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# DESIGN OF SOLENOIDAL MAGNETS WITH LAMINATED CORES

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## Abstract

HIMAC (Heavy Ion Medical Accelerator in Chiba), which is the first heavy-ion accelerator facility for medical use in the world, is in operation at NIRS. A project of time-sharing-operation of the injector is in progress and a solenoidal magnet with a laminated core is designed and assembled for the time-shearing-operation of the injector. Specifications and results of magnetic-field measurement are described.

## Introduction

The HIMAC facility can be divided into three parts; the injector, the synchrotron with two identical rings, and the irradiation system with horizontal and vertical-beam lines. The injector comprises two kinds of ion sources ( ECR and PIG ), two kinds of linear accelerators ( RFQ and Alvarez linac ), and beam-transport systems. The linacs accelerate various ions of 8 keV/u, ranging from He to Ar, up to 6 MeV/u. A medium-energy beam line, in cooperation with two pulse-operated magnets, can supply beams to three beam lines, i.e. two synchrotron rings and a medium energy experimental room ( see Fig.1 ), 'simultaneously', changing the beam directions from pulse to pulse.

In order to increase the versatility of the facility, the time-sharing-operation of the injector, i.e. acceleration of different kinds of ions from pulse to pulse, was studied and the project is in progress. In the present case operating parameters of all devices will be adjusted to the optimum values so that ions with values of largely different q/A can be accelerated. All the magnets and monitoring devices in the beam transport line must, therefore, be replaced by those bearing pulsed-operation. Since a solenoidal magnet of DC-operation is installed in the low-energy beam-transport line, in addition to the electro-static quadrupole lenses, a new solenoidal magnet with a laminated core is designed and assembled.

## Structure of the solenoidal magnet

Specifications of the solenoidal magnet are listed in Table 1 and its dimensions and structure are displayed in Fig.2. A coil of 288 turns with a current of 350 A generates maximum magnetic field of 6.8 kGauss at the center. A water-cooled coil is made of the hollow copper conductors. A magnet core consisted of two types of segments, Core-A and Core-B ( see Fig.2 ), both of which are made of 0.5 mm thick steel plates coated with electrical insulators. The Core-A is a pile, 25 mm thick, of octagonal plates and is fixed to the Plate-A being made of SUS304. Rectangular plates of 65 mm × 218 mm in size are piled up to form eight pieces of Core-Bs; six of them are 160 mm thick and two of them are 130 mm thick. Each one is tightened by bolts and Plate-Bs, then fastened to the plate-A. The coil is also fixed to the Plate-A with supporting rods.

All the components, cores and the coil, were bolted, and no welding method was employed. It is, therefore, free from the strain induced by the welding. End faces of the coil, which define the spacing between Plate-Bs, were carved with accuracy of $\leqq$ 0.2 mm. Overall accuracy is within ±0.5 mm by controlling torque of the bolts. Omission of the welding process can cancel out the additional cost due to longer machining and assembling processes.

## Magnetic-field distribution

Measurement of magnetic-field distribution was carried out. The current source was operated in a DC mode. An example of the field distribution is shown in Fig.3 for the cases of I = 50, 100, 150, 200, 250, 300, 350 A. An effective field length was calculated to be 180 mm. Relation between the maximum magnetic field ( Bmax ) and the electric currents ( I ) is plotted in Fig.4.

The Bmax values linearly depend on the current values, so that saturation effect inside a core seems to be negligible small. The Bmax of 6.915 kGauss obtained with the current of 347 A is strong enough compared to the specification.

Laminated cores of solenoidal magnets have more complicated structure then that of ordinary dipole magnets. Our design of the new magnet can be one of the solution.

References

(1) A.Kitagawa, et al., The 5th Japan-China Joint Symposium on Accelerators for Nuclear Science and Their Applications. (1993)

Table 1
The specifications of the solenoidal magnet

| | |
|---|---|
| Coil length | 218 mm |
| Bore diameter | 110 mm |
| Maximum magnetic field | 6.87 kGauss |
| Maximum magnetomotive | $1\times10^5$ AT |
| Turns | 288 turns |
| Maximum current | 347.2 A |
| Maximum voltage(at 20℃) | 34 V |
| Maximum power(at 20℃,DC) | 11.8 kW |
| Cooling water circuits | 8 |
| Pressure drop | 3 $kg/cm^2$ |
| Water flow | 14.2 l/min |
| Water temperature rise | 12.5 deg |

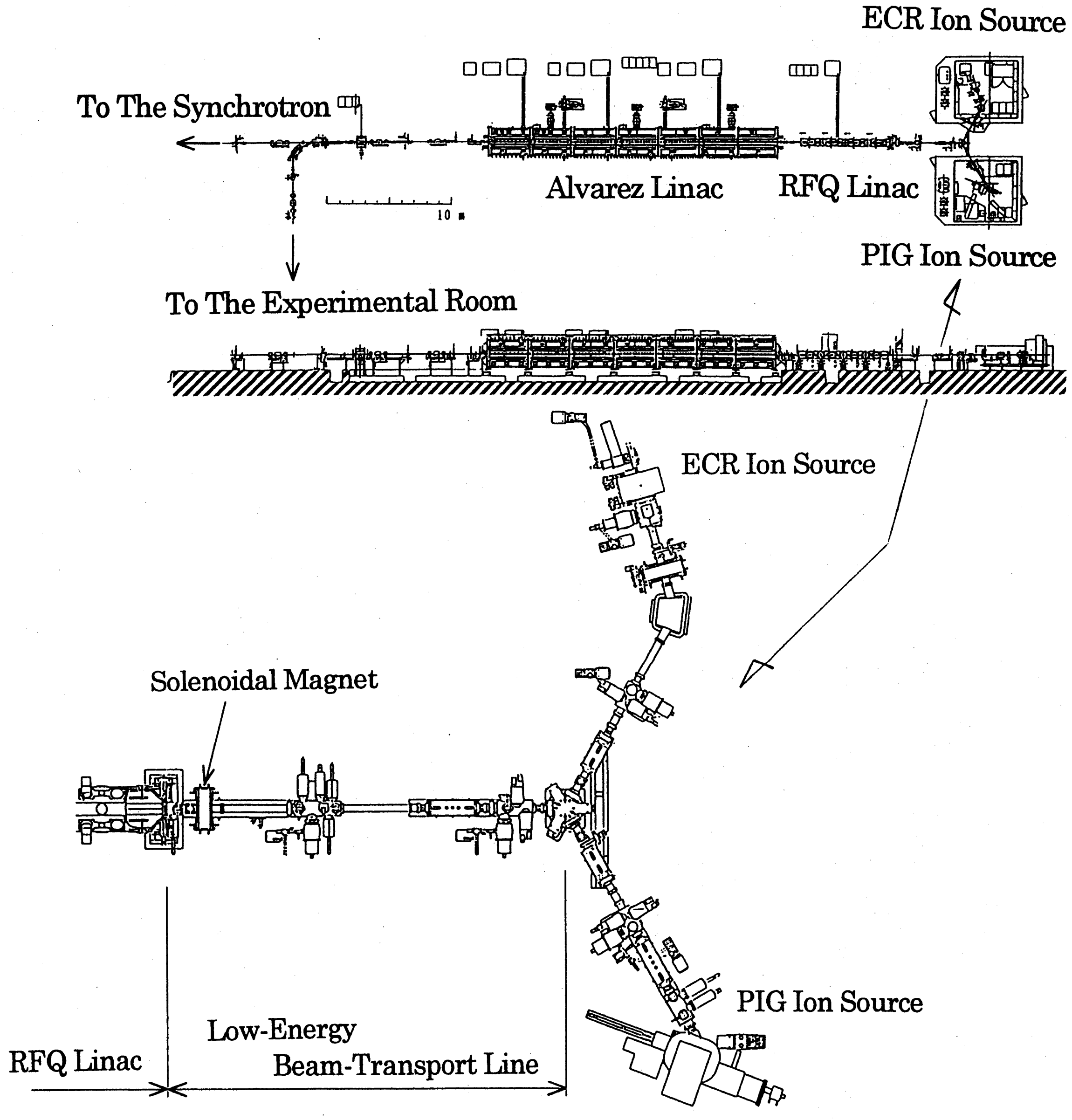


Fig.1 Layout of the injector

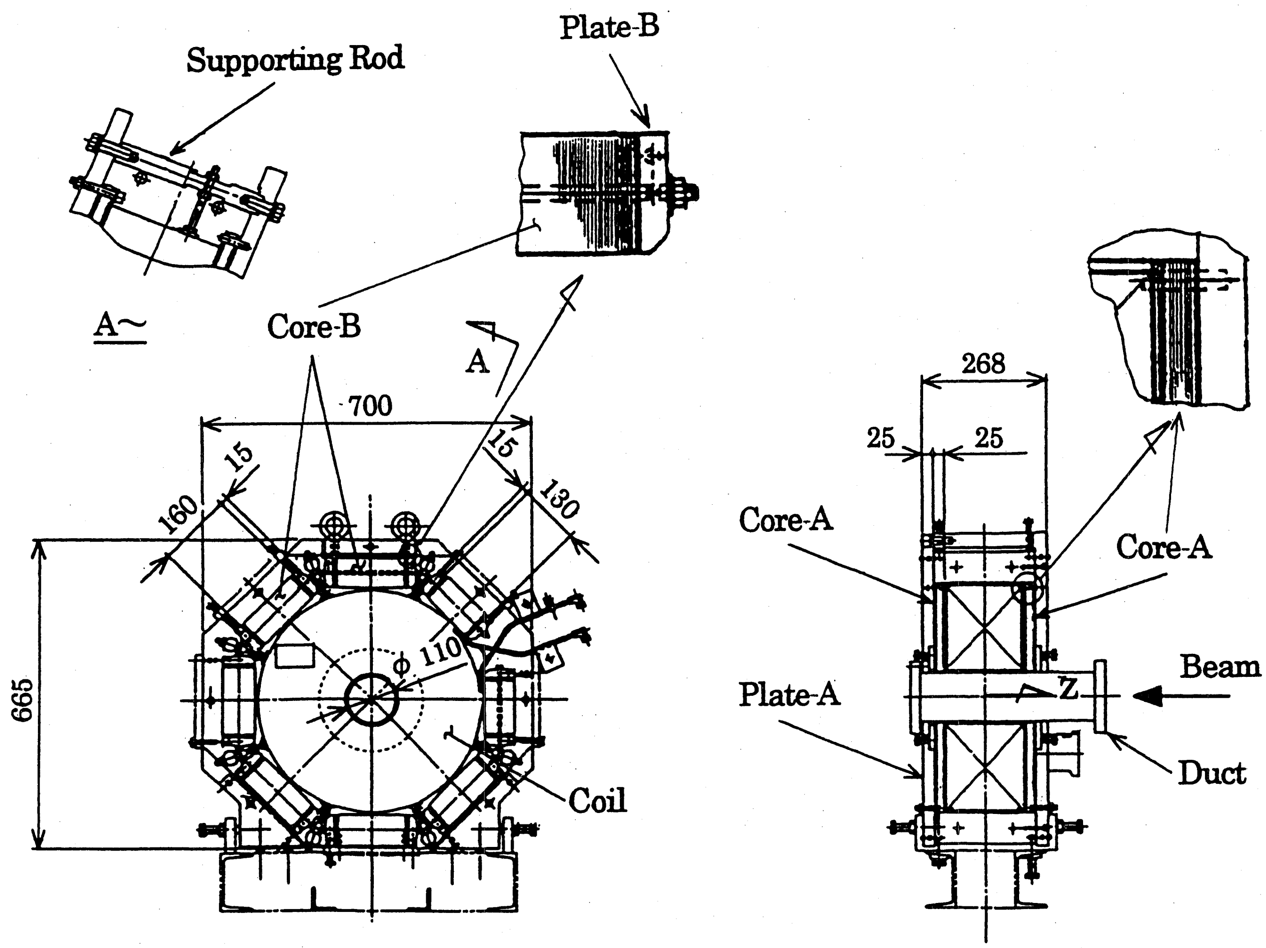


Fig.2 Structure of the solenoidal magnet

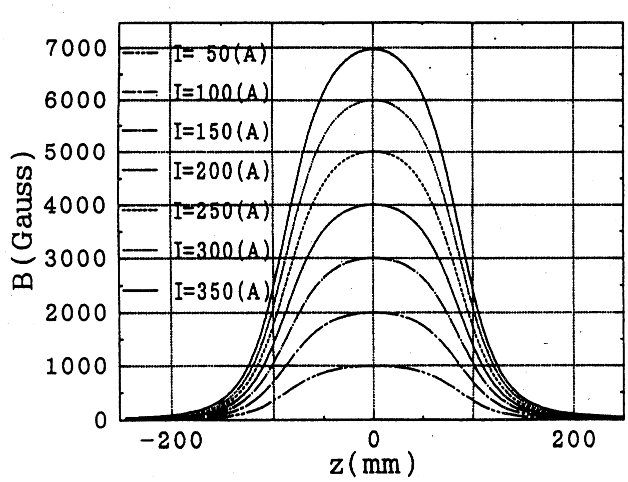


Fig.3 Magnetic field distribution

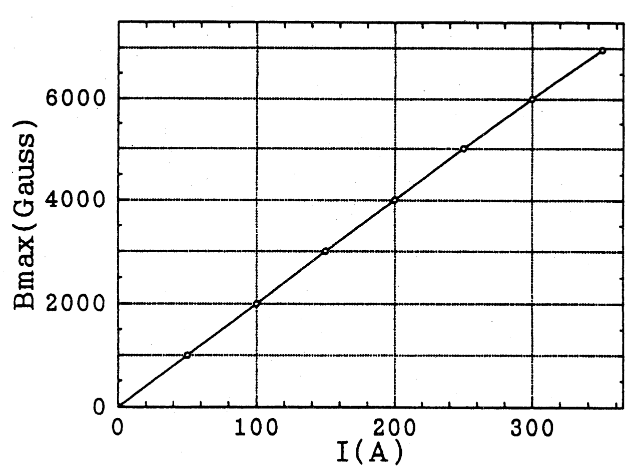


Fig.4 Relation between Bmax and I