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DC SEPTUM MAGNET FOR TARN II

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ABSTRACT

A septum magnet for the resonant beam ejection at TARN II is designed and fabricated. Its gap, septum thickness and maximum field strength are 25 mm, 9 mm and 5 kG, respectively. Although the current density in the septum coil amounts to 78 A/mm^2 at the maximum excitation level, the temperature rise in the septum coil is estimated at 66°C for DC excitation if the flow rate of cooling water is 9.6 ℓ/min.

The magnet is designed based on the DC excitation mode utilizing solid iron core for the merit of precision of fabrication and lighter out-gas load than the laminated one.

INTRODUCTION

At Institute for Nuclear Study, University of Tokyo, a heavy ion synchrotron and cooler-ring, TARN II is now under construction. Due to rather limited beam intensity of TARN II($\sim 10^8$ ions/cycle), an emphasis is put upon the internal target experiment with beam cooling technique from the point of view of nuclear or atomic physics[1]. However, high energy heavy ion beam is known to be hopeful for cancer-therapy and medical diagnosis, which can, for the moment, tolerate the rather limited beam intensity of the extracted beam of TARN II. So as to provide a beam course useful for the basic study of biomedical irradiation, a slow beam ejection course which utilize 1/3 resonance is designed.

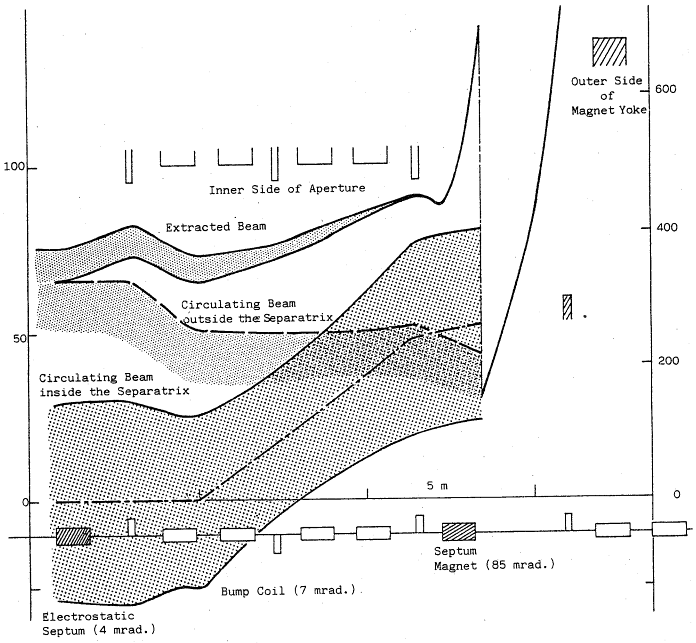

Fig. 1 Beam behavior during slow ejection process at TARN II. The beam trajectories of the ejected beam and circulating beam outside the separatrix are shown together with the envelope of the beam in the separatrix for the case of the kinetic energy of 200 MeV/u. The vertical axis is the displacement from the center of the machine aperture in unit of mm.

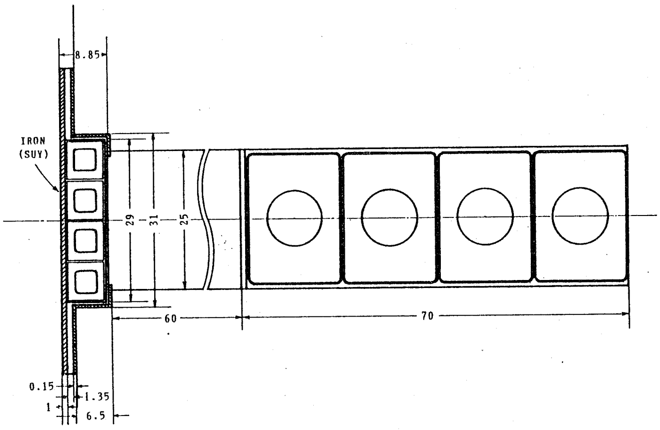

Fig. 2 Cross sectional view of the septum magnet. The pole shape of the iron core relative to the septum coil is optimised to reduce the leakage field outside the septum coil. An iron plate, 1 mm in thickness, which is magnetically shielded from the core, is added further to suppress the leakage field level.

The beam extracted from the stable orbits in the ring is to be deflected by an electrostatic deflector and two septum magnets as given in Fig. 1.
In this scheme, an effort is made to enlarge the space for the septum thickness available in the first septum magnet so as to enable its DC excitation with the combination of an electrostatic deflector at the position nearly one cell upstream from the septum magnet and applying an additional bump angle with the bump coil in one of the dipole magnets. As a result, the allowable septum thickness and the required deflection angle are set to be 9 mm and 85 mrad., respectively. The main specifications of this magnet is given in Table 1.

In the present paper, the design of this DC septum magnet is described. The detailed description of the entire beam extraction system with 1/3 resonance at TARN II which aims at good emittance of the extracted beam and high extraction efficiency is given elsewhere[2].

FIELD CALCULATION

From the required deflection angle of 85 mrad for ions with kinetic energy and charge to mass ratio of 350 MeV/u and 1/2, respectively, the maximum field level of this magnet with core length of 1000 mm is

Table 1

SPECIFICATIONS OF THE FIRST SEPTUM MAGNET

Maximum Field Strength	5	kG
Septum Thickness	less than 9	mm
Core Length	1	m
Magnet Gap	25	mm
Useful Field Region	25 x 60	mm^2
Maximum Ampere-Turn	10000	AT
Field Homogeneity (in the Useful Region)	within 1	%
Deflection Angle (for ions with $B \cdot \rho = 5.8$ T·m)	85	mrad

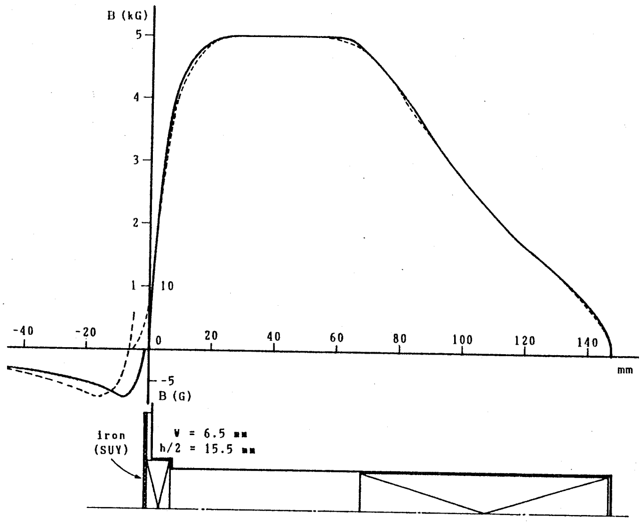

Fig. 3 Calculated field structures of the septum magnet. Solid and dashed lines represent the field structures with and without the thin iron plate just outside the septum coil, respectively.

determined to be 5 kG. The vertical beam emittance is assumed to be 15π mm·mrad at the injection energy of 20 MeV/u, which is expected to be reduced to 4.5π mm·mrad after acceleration up to 200 MeV/u. So the vertical beam size in this septum magnet is calculated at less than ±7 mm for β_V size of 10 m. Taking into account of the clearance between the pole-faces of the magnet and the beam, the gap height of this magnet is determined to be 25 mm. (Here we have assumed the beam extraction at energies higher than 200 MeV/u and this septum magnet is assumed to be used in the vacuum vessel.)

The horizontal aperture of this magnet is decided to be 60 mm considering the possibility of utilizing the septum magnets system also for the fast beam ejection with a full aperture kicker magnet in future.

The required Ampere-turn is calculated to be 9947 AT if the magnetic resistence in the iron core is negligible. Considering the allowable thickness of the septum coil of 9 mm, a hollow conductor with dimension of 7 x 7 mm^2 with inner hole size 4 x 4 mm^2 for cooling water is used in 4 turns for the septum coil as shown in Fig. 2. As the cross sectional area of the conductor is 32 mm^2, the current density in the coil amounts to 78 A/mm^2 if 10000 AT is applied in 4 turns. The return current is fed into the rather larger coil so as to reduce the temperature rise in the return coil.

The shape of the iron core and the coil position are optimized to suppress the leakage field level utilizing the computer code TRIM[3]. The configuration given in Fig. 2 is finally adopted. In order to reduce the leakage field as small as possible, a thin (1 mm in thickness) iron plate is attached just outside of the septum coil in the manner as illustrated in Fig. 2. It should be noted that this iron plate is insulated magnetically from the iron core[4]. In Fig. 3, the calculated field levels are shown for both cases with and without this iron plate. For the configuration with such an iron plate, the level of the leakage field in the side of circulating beam is expected to be less than 1.5×10^{-3} of the gap field.

POWER DISSIPATION AND COOLING

The maximum power dissipation in the septum coil is calculated to be 15 kW in case of the DC operation. If all the heats due to this power are transferred entirely to the cooling water, then the temperature rise of the water is estimated to be 22.3°C if the velocity of 2.5 m/sec is assumed for the flow of cooling water (corresponds to 9.6 ℓ/min). In addition to this, the temperature difference between the conductor and the cooling water and the temperature gradient in the copper conductor should be taken into account. The former is estimated to be 44°C, while the

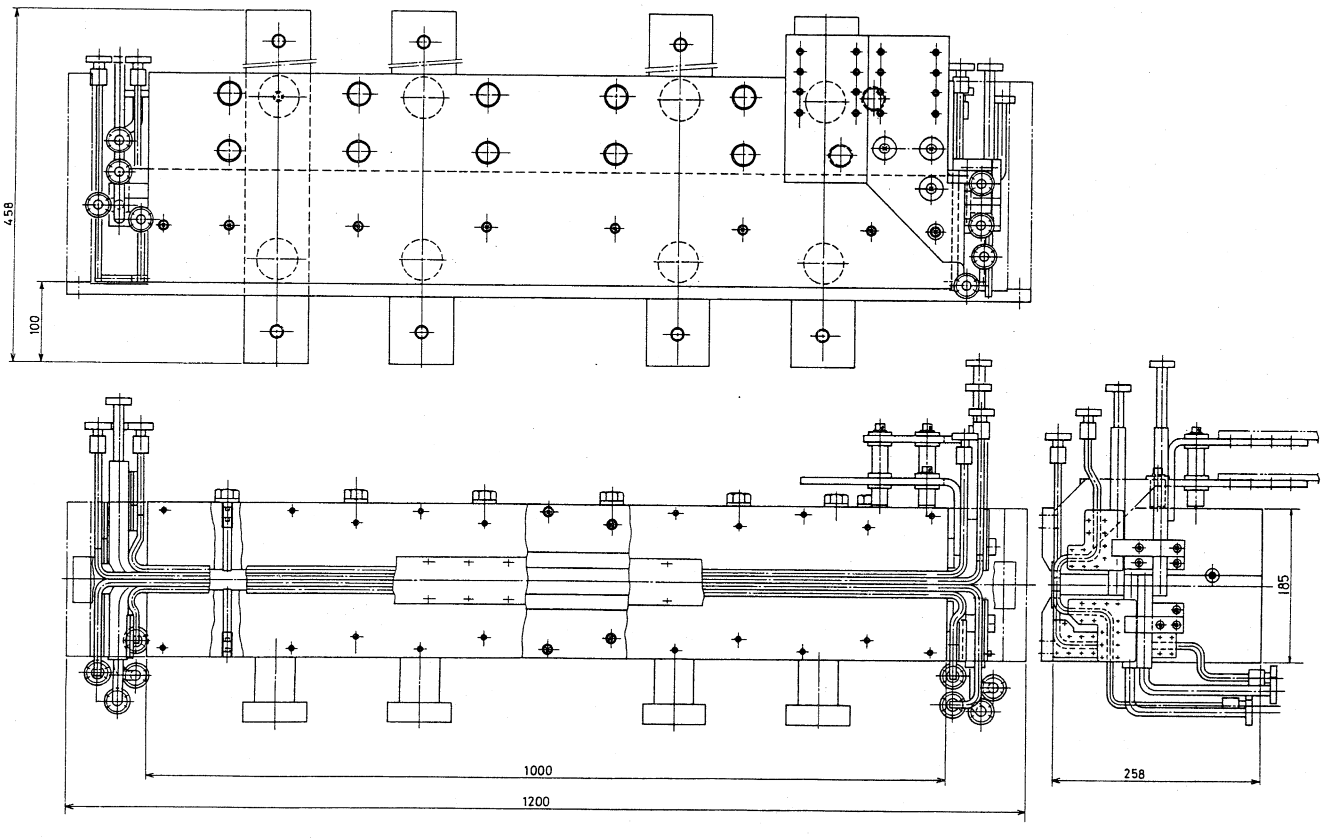

Fig. 4 The drawing of the mechanical design of the septum magnet.

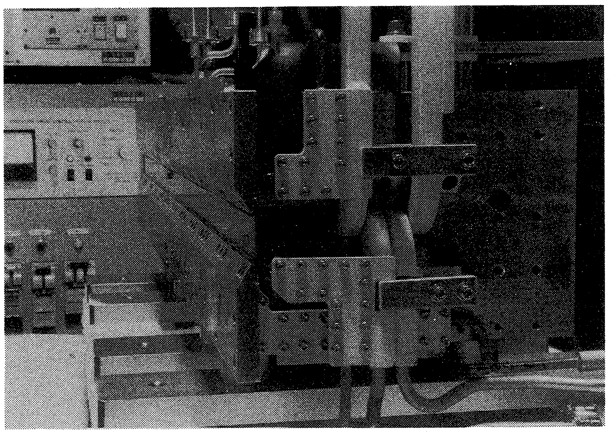

Fig. 5 An overall view of the fabricated septum magnet.

latter is rather small value (1.5°C)[5]. Thus the highest possible temperature in the coil is expected to be less than 100°C even if the temperature of the input water amounts to 30°C, which is considered to be tolerable condition from the point of view of the melting point of the insulator of the coil. As there is temperature difference about 44°C between the conductor and the cooling water, the boiling of the cooling water can be avoided even if DC excitation is applied.

In order to evaluate the reliability of the formula for the temperature rise, an experimental test had been performed before the design of the septum magnet was fixed. Due to the limitation of the available power supply, a smaller size coil with dimension of 5 mm in outer diameter including a hole for cooling water with the size of 4 mm in diameter was used to realize the similar value of current density. For such a condition as the velocity of the cooling water and the current density in the coil are 2.0 m/sec and 75 A/mm^2, respectively, the temperature of the cooling water was observed to be raised from 20°C to 32°C after passage through the coil of 1 m length, while the formula used in the design stage gave the temperature rise of 15°C. The reason why the real measurement gave a little lower temperature rise is considered to be due to the fact that the heats originated by the dissipated power in the coil are partially taken away into the air by radiation and convection.

Because this septum magnet is to be used in the ultra-high vacuum ($\sim 10^{-10}$ Torr) system, it is indispensable to suppress the outgassing rate. So the core is decided to be made of solid iron, which is also preferable to attain better fabrication precision. As the core material, soft magnetic iron plates (C 2504 in Japanese Industrial Standard) are used. In Fig. 4, the outline of the design of this septum magnet is given. The insulation is made by ceramic coating for return coils and by Kapton sheets between septum coils, which might lower the bakable temperature below 300°C.

The magnet has been fabricated, which is shown in Fig. 5.

The experimental study of the temperature rise with DC mode for the real septum magnet and the field measurement are to be made just from now on. Another equally important test is the measurement of the outgassing rate of this septum magnet before the installation as an equipment in a heavy ion synchrotron, which requires ultra-high vacuum.

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