HEAVY ION SYNCHROTRON - COOLER RING, TARN II

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Abstract

TARN II is a ring with the mean radius of 12.4 m, which can accept the beam with magnetic rigidity up to 7.3 T·m, corresponding to the maximum energies up to 1400 MeV and 500 MeV/u for proton and ions with charge to mass ratio of 1/2, respectively. Its main magnet system is based on FODO lattice and is composed of 24 dipole and 18 quadrupole magnets. A maximum field higher than 1.9 T is attained for the dipole magnets. From the field measurements with a precision better than $\pm 5\times 10^{-5}$, the sextupole component of the dipole magnets is less than $0.45\ m^{-2}$ below 1.8 T. All the magnets have been already aligned to their precise positions taking the field properties into account from beam dynamical point of view. An RF cavity of ferrite-loaded two quarter wavelength coaxial type with bias windings of 4-turns has attained a tunable range about 15 times. An electron beam cooling system with a high voltage of 120 kV is designed to be applied to the beams lower than 200 MeV/u. Field properties of the guiding magnetic field of electron has been studied and a good quality field has been realized.

Introduction

At Institute for Nuclear Study, University of Tokyo, a heavy-ion synchrotron which can be used also as a cooler ring in the intermediate energy region has been under construction since 1984. The SF cyclotron, an ordinary AVF cyclotron with K-number of 67, is to be used as an injector (Fig. 1). Expected intensities are $\sim 10^8$ for proton and α-particle, which is reduced to $\sim 5\times 10^6$ for heavier ions as Neon. Owing to this rather limited beam intensity, a scheme of experiment utilizing an internal target (a few tens $\mu g/cm^2$) is intensively studied so as to increase the effective luminosity.[1] A slowly extracted beam is also to be provided for special experiments which can tolerate rather lower beam intensity as the basic study for biomedical irradiation.

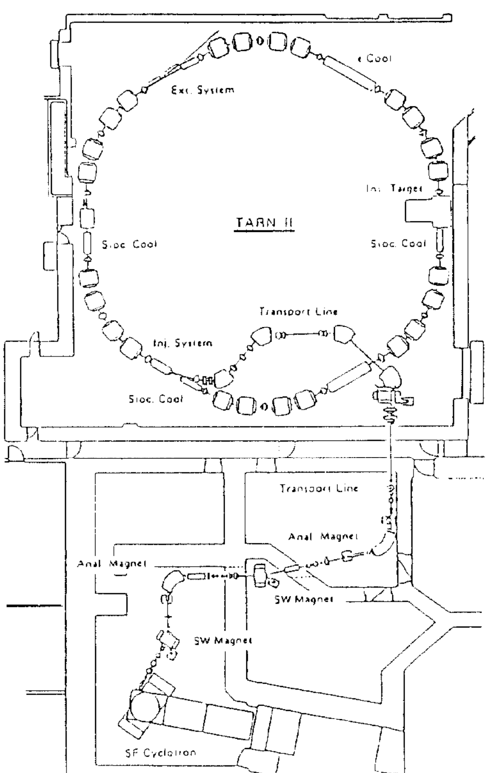

Fig. 1 Layout of TARN II and its transport line.

Magnet System

Lattice

TARN II lattice is designed on a simple FODO structure with such modification as gives doubletlike structure at long straight sections to provide smooth behaviour of Twiss parameters. The ring is originally designed as a synchrotron with superperiodicity 6 to have a compact and regular structure (Synchrotron Mode). Cooler Ring Mode with superperiodicity 3 is proposed, in order to attain doubly achromatic sections needed for an electron beam cooling together with long straight sections of fairly large dispersion ($\sim$4.5 m) for an internal target (Fig. 2). These two modes are considered to be transferable between each other keeping the operating point at the same position in the tune diagram.[2]

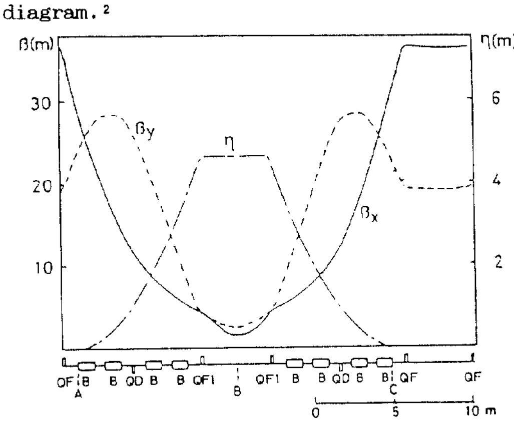

Fig. 2 β and dispersion functions of Cooler Ring Mode.

Magnetic Field Measurement

All the main magnets in the TARN II ring are made of laminated steel 0.5 mm in thickness considering the eddy current effect due to AC operation. The

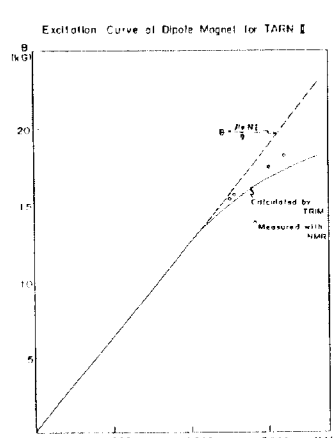

Fig. 3 Excitation characteristics of the dipole magnet for TARN II.

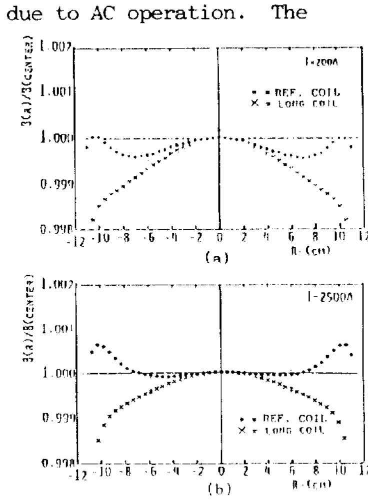

Fig. 4 Radial field distributions of dipole magnet, (a) 200 A and (b) 2500 A.

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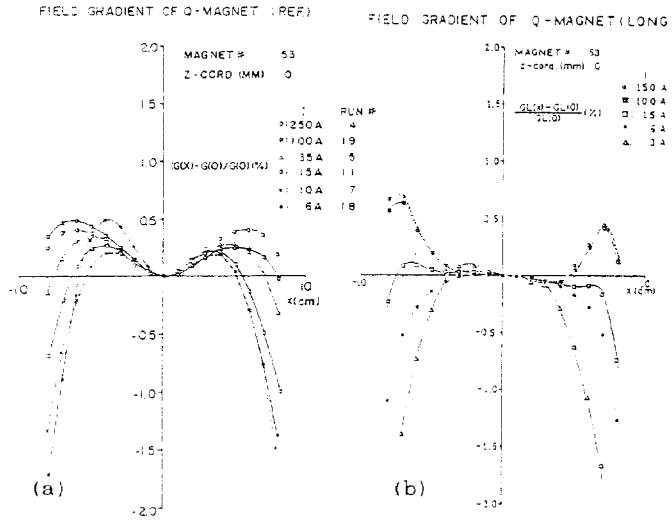

Fig. 5 Radial distribution of (a)field gradient and (b)its integrated value of quadrupole magnet.

dipole magnet of TARN II is designed with H-type and straight iron core.[2] The absolute field strength for various excitation currents are measured by a proton resonance (Fig. 3). Combining the results of the above measurement and the effective length measurements, the deviation of the integrated field strength is obtained for all the magnets, which was reflected on arrangement of the dipole magnets so as to reduce the size of closed orbit distortion. The radial field distributions of the field strength and the integrated field strength are measured with flipping coils, whose dimensions are 8 × 100 mm^2 (REF. COIL) and 18 × 1600 mm^2 (LONG COIL), respectively.[3] Typical examples of the measurements are given in Fig. 4. It is seen that at the lowest excitation level (1.25 kG), the effect of the residual magnetic field appears. The strength of the residual field at the magnet center was 15 G after the excitation up to 2500 A (~ 15kG), which had a sextupolelike structure. This residual field caused additional sextupole component as large as 0.27 m^{-2} at the injection field level (~ 1.25 kG), which is found to be in tolerable size.[4]

Quadrupole magnets are made with hyperbolic pole shape which extends to its tangential lines at both sides.[5] The field properties of the quadrupole magnet was studied putting emphasis on low excitation level (down to ~ 1 kG/m) considering low injection energy at TARN II. The structure of the field gradient was studied utilizing a translation coil system.[5] Typical examples are shown in Fig. 5 for various excitation currents. Although a flat region of the field gradient is reduced at the low excitation level (~ 1 kG/m), needed aperture seems to be assured for the excitation levels to be used (higher than 15 A corresponding to the field gradient of ~ 2.6 kG/m). Real dynamic aperture attained for various excitation levels are to be studied by both computer simulation and beam experiments from now on.

Alignment of Magnets

As the superperiodicity of the lattice is 6 for the Synchrotron Mode, every magnet should be aligned so that the ring coincides with itself if it is rotated by as much as $2\pi/6$ with respect to the center of the ring. Two standard holes attached to each magnet, whose positions with respect to pole shape are precisely adjusted, are used to modify the position and rotation angle of the magnet in a horizontal plane. So as to keep a hexagonal shape, six standard holes located at 6-fold symmetric positions are adjusted in order to make equilateral triangles with the one on the central pillar. The azimuthal angle between one hexagon and the other is constrained by the distances between the vertices of these hexagons. The algorithm to obtain position errors is examined beforehand utilizing artificial data of the distances made by uniform random numbers. The position errors can be solved with an accuracy of a few microns if there are no errors in distance measurements. In the measurement of these distances, Invar wires 1.00 mm in diameter pulled with an 8-kg tension from both ends is used. The absolute length of the wire is calibrated with a laser interferometer on a standard bench before and after each measurement. With this procedure, a systematic error due to a change in the wire length can be eliminated. A precision of several tens μm could be attained for measurements at such distances. All the magnets have been aligned to their proper positions with an overall accuracy of ± 300 μm, which is considered of tolerable size.

Power Supply

TARN II Synchrotron Mode assumes 1/2 Hz operation as final goal and dipole magnets are designed to be able to be excited up to 4000 A. However, owing to the limitation of electric power facility at INS, a power supply for the dipole magnets with the maximum excitation current of 2500 A (corresponding to 15.5 kG and 1.1 GeV proton energy) and rise time of ~ 3.5 s has been designed and fabricated as the first phase of accelerator study and internal target experiment. It consists of 12 phases silicon controled rectifiers(SCR), passive and active filters. The excitation test has already been started with real loads of 25 dipole magnets and connecting cables. A relative current ripple (mainly 600 Hz) is found to be as low as 1×10^{-5} even at the lowest excitation current of 200 A.[6]

The power supplies of the quadrupole magnets are designed with final specifications (maximum current of 400 A, rising time of 0.75 s) because their maximum peak powers are rather limited and acceptable for the present electric power facility. They consist of 12 phases SCR, passive filter and transistor regulator to attain fast tracking to the dipole current.

RF system

An RF acceleration system for TARN II is designed to be capable of both operations, adiabatic capture and acceleration and synchronous capture of the beams from the SF cyclotron. The harmonic number is 2 and 17 for adiabatic and synchronous capture, respectively. Required frequency sweep range and maximum acceleration voltage of the system are 0.59 ~ 8.00 MHz and 6 kV, respectively if Ne^{4+} with kinetic energy of 2.68 MeV/u is to be accelerated.

The RF cavity of two ferrite-loaded quarter wavelength coaxial type has already been fabricated (Fig. 6). As a ferrite material, TDK SY-6 is selected

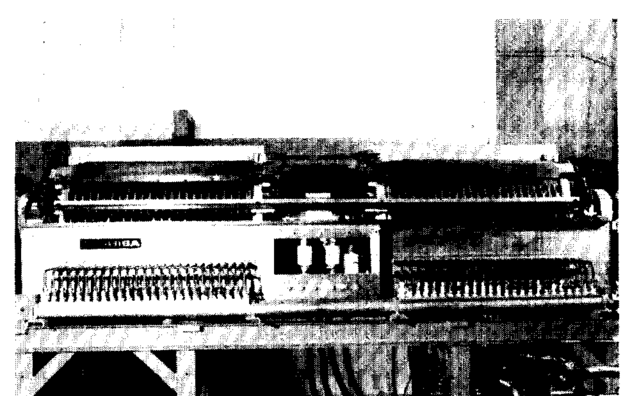

Fig. 6 An overall view of the RF cavity for TARN II.

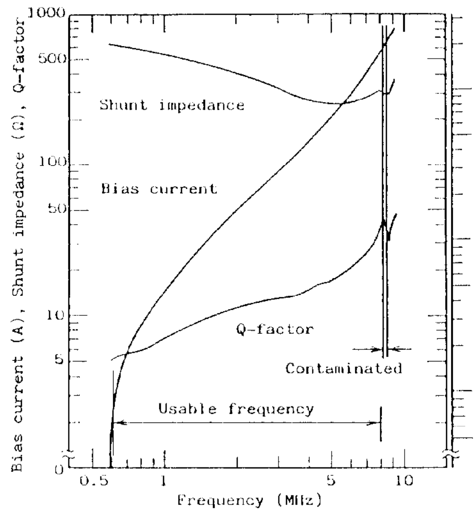

Fig. 7 Results of low-level measurement of RF cavity.

to realize a wide sweep range. Four turns bias windings of "figure of eight" configuration are wound, which are capable of excitation up to 850 A.[7]

Low power level RF measurements have been performed and frequency of the fundamental resonance, shunt impedance and Q-factor are measured changing bias currents (Fig. 7).[5] Recently the frequencies of parasitic resonances are shifted and wider sweep range from 0.57 MHz to 8.5 MHz is attained.[9]

Vacuum System

At TARN II, a vacuum pumping system composed of sputter ion pum, titanium getter pump and turbo-molecular pump are to be constructed to attain ultra high vacuum (~ 1 × 10^{-10} Torr). Additional non-evaporable getter pumps are to be used at the electron cooling section to cope with a heavy gas load owing to an electron gun.

As the magnet power supplies assume rather slow rising time (~ 3.5 s) and dB/dt is rather small (0.4T/s), the vacuum chambers in the magnets are determined to be made of stainless steel (SUS316L) 4 mm in thickness. The chambers at the dipole sections are being delivered and the first one has already been pumped down at a test bench. After baking process at 320° C with duration of 72 h, the vacuum pressure of 1 × 10^{-9} Torr is attained with only a turbo-molecular pump with pumping speed of 450 l/s. A residual gas spectrum of the chamber is shown in Fig. 8. No peak of hydrocarbon is observed. The end vacuum pressure is considered to be limited by the capability of the pump and no noticeable leak exists to attain much better pressure.[10]

Beam Cooling

Beam cooling methods are to be applied at TARN II

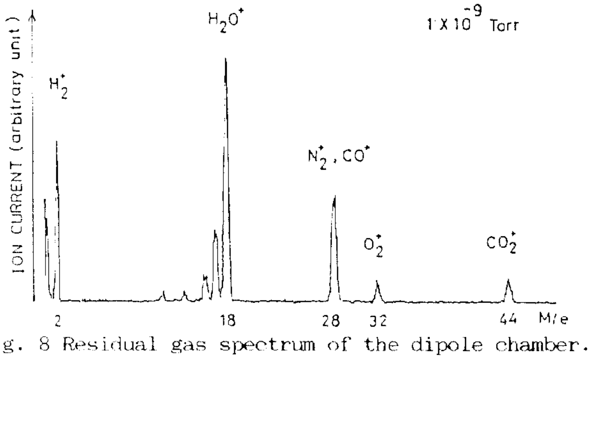

Fig. 8 Residual gas spectrum of the dipole chamber.

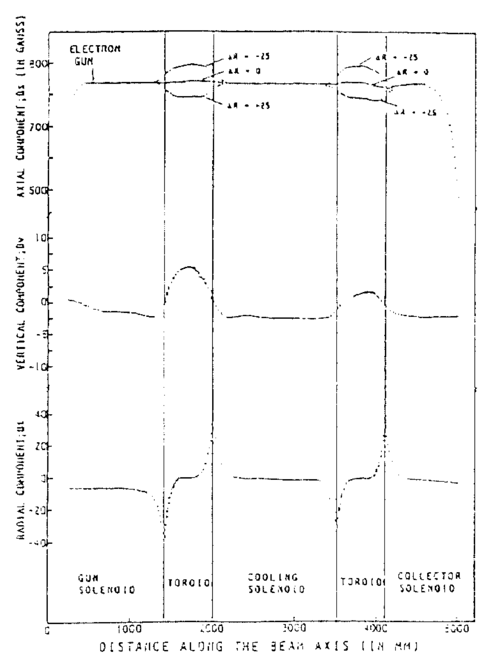

Fig. 9 Measured components of electron guiding field.

so as to increase the phase space density of circulating beam. An electron cooling system with high voltage up to 120 kV (corresponding to beam energy of 200 MeV/u) is under construction. The length of the cooling section, the diameter and current density of the electron beam are 1.5 m, 50 mm and 0.5 A/cm², respectively. Electron guiding field composed of three solenoids and two troids has been fabricated and the field measurement was finished. As is known from Fig. 9, field perturbations at the junction parts between the solenoid and the troid is well suppressed.[11] Stochastic cooling method is to be applied for beams with higher energies than 200 MeV/u. It is also to be used in transverse precooling of rather hot beam after multiturn injection with Synchrotron Mode.[2]

Aknowledgement

The works presented here are being performed by collaboration of all the members of TARN II construction group at INS under the leadership of Prof. Y. Hirao. The author would like to present his sincere thanks to all of them. He is also grateful to Prof. I. Katayama at RCNP for his efforts to realize an internal target experiment at TARN II. The calculations in this work are performed with FACOM M380R in the computer center at INS.

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