OBSERVATION OF LONGITUDINAL SPACE CHARGE EFFECTS IN THE INJECTION BEAM LINE OF NIRS-930 CYCLOTRON

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Abstract

The dependence of bunching efficiency on the position of the beam buncher was measured for the AVF cyclotron (NIRS-930) at the National Institute of Radiological Sciences (NIRS) using 30 MeV proton beams with intensities of up to 100 µA at injection. The measurement was carried out for two buncher positions: 1.53 m and 2.33 m upstream from the inflector. At 2.33 m, the bunching efficiency decreased as the beam intensity increased to about half that at low intensity. For 1.53 m, bunching efficiency was constant up to 100 µA. Intensity distributions of the extracted beam with respect to buncher phase were also measured for the two buncher positions. The dependence of bunch length on the beam intensity is discussed by comparing the data with one-dimensional simulations on longitudinal space charge effects.

INTRODUCTION

The NIRS-930 cyclotron is used mainly for production of radioisotopes and short-lived radio-pharmaceuticals [1]. It delivers frequently a high-intensity beam (20 µA) of 30 MeV protons for those applications. To meet the demand from users of higher intensity beams, we replaced the beam buncher with a new single-gap type, which is planned for application as a saw-tooth rf voltage [2]. We then used this opportunity to investigate longitudinal space charge effects on a beam in the injection beam line.

MEASUREMENT OF BUNCHER EFFECTS

Effect of Buncher Position for High-Intensity Beams

The layout of the beam injection line is shown in Figure 1. A beam is transported axially through four sets of Glazer lenses in the hole of the upper yoke, and bent by the inflector onto the median plane of the cyclotron. The old and new beam bunchers were set at two different positions (measured in terms of the distance L upstream from the inflector). The new one was set at L = 2.33 m, with the old one kept at L = 1.53 m, the normal position in routine operation. A Faraday cup (FC4) is located 1.6 m from the inflector.

Measurements were carried out for a 30 MeV proton beam, for which the injection energy was 8.2 keV. The cyclotron was operated at an rf frequency of 12.83 MHz, with an acceleration harmonic of 1. A sine wave voltage was applied to the two bunchers through a resonant circuit.

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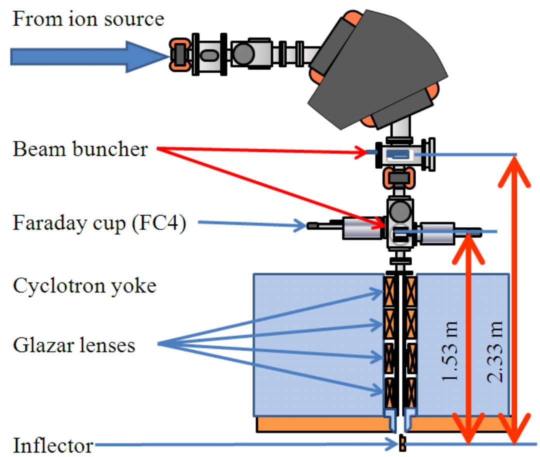

Figure 1: Layout of the beam injection line.

Tables 1 and 2 show the beam intensities and bunching efficiencies obtained when the old and new beam bunchers were set at L = 1.53 m and 2.33 m, respectively. The bunching efficiency is defined as the ratio of beam intensity when the beam buncher is on to the intensity when it is off. The labels "R=0.05 m" and "R=0.93 m" refer to the measurement positions of the radial probe in the cyclotron: at a radius of 0.05 m (2 turns after injection) and at the radius of 0.93 m (the entrance of the deflector), respectively. The label "BS0" denotes a faraday cup located downstream of the cyclotron. In both cases, the beam intensity at the FC4 was 100 µA.

Table 1: Beam Intensities and Bunching Efficiencies Obtained when the Buncher was set at L = 1.53 m.

	Buncher off [µA]	Buncher on [µA]	Bunching efficiency
R=0.05 m	13.1	31.3	2.39
R=0.93 m	10.2	30.3	2.97
BS0	4.0	20.0	5.00

Table 2: Beam Intensities and Bunching Efficiencies Obtained when the Buncher was set at L = 2.33 m.

	Buncher off [µA]	Buncher on [µA]	Bunching efficiency
R=0.05 m	13.8	21.1	1.53
R=0.93 m	11.0	19.5	1.77
BS0	4.3	12.8	2.98

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The beam intensities and bunching efficiencies obtained at BS0 were:

1. The beam intensity was 4 μA when the beam bunchers were off.
2. When the beam buncher located at L = 1.53 m was on, the beam intensity increased to 20 μA and the corresponding bunching efficiency was 5.
3. When the beam buncher located at L = 2.33 m was on, the beam intensity and the bunching efficiency were only 60% of those obtained for the case of L = 1.53 m.

It could be concluded that the bunching efficiency depends on the buncher position. The longitudinal space charge effects might affect bunching efficiency at a beam intensity of as high as 100 μA. As such, we further measured the dependence of beam intensity for the two buncher positions.

Dependence of Bunching Efficiency on Beam Intensity for Two Different Buncher Positions

The dependence of bunching efficiency on beam intensity was measured at R = 0.05 m, R = 0.93 m, and BS0, as shown in Figures 2, 3, and 4, respectively. Dependence for both buncher positions were compared, with the following results:

1. For L = 1.53 m, the bunching efficiencies were almost constant irrespective of beam intensity.
2. For L = 2.33 m, the bunching efficiencies were nearly the same as those for L = 1.53 m at low beam intensities, but decreased with the beam intensity beyond 30 μA.

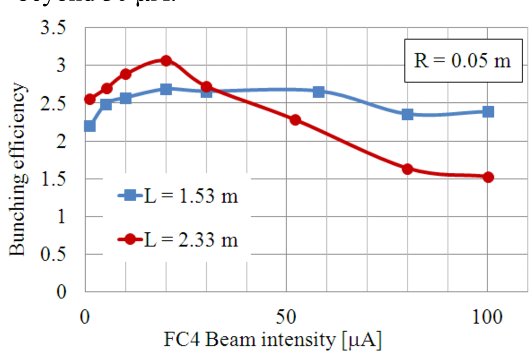

Figure 2: Dependence of bunching efficiency on beam intensity at R = 0.05 m.

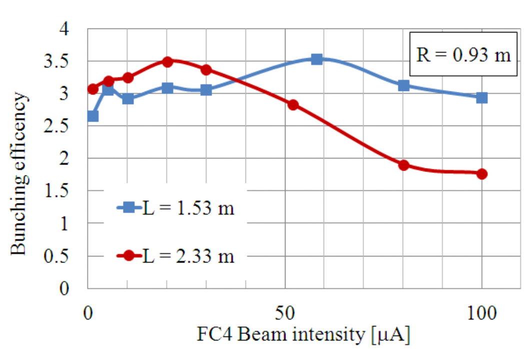

Figure 3: Dependence of bunching efficiency on beam intensity at R = 0.93 m.

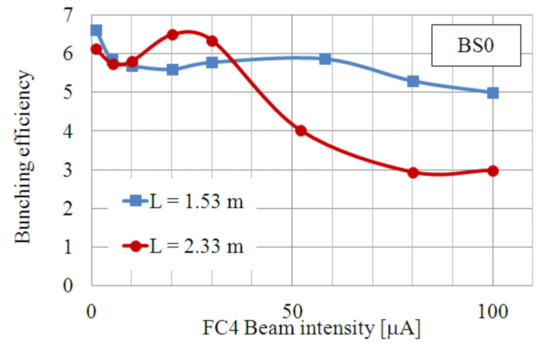

Figure 4: Dependence of bunching efficiency on beam intensity at BS0.

Dependence of Bunch Length on Beam Intensity for Two Different Buncher Position

The decrease in bunching efficiency with increased injection beam intensity might be because space charge effects weakened longitudinal focusing to such a degree that the beam could not be kept within the cyclotron phase acceptance. To confirm this, the change of beam intensity at BS0 based on the buncher phase was measured for the two buncher positions. The measured data for the beam intensities at FC4 of 1, 10, 50, and 100 μA are shown in Figures 5-8, respectively. The results are:

1. For L = 1.53 m, the distribution of the beam intensity showed a triangular for all the beam intensities. The triangle distribution means that the bunch length (phase width) and the phase acceptance were almost the same as each other. They could thus be deduced to be about ± 30°.
2. For L = 2.33 m, the triangular distribution was seen up to 10 μA. However, the bunch length began to spread at 50 μA. Furthermore, at 100 μA, the bunch length spread much more and two peaks appeared. The distance between the two peaks is approximately 40°. This spread means that longitudinal focusing was not strong enough due to space charge effects.

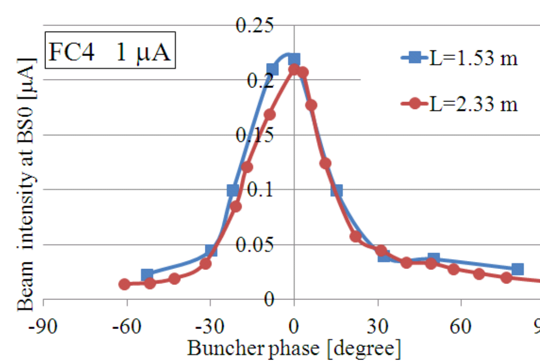

Figure 5: Change of the beam intensity at BS0 with the buncher phase. The beam intensity at FC4 is 1 μA.

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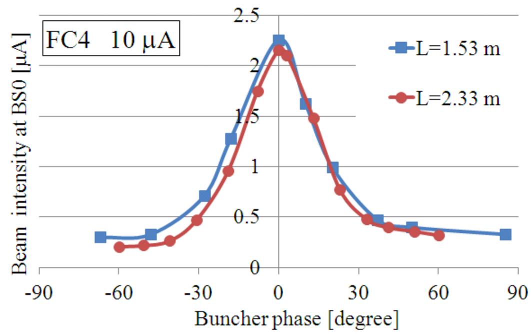

Figure 6: Change of the beam intensity at BS0 with the buncher phase. The beam intensity at FC4 is 10 µA.

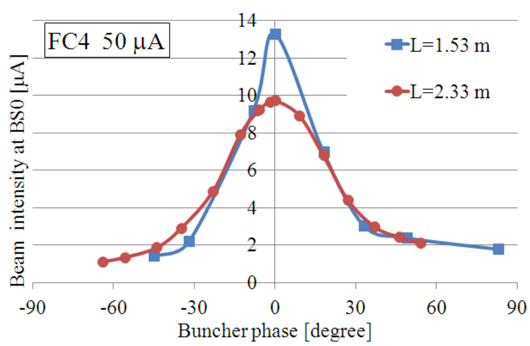

Figure 7: Change of the beam intensity at BS0 with the buncher phase. The beam intensity at FC4 is 50 µA.

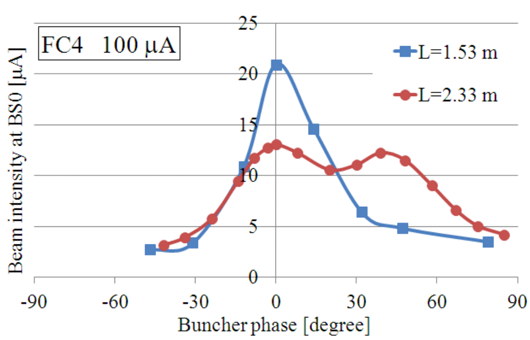

Figure 8: Change of the beam intensity at BS0 with the buncher phase. The beam intensity at FC4 is 100 µA.

DISCUSSION ALONG WITH SIMULATIONS

We performed beam simulations including one-dimensional longitudinal space charge effects to further investigate the dependence of beam intensity on bunch length, A computer program based on SPUNCH [3] was used to calculate the bunch length at the inflector. Calculations for the beam intensity of 100 µA at FC4 are shown in Figures 9 and 10 for the two buncher positions, L = 1.53 m and L = 2.33 m, respectively. The bunch length at the inflector spreads to ±50° at the minimum for L = 2.33 m, while it is within ±30° for L = 1.53 m. These results confirmed the triangular phase distribution in Figure 8 for L = 1.53 m and the two peaks for L = 2.33 m.

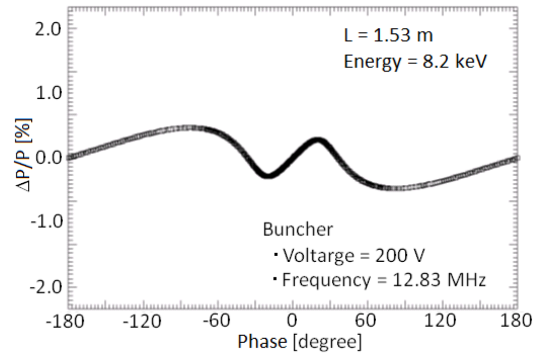

Figure 9: Calculation of the bunch length at the inflector for buncher position of L = 1.53 m. The beam intensity at FC4 is 100 µA.

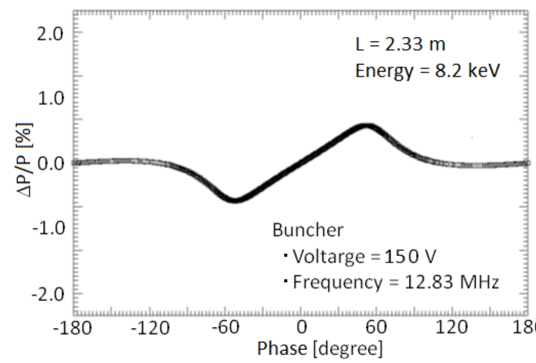

Figure 10: Calculation of the bunch length at the inflector for buncher position of L = 2.33 m. The beam intensity at FC4 is 100 µA.

CONCLUSION

The longitudinal space charge effects on a 30 MeV proton beam in the injection beam line were investigated using actual measurements and beam simulations. The bunching efficiency for a buncher position of L = 2.33 m was nearly the same as that for L = 1.53 m at low beam intensities. However, it decreased with the beam intensity beyond 30 µA, and became 60% of the efficiency for L = 1.53 m. We conclude that of 2.33 m is too far for the beam buncher to converge the beam bunch within cyclotron phase acceptance because of longitudinal space charge effects.

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