EE

INS Report

INS-Rep.-1169
Oct. 1996

SW9648

RF STACKING EXPERIMENTS AT TARN-II

S.Watanabe, T.Watanabe, M.Yoshizawa, M.Tomizawa, K.Chida, Y.Arakaki and T.Katayama
Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo 188, Japan
M.Kanazawa
National Institute of Radiological Sciences, Anagawa, Chiba 263, Japan
M.Takanaka
The Institute for Physical and Chemical Research, Wako, Saitama 351-01, Japan
A.Noda
The Institute for Chemical Research, Kyoto University, Uji, Kyoto 611, Japan

Paper presented at the 6th CHINA-JAPAN JOINT SYMPOSIUM on Accelerators for Nuclear Science and Their Applications (CJAS'96), Chengdu, China, 21-25 October, 1996

Institute for Nuclear Study
University of Tokyo
Tanashi, Tokyo 188, Japan

RF STACKING EXPERIMENTS AT TARN-II

S.Watanabe, T.Watanabe, M.Yoshizawa, M.Tomizawa, K.Chida, Y.Arakaki and T.Katayama
Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo 188, Japan
M.Kanazawa
National Institute of Radiological Sciences, Anagawa, Chiba 263, Japan
M.Takanaka
The Institute for Physical and Chemical Research, Wako, Saitama 351-01, Japan
A.Noda
The Institute for Chemical Research, Kyoto University, Uji, Kyoto 611, Japan

Abstract

Repetitive rf stacking experiments were carried out at cooler-synchrotron, TARN-II. The beam from the SF cyclotron was stored in transverse phase space by a multiturn injection method. The injected beam was slightly accelerated, and then put on the stack top orbit of the ring. After an rf stacking batch, the beam was stored in both transverse and longitudinal phase spaces. In this experiments, a 40 turn beam was stacked in both phases spaces at a repetition rate of 30 Hz. The correction of closed orbit distortion was carried out to make a stable stacking area of the ring. The choice of betatron tune numbers for avoiding a higher order resonance was carried out. The elastic and inelastic beam collisions with the residual gas in the ring were measured and evaluated, respectively.

1.Introduction

The cooler-synchrotron TARN-II was constructed so as to accelerate ion beams up to 1GeV for protons and 350MeV/u for a charge to mass ratio of 0.5.[1] Recently, the combination of rf stacking and electron cooling has been proposed to intensify RI beam in the accumulation ring.[2] In this proposal, accumulation of a high-brightness ion beam is crucial to increase the beam luminosity at the collision of ion-ion or ion-electron beams. Rf stacking experiments at TARN-II have been proposed to study the combination of rf stacking and electron-cooling methods from the view point of accelerator technology. It is indispensable to make an rf stacking area because TARN-II was designed with no space for an rf stacking area. Thus, an excess area for a closed-orbit distortion is being used for an rf stacking experiment. This experiment was authorized as a series of beam-dynamics studies while the characteristic specifications of TARN-II was being investigated.[3] This paper present the theory, method and result of rf stacking. Related topics for the rf stacking experiment are also discussed.

2. RF stacking system

The rf stacking system includes an acceleration cavity, an rf amplifier, low-level rf electronics, a function generator and a Schottky scan system. The acceleration cavity is of a ferrite-loaded reentrant cavity, which is used as a beam acceleration cavity with a frequency range - from 0.61MHz to 7.02MHz. Low-level rf electronics generates the modulated rf signal both in frequency and amplitude domains. A block diagram of the rf stacking system is shown in figure 1. The frequency change for rf acceleration is carried out with the voltage-controlled oscillator (VCO). The voltage and frequency modulation signals are generated by microcomputer and DA converters. The generated function signals are fed into the VCO and amplitude modulator, respectively. The modulated low-level signal is fed into an rf driver amplifier and the main amplifier. The resonance condition of the rf cavity is fixed because the frequency sweep range is small. The rf voltage at accelerating gap is measured with a capacitive pick up.

In figure 1, an online beam-diagnostic system is shown, which promises a precise measurement of the Schottky signal using the Schottky-signal detector.[4] The specification of Schottky scan system is listed in Table 1.

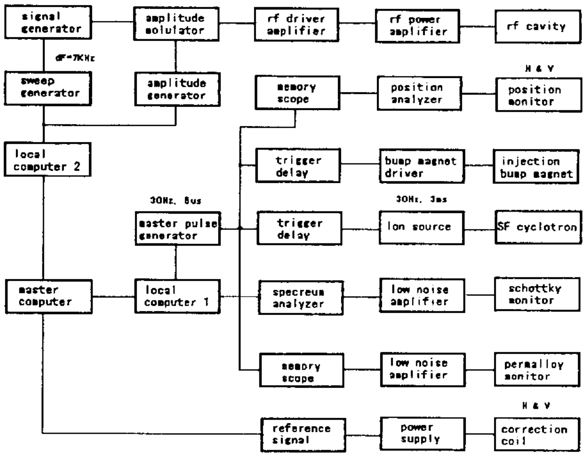

Figure 1. A block diagram of the rf stacking system

3. RF Stacking Experiment

Repetitive rf stacking is carried out as follows after multiturn beam injection:

(1) Capture: The rf voltage is switched on and the beam is captured in a stationary bucket, during the quota period of the synchrotron oscillation, and the rf voltage is increased to a higher value while keep the beam in the bucket area;

(2) Acceleration: The rf voltage, frequency and synchrotron phase are adiabatically changed, and the beam is moved to

the top of the stacking orbit;

(3) Deposit: The rf voltage is switched off and the beam remains in the stacking area.

For every rf stacking cycle, the bucket passes over the stacked particles and disturbs them. The particles lose some energy, and are moved to the stacking bottom from the top, and finally, filed into the energy gap.

Table 1.Specifications of the Schottky Scan System

Schottky-signal detector	
Detector	Helical type Traveling Wave Monitor
Characteristic impedance (Zc)	100 ohm
Coupling impedance (Zp)	700 ohm
Output impedance (Zo)	50 ohm
Signal-processing System	
Preamplifier	Analog Module 322-6-S-50
Total gain (G)	80 dB
input noise level	0.7 nV $Hz^{-1/2}$
Spectrum analyzer	ADVANTEST R3261C
computer	NEC PC9801RA
Interface	GPIB
language	Microsoft QuickBASIC
OS	MS-DOS 3.3C

Figure 2 shows an experimental procedures of rf stacking at TARN-II. The closed orbit distortion (COD) is corrected to spread the rf stacking area. The injection beam orbit is shifted to inner side of the ring before the shift of position of injection-bump magnets. Rf stacking area is located at a left side of ring as shown in figure 2.

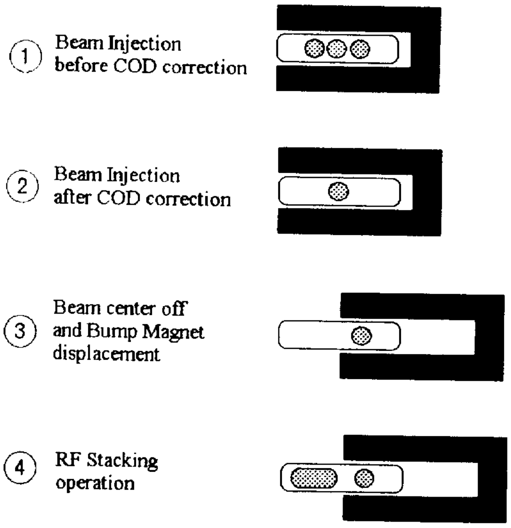

Figure 2. Experimental procedure of rf stacking.

The repetitive stacking number of TARN-II is limited by the energy gap, which is a dynamic aperture of the ring. The dynamic aperture depends on a physical acceptance due to an internal element such as beam-diagnostic instruments. A computer simulation predicts an allowable stacking number of four times the injected beam with a momentum spread of 0.1 %.

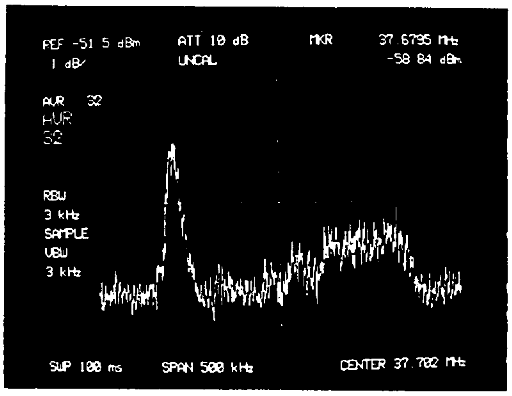

Figure 3. Schottky signal of stacked beam after the rf stacking process. Left and right peaks are multitun injected beam and rf stacked beam, respectively.

This is because the effective area of the transverse direction is 70 mm, which coincides with a momentum spreads of 0.4 %. The calculation was made while considering the bump magnets, dynamic aperture of the ring and closed orbit distortion of the ring. The COD of the ring is to be controlled within +/- 0.5 mm.[5]

The experimental results are shown in figure 3. Figure 3 shows the momentum spreads of the stacked beam measured by the Schottky scan system. All of the experimental conditions were set so that the results of a computer simulation could take into account the setting parameters of the rf stacking devices.

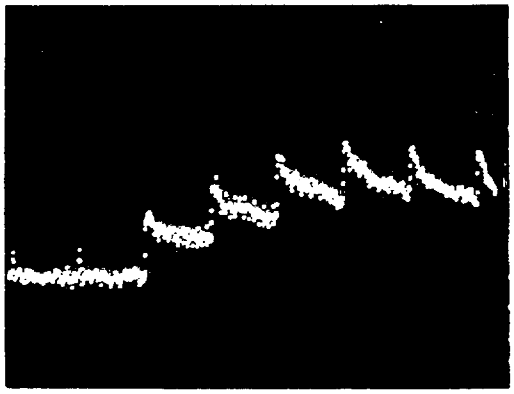

Figure 4. Rf stacked beam current measured with the permalloy current monitor. Vertical and horizontal scales are 5μA/div and 0.1sec/div, respectively.

The experimental results agreed well with theoretical calculations. An injected beam with the multiturn method is accumulated up to four times. For example, the rf stacked beam current is 20 µA when the injected beam current is 5 µA. This beam current is observed by the DCCT and permalloy monitor in the ring, respectively. Figure 4 shows the measured stacked current at a repetion rate of 8Hz. The following sections 4 and 5 are responsible to follow up the rf stacking experiment.

4. Phase Displacement Acceleration

An rf bucket scan is carried out by passing the rf separatrix on to the stored beam. It is passed far from the center of the beam energy. The energy of the circulating beam is then changed due to this bucket scan.

The relation between the momentum ($\Delta P/P$) and the frequency shift ($\Delta f/f$) is

$$\Delta f/f = \eta(\Delta P/P),$$

Finally, the frequency distribution ratio after n scan is given by rms energy spread [6]:

$$\Delta fi/fi = \eta(\sigma_0{}^2+n\sigma^2)^{1/2}/Pi.$$

The figure 5 shows the measurement results. In this figure 5, #1 to #6 indicate the moving bucket area dependence. The moving bucket #6 area becomes larger than that of #1. However, the displacement of #6 becomes larger than that of #1. Each spectrum has a different spectrum height, because the injected beam current is not constant.

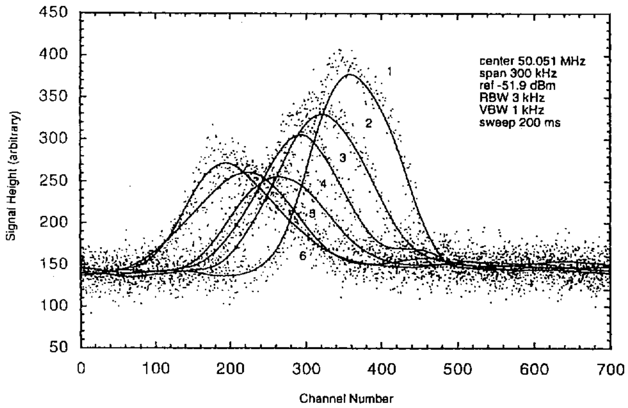

Figure 5. Phase space displacement due to empty bucket scanning. Spectra are shown as a function of moving bucket areas of empty bucket scan.

From these measurements, it has become clear that momentum shift due to the energy loss is smaller than that in the PDA process. An analytical calculation of PDA well fits the measurement data. A computer simulation shows the that measured beam distribution after the PDA well fits the calculated one.

5. Momentum loss of the circulation beam

Both the nature and strength of the interaction between the ion beams and the residual gas molecules in the storage rings depend strongly on the atomic number (Z), charge state (q) and specific kinetic energy (T_i) of the stored ions. Attention has been focused on the atomic reaction between ions and residual gas atoms. A slight reduction of T_i is observed after a large number of ionizing collisions.

A stored beam with a multiturn injection batch circulates in the ring for a long time. This circulating beam collides with residual gas, causing a loss of momentum, which is expressed as the following Bethe's law;

$$dE/dx = \{4\pi e^4 Z^2 N(Zi/Ai)/mv^2\}\ln\{2mv^2/(I(1-\beta^2) - \beta^2\}$$

Measurement of the momentum loss of a 26 MeV He^{2+} beam was carried out using the Schottky scan system. The center frequency of the spectrum analyzer was set near to the 69 harmonics of the revolution frequency of the beam because of a noise-less environment and was a good sensitive region of the Schottky monitor, respectively.

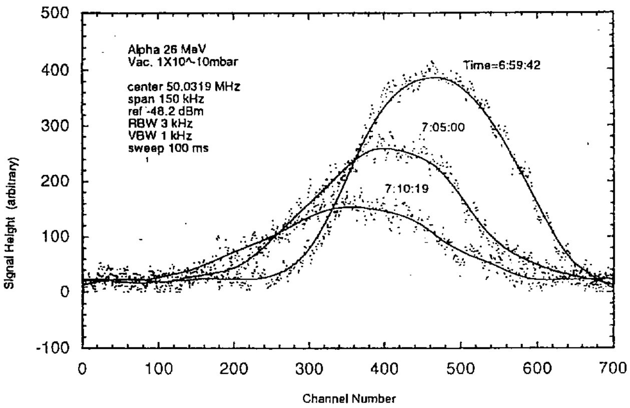

Figure 6. Momentum loss of the circulation beam due to collisions with residual gas. The right spectrum shows stored beam just after multiturn-beam injection.

Figure 6 shows the fitting data of the measured spectrums. In figure 6, the right side of the spectrum peak shows the injected beam. The peak is higher than the other two spectra because of small collisions with the residual gas.

The data show that a slight momentum loss rate can be expressed as

$$\Delta p/p = \eta^{-1}\,\Delta f/f,$$

The measured momentum loss was compared with the theoretical value calculated by Bethe's formula. The theoretical value was obtained on the basis of residual gas pressures in the ring. A mass analyzer was used to measure the molecular distribution in the ring.

6. Conclusions

An rf stacking experiment was carried out at cooler-synchrotron TARN-II. The experiment results show that complete beam stacking in the transverse and longitudinal phase spaces have been achieved. Four times the multiturn-beam injection current was stacked in the rf stacking area. It is indispensable that the COD correction was carried out before the rf stacking. The energy loss due to collisions of residual gas and the beam seemed to have only a small effect on the measured rf stacked beam.

References

[1] T.Katayama *et al.* Nucl. Instrum. and Meth. A336(1993)
[2] Y.Yano *et al.* Proc. of 14th Int. Conf. on Cyclotrons and Their Applications, 1995.
[3] S.Watanabe *et al.* Proc. of 13th Int. Conf. on Cyclotrons and Their Applications, 1992.
[4] N.Tokuda *et al.* proc. of 5th symp. on Accelerator Science and Technology
1984, Tukuba, pp265-267.
[5] T.Watanabe *et al.* (to be published)
[6] S.Watanabe *et al.* Nucl. Instrum. and Meth. A271(1988)