Preliminary Measurement of the Magnetic Field in the Aperture of the Very High Field Short Pulse Dipole Magnet for Compact Synchrotron

S. Tokura, M. Hara, K. Uematsu, S. Nakajima, and Y. Miyauchi, Ishikawajima-Harima Heavy Industries LTD., Yokohama, Japan

S. Komiya, T. Ito, H. Tsutsui, S. Tsuji-Iio, and R. Shimada, Tokyo Institute of Technology, Tokyo, Japan

Abstract

Preliminary measurement of the magnetic field in the aperture of the very high-field, short-pulse dipole magnet is presented. The dipole magnet is applied for a compact proton synchrotron dedicated for cancer therapy. After numerical analysis for the design of coil geometry of the dipole magnet using 3 dimensional field simulation, test machine of the dipole magnet has developed. Besides, the special equipment for the measurement of the field in the aperture are also made. Preliminary operation for exciting the field in the aperture to the maximum magnetic flux density of 4 [T] is carry out, and measurement data are compared with data of the field simulation.

1 INTRODUCTION

Radiation therapy using high-energy proton has been proved to be very effective method of cancer treatment. On the other hand, it is not widely used due to its very high cost and large area required for the total system. Considering that the accelerator occupies the major parts of the system, reduction of its size and cost is strongly required for the spread of this effective therapy system.

A challenging idea of proton synchrotron using pulse high field (5 T) magnet was proposed by BINP [1], and component development has been made [2]. As the joint study of Frascati and BINP, Picardi et al (Frascati) [3,4] relaxed the parameters of the original BINP design, and proposed a moderate design of the maximum bending field of 4 T (referred to as “STAC” in the papers). Using more relaxed bending field of 3 T, Endo (KEK) et al. proposed a design of better feasibility to realize a very small carbon synchrotron [5], which is also strongly required for cancer treatment.

The authors have studied the feasibility of the proton synchrotron of the type of STAC, and showed that dynamic aperture is increased by the improvement of the design of bending magnet [6]. The new design of the cross-section of current conductor of the bending magnet considerably decreases sextupole field component [7, 8]. The authors have also reported the feasibility of the lattice composed of four bending magnets and four quadrupole magnets from the standpoint of dynamic aperture using detailed distribution of the multipole coefficients of bending field [9].

This paper introduces about the high-field, compact dipole magnet which the authors have developed based on results of numerical field simulation, and also reports the preliminary measurement of the field in the dipole magnet.

2 MAIN PARAMETERS

A compact 200 [MeV] proton synchrotron with the injection energy of 3 [MeV] has been proposed [6-9]. Four bending magnets and four quadrupole magnets compose the basic lattice as

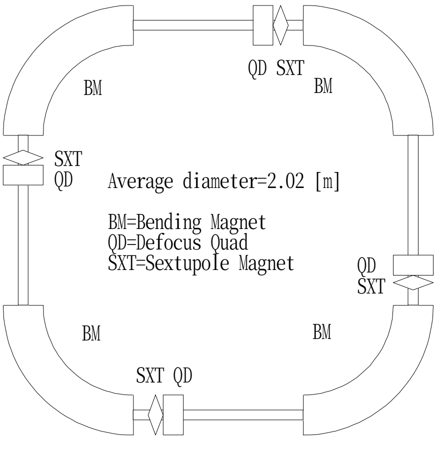

Figure 1 Lattice layout

Table 1 Main parameters

Item	Value
Extraction energy, T ext	200 MeV (644 MeV/c)
Injection energy, T inj	3 MeV (75.1 MeV/c)
Injector type	RFQ
Circumference, C	6.473 m
Bending radius, r	0.54 m
Bending field, B	0.42 - 4 T
Gap height / width, h / w	0.052 / 0.020 m
Bending angle	90 deg
Edge angle	0 deg
Acceleration time	3.5 ms
Super period	4
Betatron tune, ν_H / ν_V	1.469 / 0.420
Betatron function (Max.), β_H / β_V	1.395 / 2.641 m
Dispersion (Max.), η_H / η_V	0.596 / 0 m
Natural chromaticity, ξ_H / ξ_V	-0.049 / -0.346
RF frequency, f_{RF}	3.86 – 27.4 MHz
Harmonic number, h	1

shown in Figure 1. Four sextupole magnets are also prepared for the compensation of sextupole component of the magnetic field that may be generated near the edge of the bending. As the outer dimension is about 2.1 [m], it can be transported to hospitals after the assembly and tuning in the factory. Main parameters of synchrotron and its bending magnet are listed in Table 1.

3 DIPOLE MAGNET

Figure 2 is the photograph of the full-size dipole magnet. The bending radius is 0.54 [m], and the bending angle is 90 [deg]. The magnet core is consisted of silicon steel sheets with a thickness of 0.5[mm]. In order to laminate silicon steel sheets with high density, each silicon steel sheet is welded with seven steel bars under the condition where silicon steel sheets are clamped with special device firmly. Besides, considering the maintenance of the duct in the aperture, the magnetic core can be divided into two blocks (lower and upper sides). Figure 3 shows the conceptual cross-sectional view of the bending magnet. The current pattern for field excitation is the quarter of the sine curve, and its current rising time is 3.5 [ms]. In order to get the maximum field of 4 [T], the magnet is excited by high current of 200 [kA] using single turn copper bus.

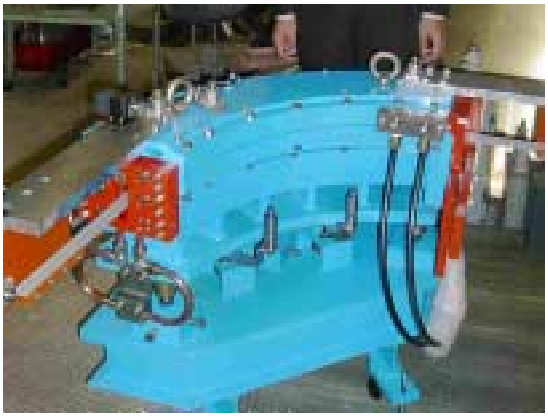

Figure 2 Photograph of the full-size dipole magnet

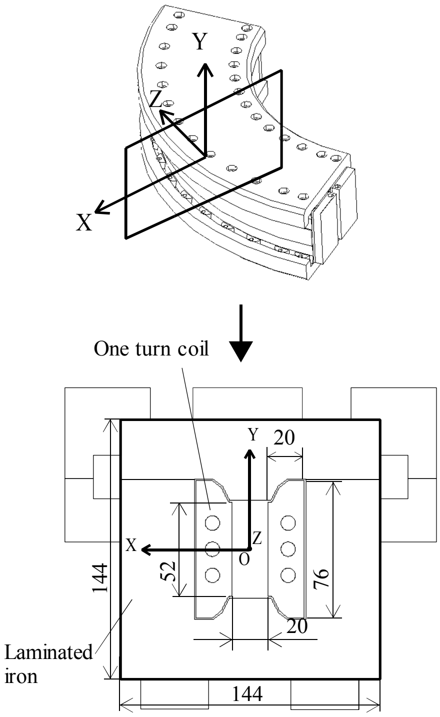

Figure 3 Conceptual cross-sectional view of the bending magnet

4 MAGNETIC FIELD MEASUREMENT

Figure 4 shows the diagram of the pulsed power supply for preliminary measurement of the magnetic field of the dipole magnet. The time shape of the current is a quarter sine function with 3.5 [ms] duration, which comes from the discharge of a 2.7 [mF] capacitor bank. The transformation ratio is 100:9.

The magnetic field measurements are performed using a set of 5 search coils to obtain the values of the magnetic field on X axis. The

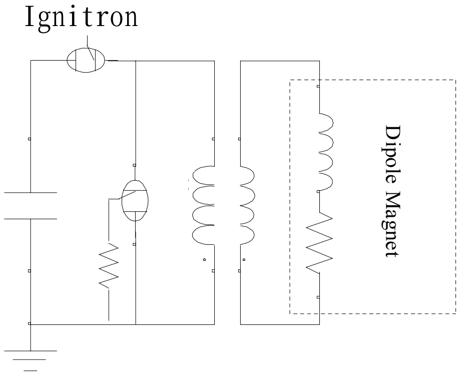

Figure 4 Diagram of the pulsed power supply of the dipole magnet

values of the magnetic field in the direction of the beam orbit are also measured. Figure 5 is the typical result obtained from 3 dimensional magnetic field simulation. This figure shows the distribution of the sextupole component in the direction of the beam orbit near the edge of the dipole magnet at extraction (200 [MeV]). The measurements of the magnetic field are mainly performed near the edge of the dipole magnet because of the figure suggesting the increase of the sextupole component near the edge.

6 SUMMARY

The proto type of the very high field short pulse dipole magnet has been developed, and preliminary field measurements have been performed. The values obtained from field measurements are compared to the result of the 3 dimensional magnetic field simulation.

ACKNOWLEDGEMENT

The authors would like to thank Dr. K. Endo (High Energy Accelerator Research Organization) for valuable advice and helpful suggestions to this research. They also thank Tokin Machinery Corporation for great help.

REFERENCES

[1] I. Averbukh et al., “Project of Small-Dimensional 200 MeV Proton synchrotron”, EPAC’88, Rome, 1988, pp413-6.
[2] “Prototype of the Proton Synchrotron with 5-Tesla Dipole Magnets”, BINP annual report, 1998, pp207-9.
[3] L. Picardi et al., “Preliminary Design of a Technologically Advanced and Compact Synchrotron for Proton therapy”, ENEA, 1994.
[4] L. Picardi et al, “Preliminary Design of a Technologically Advanced and Compact (STAC) for Proton therapy, Hadron therapy and Oncology”, 1994, pp367-376
[5] K. Endo et al., “Table-top Proton Synchrotron Ring for Medical Applications”, EPAC2000, Vienna, 2000, pp2515-7.
[6] Y. Miyauchi et al., “Preliminary Study of the Feasibility of Pulse High Field Compact Synchrotron for Medical Use”, Kyoto Univ. activity report, Vol.6, 2001.
[7] S. Tokura et al., “Very High-Field Short-Pulse Dipole Magnet For Compact Proton Synchrotron“, PAC’2001, Chicago, 2001.
[8] S. Tokura et al., “Design of the Very High-Field Short-Pulse Dipole Magnet“, The 13th Symposium on Accelerator Science and Technology, Japan, 2001, pp271-273.
[9] S. Tokura et al., “Study of the Dynamic Aperture of the Pulse High Field Compact Proton Synchrotron for Medical Use”, Kyoto Univ. activity report, Vol.7, 200.2.

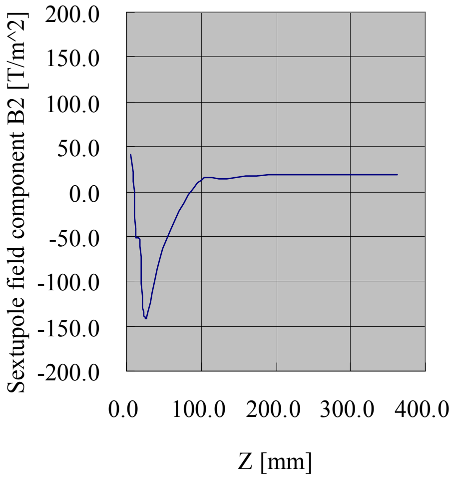

Figure 5 Sextupole component in the direction of the beam orbit (200MeV)