) accelerates a high intensity proton beam, some cures should be considered at the rf system to suppress space charge effects, beam instabilities, bucket distortion and beam loading effects on the longitudinal beam motion.

At the injection, the bunching factor should be improved to alleviate the space charge effects. We plan the adding of a 2nd higher harmonic voltage and introducing a momentum offset injection scheme, then the bunching factor of 0.4 should be achieved by choosing suitable injection parameters.

At the extraction, the RCS provides 25 pulses/sec of bunched beam where 4 pulses are for the 50 GeV Main Ring (MR) and the others are for the experimental hall. There are 3 types of the bunched beam required and they should be obtained by some rf manipulations until the extraction. One is for the neutron scattering experiment, and it is achieved without any manipulation during the acceleration. The 2nd one is a short bunched ($<$ about 100 ns) for the muon experiment, and is achieved by increasing the accelerating voltage at the near the end of the acceleration cycle. The last one is for the MR injection where the bunching factor should be over 0.3 considering the space charge effects in the MR, and it is achieved by adding a 2nd higher harmonic voltage again near the end of the acceleration cycle.

Furthermore, heavy beam loading effect at the rf acceleration system is a severe problem especially at the extraction where the accelerating voltage becomes much smaller than the induced beam voltage. A beam current feedforward compensation method is foreseen to suppress the beam loading effect.

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2 LONGITUDINAL EMITTANCE CONTROL

The parameters of RCS are a little bit different from the previous ones which we reported before [2, 3, 4] because the circumference of RCS ring has been lengthened. The revised parameters are listed in [5].

2.1 Injection

The Linac provides a bunched beam (called "macro bunch") to the RCS by the multi-turn injection during about 500 μsec. The maximum beam current is $\sim$50 mA (= 3.1 $\times 10^{17}$ protons per sec.) and its momentum spread is $\Delta p/p \sim \pm 0.1$%. The bunch length from Linac is expressed as a chopping factor which is defined by (macro bunch full length) / (RCS rf voltage wave length at the bottom of the bending field). The chopping factor is an important parameter at the injection because it strongly affects the longitudinal beam emittance in the RCS. The correlation among the macro bunch length, the chopping factor, number of the injection turns and the injection time is listed in Table 1 where the Linac beam current is fixed at 50 mA.

	Macro bunch length (ns)			
	350	400	450	500
Chopping factor	0.43	0.49	0.55	0.61
Injection turns	381	334	297	267
Injection time (μs)	619	544	482	433

Table 1: Correlation among the macro bunch length, the chopping factor, number of the injection turns and injection time.

If the macro bunch from Linac is injected into just the center of the rf bucket of the RCS, the charge density at the center of the rf bucket becomes fairly high, then the bunching factor becomes very small. In order to avoid such a situation, it is planned that the macro bunch from the Linac is injected with a momentum offset, then it is expected that the charge density should be smeared and the bunching factor should be getting bigger.

The Figures 1 and 2 show the simulation results around the injection by the longitudinal particle tracking code, and the momentum offset of + 0.4 % and + 0.5 % are simulated, respectively. The beam emittance and bunch shape shown in Figs. 1 and 2 are snapshots taken at the 2 ms from the bottom of the bending field. In all cases, the 2nd higher harmonic voltage of $0.8V_{\text{fund}}\cos\phi_s$ is added where V_{fund} is an amplitude of the fundamental acceleration voltage and ϕ_s is the synchronous phase. The bunching factor is calculated from the bunch shape after binning and averaging 7 adjacent bins. The simulation results are summarized in Fig. 3 where the correlation between the bunching factor and the macro bunch length is shown on each case of the momentum offset. From these results, the bunching factor of 0.4 should be achieved by choosing optimum momentum offset and macro bunch length, and adding 2nd harmonic voltage is also required. The most suitable parameters are; (1) momentum offset of 0.4 % and macro bunch length of around 500 ns or (2) momentum offset of 0.5 % and macro bunch length of around 400 ns.

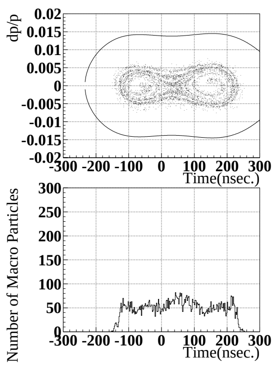

Figure 1: Simulation result with the macro bunch length of 400 ns and the momentum offset of 0.4 %. The bunching factor is 0.40.

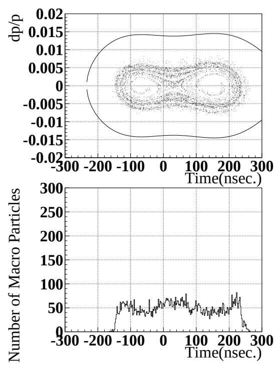

Figure 2: Simulation result with the macro bunch length of 400 ns and the momentum offset of 0.5 %. The bunching factor is 0.41.

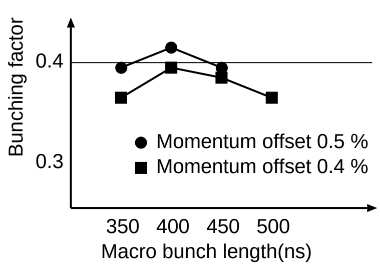

Figure 3: The bunching factor vs the macro bunch length in the case of momentum offset of 0.4 % and 0.5 %.

2.2 Extraction

As mentioned above, it is required that the RCS provides three types of bunched beam to the experimental hall and the MR. In these cases, the injection pattern is same which is described in the previous section. We used the chopping factor of 0.54 and momentum offset of 0.4 % at the injection as a reference injection pattern. The longitudinal emittance control for the extraction is managed at the latter part of the acceleration period.

For the neutron scattering experiment This is a reference rf operation of the RCS because no manipulation is required for the rf voltage pattern at a latter part of the acceleration. In this case, the beam emittance is about 3.5 eVs and the bunch length is about 140 ns. The beam emittance and the bunch shape for the neutron scattering experiment are shown in Fig. 4.

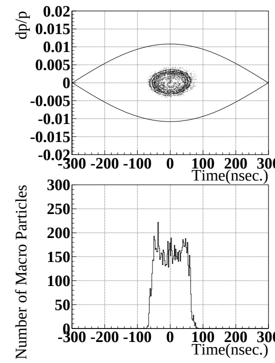

Figure 4: The beam emittance and the bunch shape at the extraction for the neutron scattering experiment.

For the muon experiment This operation is for the muon experiment users. They need a shorter bunch than the reference operation such as bunch length of ~100 ns. In order to provide such bunch, the accelerating voltage is kept 300 kV from 14 ms to the extraction, whereas that of the normal operation is 60 kV at the extraction. Finally, the bunch length of about 90 ns can be obtained. The beam emittance and the bunch shape for the muon experiment are shown in Fig. 5.

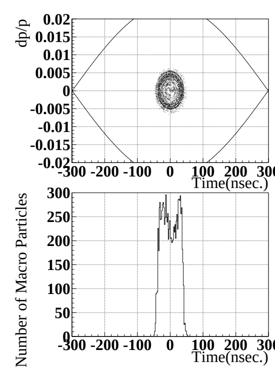

Figure 5: The beam emittance and the bunch shape at the extraction for muon experiment.

For the MR injection There are some requirements for the MR injection. One of them is the bunching factor, which should be over 0.3 at the injection. If it is not obtained, fast beam loss by the space charge tune shift at MR injection will occurr. To avoid such a situation, the bunching factor of RCS at the extraction also should be over 0.3. The 2nd higher harmonic voltage of $0.8V_{\text{fund}}\cos\phi_s$ is added to flatten the bunch shape again from 19 ms to the extraction. In this case, the bunch factor of 0.3 and the bunch length of 250 ns can be obtained. The beam emittance and the bunch shape for MR injection are shown in Fig. 6. Then, the simulation for the MR shows that the bunch is successfully captured without big dipole and quadrupole oscillation which will cause the reduction of the bunching factor [7].

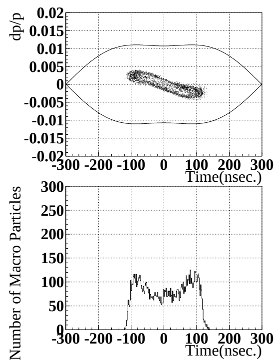

Figure 6: The beam emittance and the bunch shape at the extraction for MR injection.

2.3 Beam Loading

It is recommended that the relative loading factor Y should be lower than 1 [8], and it is almost always under 1 in the RCS. However, it becomes a fairly large number especially at the extraction because the accelerating voltage should be small to match the rf bucket of the RCS with that of the MR. In order to stabilize the rf feedback loop under the heavy beam loading condition, we plan the beam loading compensation.

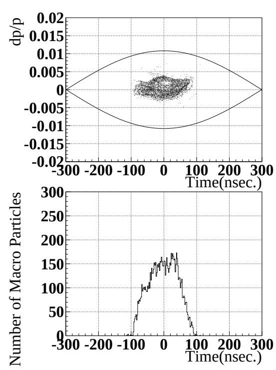

Figure 7: The beam emittance and the bunch shape at the extraction by using beam loading compensation up to 2nd higher harmonic component.

The compensation scheme is that the beam current is picked up by a longitudinal monitor such as wall current monitor or fast current transformer, then added into the cavity drive signal as it has a opposite phase to the original picked up signal [9]. Since the beam has many Fourier components, and since the magnitude and the phase of the cavity changes during acceleration, the feedforward module separates each of the Fourier components and adjusts the amplitude and the phase to cancel the beam loading clearly. The details of this module will be described in [10].

The Figure 7 shows the simulation results which includes the beam loading, the space charge effect and the beam loading compensation up to 2nd higher harmonic component (h=2, 4). As seen in the plot, the distortion of the beam emittance is not so big. Thus, the beam loading compensation up to 2nd one is enough for the stable acceleration.

3 SUMMARY

The longitudinal emittance control has been investigated for the JKJ 3 GeV RCS. We have shown the following points by using particle tracking code.

- It is possible to obtain the bunching factor of 0.4 by using the momentum offset and the 2nd higher harmonic voltage at the injection.
- The RCS will be able to provide different types of the bunched beam by manipulating the rf voltages until the extraction.
- The beam loading compensation up to the 2nd higher harmonics is enough for stable acceleration.

4 REFERENCES

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