LONGITUDINAL EMITTANCE CONTROL IN HIGH INTENSITY PROTON SYNCROTRONS

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Abstract

Experiments of synchrotron injection using the direct fast chopped H^- beam extracted from a surface-plasma-type H^- ion source has been successfully achieved. The injection phase of the fast chopped beam from linac into the booster synchrtron is adjustable to the center of rf bucket by using this beam. It was obtained that the longitudinal emittance was controlled at the extraction of the booster synchrotron, and that the beam loss during the injection into main ring of the KEK-PS was reduced by this fast chopped beam.

1 INTRODUCTION

Recently, high energy and high intensity beam acceleration programs are proposed and developed. For example, JHF project shows the beam intensity of 2×10^{14} particles per pulse at the 50 GeV proton synchrotron.[1] One of the difficulties to realize such a high intensity project is the beam loss due to the beam divergence by the space charge effects of the beam itself.

The beam in the synchrotron is bunched and captured to the rf bucket. The space charge effects can be reduced by making the line density of the bunched beam small. To control the line density, the injected beam from the linac has to be bunched beforehead to the same frequency of the rf bucket of the synchrotron. And the injection phase of the linac beam is shifted to the cneter of the rf bucket. Using this method, the beam can be spread into the rf bucket by the spread of the synchrotron frequency. There are some methods to make the injection beam chopping.[2][3][4] One of the methods is the beam chopping directly at the beam production in the ion source. At KEK, a surface-plasma-type H^- ion source has been used to produce the H^- beam. The method to produce the chopped beam extracted form this ion source was reported previousely.[5]

To control the line density by using the direct fast chopped H^- beam method effectively, the adjustment of $\frac{\Delta p}{p}$ of the linac beam is necessary. When $\frac{\Delta p}{p}$ of the linac beam is not small, the beam dilution at the booster rf bucket cannot occur effectively. Therefore, debuncher installed at the 40 MeV beam transport line is used to optimize the $\frac{\Delta p}{p}$ of the linac beam.

In this paper, the results of the experiment of the inejction into KEK 12 GeV proton synchrotron using the direct fast chopped H^- beam extracted from the ion source is reported.

2 EXPERIMENTAL APPARATUS AND CONTROL SYSTEM

In KEK-PS, a surface-plasma-type negative hydrogen ion source has been developped and used. The H^- ions are mainly produced by the sputtering process on the metal surface, called converter, which is negatively biased to the plasma. As the H^- ion beam current extracted from the ion source depends on the converter bias voltage, the direct fast chopped H^- beam extracted from ion source is produced by modulating this bias voltage. The results of this chopped H^- beam experiment is reported.[5] Using this chopped H^- beam, the longitudinal emittance control at KEK booster synchrotron is examined and this controlled beam is injected into the main ring of KEK-PS.

By mismatching the phase of the injected beam to the rf bucket of the booster synchrotron at injecting the chopped H^- beam from the ion source into the booster synchrotron, the particles spread into the bucket because of the spread of the synchrotron frequency. And then, the longitudinal emittance of the beam extracted from the booster synchrotron can be controlled. The scheme of the longitudinal emittance control system of the direct fast chopped H^- beam extracted from the ion source is shown in Fig.1.

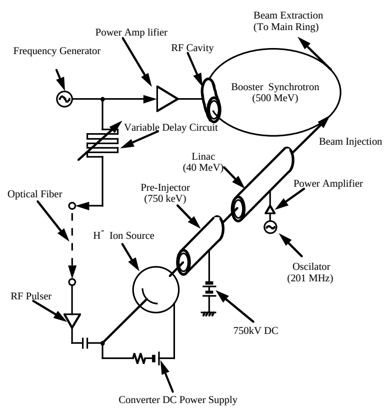


Figure 1: The longitudinal emittance control system of the direct fast chopped H^- beam.

The signal of the frequency generator of the rf cavity in the booster is triggered to the high voltage pulser biassing the converter in the ion source. The delay circuit is set between the frequency generator and the pulser to control the injection phase to the rf bucket. The acceleration frequency of the rf cavity at the beam injection is about 2.25 MHz, equal to about 444 ns period, and the injection phase control can be changed to 1 ns (about 0.81 radian). The rf pattern of the booster synchrotron is not that using for the adiabatic capture but that of high voltage beforehead at beam injection. The experimentals are examined using this rf pattern and the control unit.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Effect of Debuncher for $\frac{\Delta p}{p}$ Control of the Linac Beam

The $\frac{\Delta p}{p}$ of the linac beam must be optimized. Because the line density of the injected beam cannot be diluted at the large $\frac{\Delta p}{p}$. To optimize it, debuncher installed at 40 MeV beam transport line is used.

The injection beam width from linac is as short as possible to measure the $\frac{\Delta p}{p}$ of the linac beam. The envelope of the bunch is observed by the electrostatic monitor (ESM) for several ten μs after the beam injection into the booster synchrotron. At the injection, the beam is the minimum $\frac{\Delta p}{p}$. Becuase the envelope of the bunch starts at the minimal point.

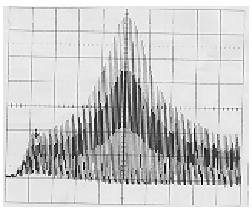


Figure 2: An example of the beam envelope measured by ESM at the injection into booster synchrotron.

At the first maximal point, which is the $\frac{1}{4}$ period of the quadrupole oscillation, the beam is the minimum of the bunch length. At the beginning of the injection, it can be assumed that the beam dilution does not start and the linearity is aproximately right. And then, the $\frac{\Delta p}{p}$ of the linac beam can be estimated by measuring the bunch length at the first maximal point of the bunch envelope. A result of the obtained $\frac{\Delta p}{p}$ of the linac beam dependent on the debuncher rf power is shown in Fig. 3. The rf bucket height is calculated about 1.8 %. Using the debuncher, 0.6 % of the $\frac{\Delta p}{p}$ can be obtained.

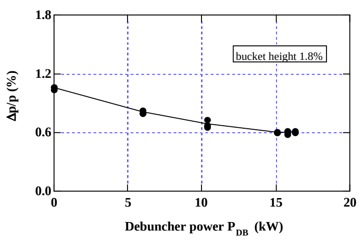


Figure 3: Debuncher rf power dependence of $\frac{\Delta p}{p}$ of the linac beam.

3.2 Longitudinal Emittance Control by Mismatched Injection of Fast Chopped Beam

The injection phase of the linac beam is changed using the delay circuit between the frequency generator of the booster rf cavity and the high voltage pulser to modulate the converter bias voltage. At the injection phase of the linac beam matched to the center of the rf bucket, the longitudinal emittance is minimum. And it increases at the injection phase of the linac beam which is shifted until $\pm 90^\circ$ to the cneter of the rf bucket. The experimetal result is shown in Fig. 4.

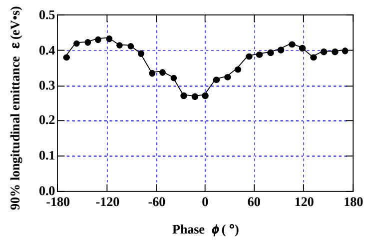


Figure 4: Injection phase dependence of longitudinal emittance.

The waveform of the bunched beam just before the extraction from 500 MeV booster synchrotron is shown in Fig. 5. The beam intensity of these bunched beam is same. This figure shows that the line density of the synchrotron beam can be controlled. The bunching factor of 90° shifted injection beam is about 0.34 although that of the center of rf bucket injection beam is about 0.22.

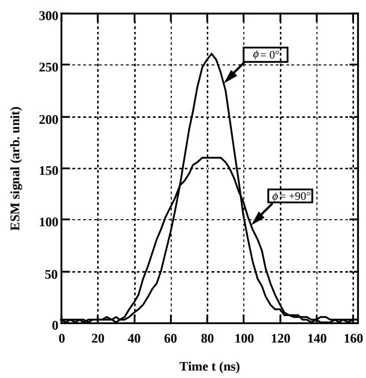
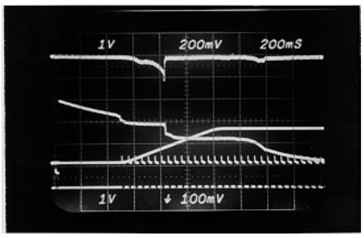


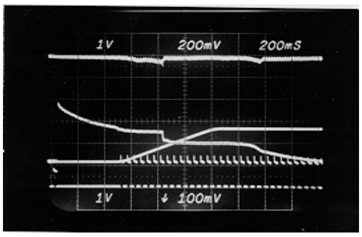
Figure 5: The waveforms of the bunched beam just before the extraction from 500 MeV booster synchrotron.

3.3 Beam Injection into Main Ring at Longitudinal Emittance Control

The waveforms of the beam intensity at the main ring is shown in Fig. 6. The decays of the beam intensity from the time of the injection into the main ring to that just before the acceleration is different. The decay of 90° shifted injection into booster synchrotron shows more gentle than that of the center of rf bucket injection. This is because the line density of the beam is controlled.



(a) 90° shifted



(b) center of rf bucket

Figure 6: Waveforms of the beam intensity at the main ring.

To confirm it, the size of the beam injected into the main ring is measured by the fast wire scanner[6]. The beam size increment is shown in Fig. 7. The beam size increment of the 90° shifted injection is smaller than that of the center of the rf bucket injection, although the beam intensity of the 90° shifted injection is higher than that of the center of the rf bucket injection.

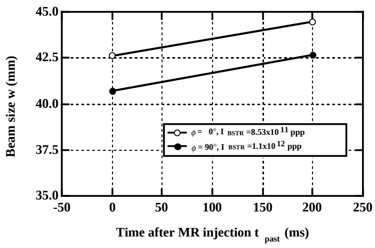


Figure 7: Beam size at the injection into the main ring measured by the fast wire scanner.

Using this method, the beam intensity of the 9 pulses injection into KEK-PS main ring is measured. The result is shown in Fig. 8. The experiments of synchrotron injection using the direct fast chopped H^- beam extracted from the surface-plasma-type H^- ion source has been achieved. The blow up of the transverse beam size due to the space charge effects by the beam itself could be reduced by the control of the longitudinal emittance from the booster synchrotron. Using this method, the beam intensity of the 9 pulses injection into the KEK-PS main ring is obtained a new record of the beam intensity at the KEK-PS main ring injection.

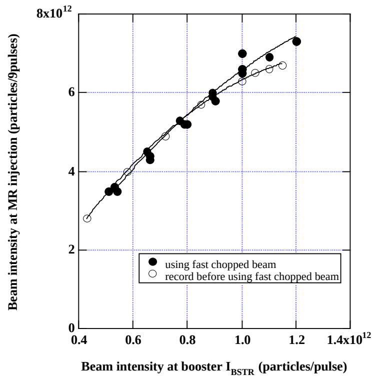


Figure 8: The beam intensity of the 9 pulses inejection into KEK-PS main ring.

4 SUMMARY AND FUTURE PLAN

The longitudinal emittance control could be practiced by using the direct fast chopped H^- beam and mismatched injection into the rf bucket. As a result, the beam intensity of the main ring at the beam injection could be increased. For the neutrino oscillation experimets, using the direct fast chopped H^- beam method is one of the most promissing one to obtain the high beam intensity.

5 REFERENCES

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