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COOLER SYNCHROTRON TARN II

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Abstract

A cooler synchrotron TARN II has been under construction at INS since 1986. It aims the beam acceleration up to 1.1 GeV for proton and 370 MeV/u for heavy ions of q/A=0.5, corresponding to the maximum magnetic rigidity of 6.1 T.m. An electron cooling device and a slow extraction channel are prepared for the various beam experiments. In the present paper, the status of TARN II is described as well as the results of ring operation.

INTRODUCTION

TARN II is an experimental facility for accelerator, atomic, and nuclear physics with an electron cooler equipment as well as the functions of beam acceleration and slow extraction.[1] This cooler synchrotron has the maximum magnetic rigidity of 6.1 T.m, corresponding to a proton energy of 1.1 GeV. The main parameters of the ring are shown in Table 1. The ring is hexagonal in shape with an average diameter of 24.8 m. Its circumference is 77.76 m, just 17-times that of the extraction orbit of the injector SF cyclotron. It has 6 long straight sections of 4.2 m length each, which are used for the beam injection system, an RF cavity, an electron cooling device, and a slow beam extraction system. It takes 3.5 sec for the power supply to excite the whole magnet system to the full excitation. The flat top duration of magnetic field is variable and sufficiently long for beam cooling and extraction. The RF cavity can be tuned from 0.5 to 8.5 MHz and the power amplifier can produce a gap voltage of 2 kV. The electron cooling system can cool the ion beam with energy of up to 200 MeV/u. It consists of an electron gun, an interaction region of 1.5 m in length, collector and electron guiding coils.[2]

At present, all ring system are completed, including the extraction system. The first trial of beam injection was performed in December 1988, and α beams of 28 MeV were circulated in TARN II. Subsequently the beam injection experiments have been performed several times for the investigation of multi-turn injection and beam monitoring system. On the other hand the off-line test of e-cooling has been successfully performed. Beam acceleration and cooling experiments are scheduled in the autumn of 1989.

TABLE 1 Main parameters of TARN II ring

Maximum magnetic rigidity		6.1 T.m
Max. beam energy	proton	1.1 GeV
	ions with q/A=1/2	370 MeV/u
Circumference		77.76 m
Average radius		12.376 m
Radius of curvature		4.045 m
Focusing structure		FBDBFO
Length of long straight section		4.20 m
Superperiodicity	acceleration mode	6
	cooling mode	3
Rising time of magnet excitation		3.5 sec to full
Repetition rate (max.)		0.1 Hz
Max field of dipole magnets		15.0 kG
Max gradient of quadrupole magnets		70 kG/m
Revolution frequency		0.31 - 3.75 MHz
Acceleration frequency		0.62 - 7.50 MHz
Harmonic number		2
Max rf voltage		2 kV
Useful aperture		50 x 200 mm^2
Vacuum pressure		10^{-11} Torr

MAGNET SYSTEM

The focusing structure of the magnet system is based on an FODO lattice, and the long straight sections are prepared by inserting drift space of 4.20 m length between horizontally focusing quadrupole magnets at every unit cell. (Fig.1) The whole circumference is composed of six unit cells. For the synchrotron acceleration mode, these cells are excited identically and the dispersion function and the maximum β_x-value can be kept small which results in the large machine acceptance, 400π mm.mrad.
On the other hand, to realize the zero dispersion straight section for the momentum cooling, the superperiodicity is reduced from six to three with the change of excitation current of quadrupole magnets. In this cooler ring mode, the maximum β_x-value becomes large and the acceptance is reduced to 140π mm.mrad.[3]

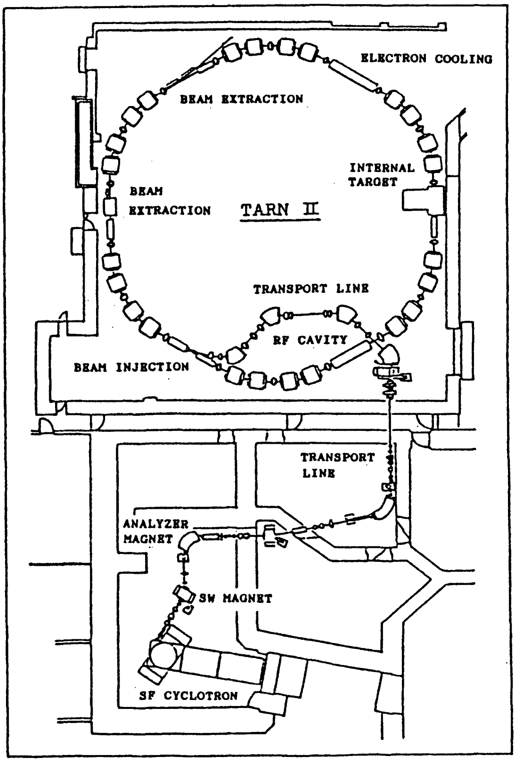

Fig. 1 Layout of TARN II

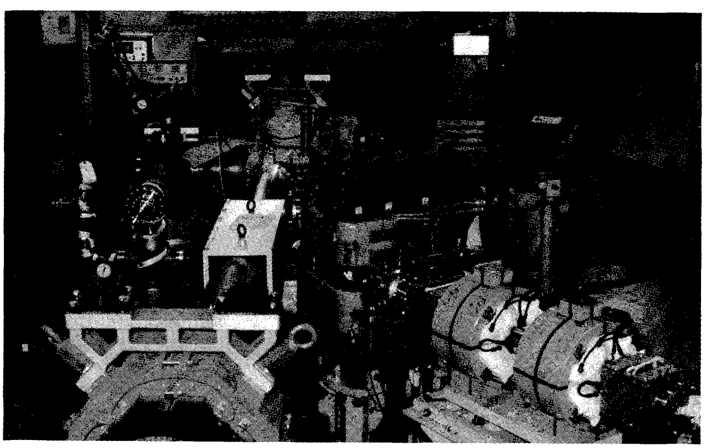

Fig. 2 Injection point of TARN II(left) and beam transport line (right)

The excitation of current for the magnets are performd with four power supplies, one for the dipole magnets and three for the quadrupole magnets. The ramp shape of the dipole field B and its time derivative dB/dt are shown in Fig. 3, where the excitation pattern is a trapezoid wave form with a repetition rate of 0.01 Hz and the rising period is 8 sec. The dB/dt signal is used for the pattern production of RF acceleration frequency. The currents of three power supplies of Q magnets are tracked with the bending magnet current within the tracking error less than $1x10^{-4}$ with use of the self learning procedure in the control computer system.

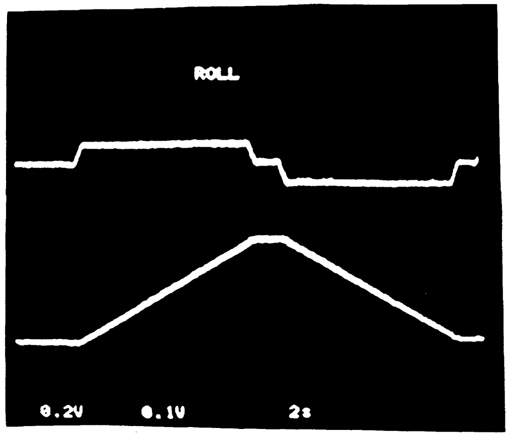

Fig. 3 Current pattern of bending magnet(lower) and its time deriva tive (upper) in the synchrotron mode.

VACUUM SYSTEM

The ramping rate of magnetic field is so low as 0.4 T/sec and then the vacuum chambers at dipole and quadrupole magnets are made of SUS 316L with thickness of 4 mm. They are bakable up to 350 °C by heating with current flowing directly through them. Between each pair of dipole magnets, either a sputter ion pump (800 or 400 l/s) or a titanium sub-limation pump (100 l/s) is installed. The inflector chamber and the chamber at the crossing point of the main ring with the beam injection line are especially evacuated by sputter ion pumps of 800 l/s in order to pump the ring differentially. Totally, 7 titanium sublimation pumps (1500 l/s), 5 sputter ion pumps (800 l/s), 3 sputter ion pumps (400 l/s), and 3 turbo-molecular pumps (500 l/s) are used for the evacuation. Presently, the average vacuum pressure in the ring is several times 10^{-9} Torr[4] and the goal of 10^{-11} Torr will be obtained after the baking of chambers.

RF SYSTEM

The lowest injection energy has been set to be 2.58 MeV/u for $^{20}Ne^{4+}$ among the various ions from the SF cyclotron, corresponding to the revolution frequency of 0.307 MHz. At the top energy of 1100 MeV for protons, the revolution frequency is 3.5 MHz, thus the ratio of the lowest to highest frequencies is thirteen. The harmonic number was chosen to be 2 and the designed acceleration frequency is 0.6 MHz to 7.0 MHz. An acceleration voltage of 2 kV is enough for the beam with 0.5 % momentum spread within the acceleration period of 3.5 sec.

An rf cavity, a single-gap, ferrite-loaded, two quarter-wave coaxial resonators, has been constructed.[5] It covers the frequency range from 0.61 to 8.0 MHz by changing the ferrite bias current from 0 to 770 A. A power amplifier with a maximum output power of 5 kW can produce 2 kV of accelerating voltage over the gap throughout the whole frequency range.

Three memory modules store the functional forms of frequency, voltage and bias current to be produced as a function of the field strength. At every increment 1 Gauss of the magnetic field, measured at the 25th dipole magnet for field monitoring, the data are read from memory and converted into analog voltages through DAC's, which are fed into a voltage controlled oscillator, amplitude modulator and bias current power supply, respectively. The error of bias current and frequency are corrected by hardware feedback loops. In addition, position and phase error signals are picked up from the beam monitor and fed back to the voltage controlled oscillator. The output rf signal of this oscillator is fed to the amplifier.

At the injection, however, the signal is fed from a frequency synthesizer and frequency and voltage are finely adjusted manually to get maximum capture efficiency.

SLOW BEAM EXTRACTION

The accelerated and cooled heavy ion beams are to be slowly extracted utilizing the third integer resonance. The extracted beam energy is required to be variable over a wide range from 150 MeV/u to 370 MeV/u. Thus, the beam extraction must be performed for a circulating beam with a rather large emittane (60π mm.mrad). To respond these requirements, high-efficient extraction method was proposed[6] with uses of rather complicated ajustment of the currents of dipole magnet and quadrupole magnet. In viewing this scheme as a final goal, as a first trial of the extraction, a simple extraction method has been in progress where one sextupole magnet is used for resonance excitation, three bump fields for the closed orbit distortion and tunes are varied from (1.75, 1.80) to (1.667, 1.80) with the change of quadrupole magnet currents. In this scheme, the sextupole fields is dc excited and it can be seen from the simulation results that the beam safely circulates on an ellipse, even with an existence of nonlinear sextupole field at the injection energy. An electric septum, 70 kV/cm and 1.0 m long, is located in the second straight section and the first septum magnet, 5 kG in magnetic field strength and 1.0 m long, is at the third straight section.

BEAM EXPERIMENTS

The beam injection experiments started in the fall of 1988. The 28 MeV α particles was used for these experiments. The emittance of the extracted beam from the cyclotron was measured to be 15π mm.mrad (horizontal) and 20π mm.mrad (vertical) and the momentum spread was 0.1 %. The peak current of the cyclotron beam was around 20μA. The pulse width and repetition rate in the multi-turn injection were 1 msec and 30 Hz, respectively. Generally, 30 % of the extracted beam was transported to the injection point of the ring through the transport line of about 55 m long. At the inflector channel, the beam was focussed and the measured transmission in the inflector was found to be better than 90 %. The time constant of the decay of the bump

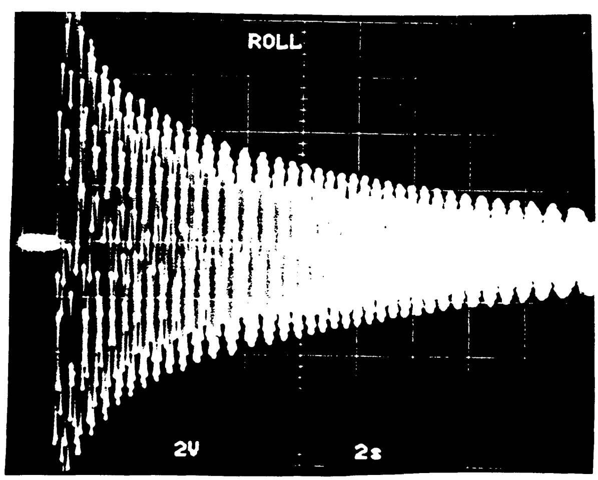

Fig. 4 Beam signals from the electrostatic monitor. Horizontal scale is 2 sec/div.

magnets was adjusted to be 40 μsec corresponding to 20 times the revolution time of the 28 MeV α particles. The injected beam was captured by the rf voltage after 500μsec after the injection. The rf frequency and voltage were so adjusted as to get the maximum capture efficiency.

The lifetime of the beam was measured by the decay constant of the signal from one of the electrostatic monitors (Fig. 4). The e-folding lifetime was found to be 12 sec. It was determined by the scattering with the residual gas. This lifetime is roughly in agreement with the calculated result on the condition that the average vacuum pressure in the ring was about 2 $\times 10^{-9}$ Torr and the beam energy was 7 MeV/u. In these early experiments, the vacuum chambers were not yet baked out. In the next coming beam time the pressure is to be improoved up to 10^{-11} Torr and the lifetime is expected to be improved. The e-cool and RF acceleration experiments are planned from September 1989.

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