DEVELOPMENT OF A QUADRUPOLE MAGNET FOR CSNS DTL*

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Abstract

In the 324MHz CSNS Drift Tube Linac, the electromagnetic quadrupoles will be used for transverse focusing. The R&D of the quadrupole for the lower energy section of the DTL is a critical issue because the size of the drift tube at this section is so small that it is not possible to apply the conventional techniques for the fabrication. Then the electromagnetic quadrupoles containing the SAKAE coil and a drift tube prototype containing an EMQ have been developed. In this paper, the details of the design, the fabrication process, and the measurement results for the quadrupole magnet are presented.

INTRODUCTION

The China Spallation Neutron Source (CSNS) Accelerator Facility mainly consists of a high intensity H^- ion linac and a rapid cycling synchrotron of 1.6GeV [1]. The main parts of the CSNS linac includes a 50keV H^- ion source, a 3.0MeV RFQ accelerator and a conventional Alvarez DTL structure which accelerates the H^- ion from 3.0 MeV to 80 MeV at the first stage and 132MeV for upgrade (Figure 1).

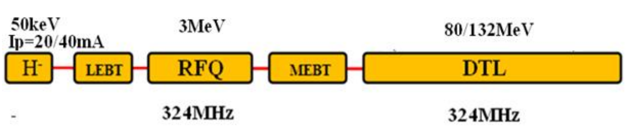

Figure1: CSNS Linac layout.

The electromagnetic quadrupoles (EMQs) are widely used in linear accelerator for transverse focusing since the magnetic field gradient can be adjusted by varying the current flow in the conductors [2, 3]. The EMQs will be installed in each of the drift tubes of the DTL as the injection part of the high-intensity proton accelerator facility in the CSNS Project.

Since the operating frequency is much higher (324 MHz), the size of the drift tube (DT) becomes smaller, resulting in many technical difficulties in the fabrication especially for the low-energy part of the DTL. The main challenge of such a structure is to house a strong gradient EMQ in the much reduced space of the DT. And the insulation between the coil and the shell should be treated carefully. After an EMQ being successfully fabricated, a DT prototype containing this EMQ has been built to test the technological feasibility such as quadrupole magnet design and manufacturing process, vacuum problems, cooling issues, mechanical aspects, etc.

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THE CHARACTERISTICS OF THE QUADRUPOLE FOR THE LOW-ENERGY PART OF THE DTL

Beam dynamics for the CSNS DTL has been calculated in PARMILA and field gradients for each magnet have been obtained. All the DTL magnets were divided into two sizes to allow standardization and to reduce the size of the DT. This design improves the shunt impedance, thus minimizing power losses in the machine walls.

The major parameters of the designed quadrupole for the injection section (3MeV) are given in Table1. The main goal of the design was to minimize saturation in both poles and yokes while maintaining small dimensions, the required gradient, and as low current density as possible. Furthermore the high-order multipole components also should be considered. Figure 2 shows the field design of the electromagnetic quadrupole calculated by using the POISSON code [4].

Table 1: Design parameters of the Q-magnets and the DTs for the low-energy part of the DTL.

Magnet aperture diameter (mm)	15
Yoke out diameter (mm)	118
Core length (mm)	35.0
Magnetic field gradient (T/m)	75
Effective length (mm)	41.3
Core material	Silicon steel 50WW470
Thickness of steel leaf (mm)	0.5
Number of turns per pole	3.5
Integrated field *GL* (T)	3.1
Water flow rate (l/min)	1.0
Max. excitation current (A)	528
Conductor area (mm^2)	18.75
Current density (A/mm^2)	28.16
Resistance of coil (mΩ)	4.25
Inductance of coil (μH)	31.66
DT aperture diameter (mm)	12.0
DT outer diameter (mm)	148

At the low energy section of DTL, the electromagnet must be installed within the compact DT (outer diameter within Φ148 mm, length about 49.89 mm minimum). The magnet should have a sufficiently large bore diameter (nearly Φ15 mm) and a high magnetic field (an integrated magnetic field gradient is 3.1 Tesla). The deviation of a quadrupole field center from the mechanical center is limited to be within ±30 μm required by beam dynamics. In order to satisfy these critical requirements, the conventional hollow conductor type coil is not suitable any more since the large bending-radius reduces the area of flux. Consequently, we adopted an electroformed hollow coil, the SAKAE type coil [5], which has no bending radius. The wire cutting and the Periodic Reverse (PR) copper electroforming method are applied to the coil manufacture process. Figure 3 shows the EMQ assemblies within this type coil. The quadrupoles will be installed into the DTs, which is made of Oxygen Free Copper (OFC) and use the electron-beam weld method.

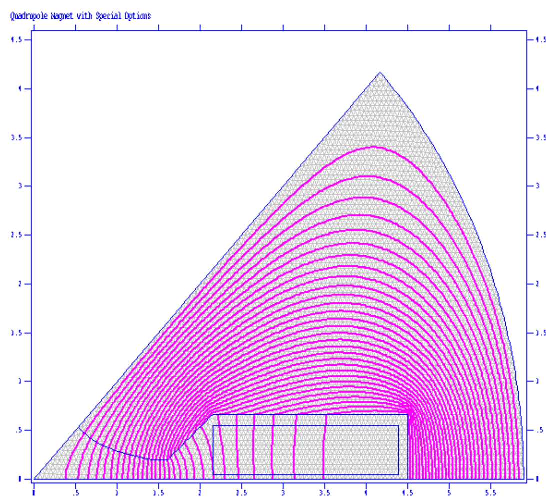

Figure2: The design field of the EMQ by POISSON code.

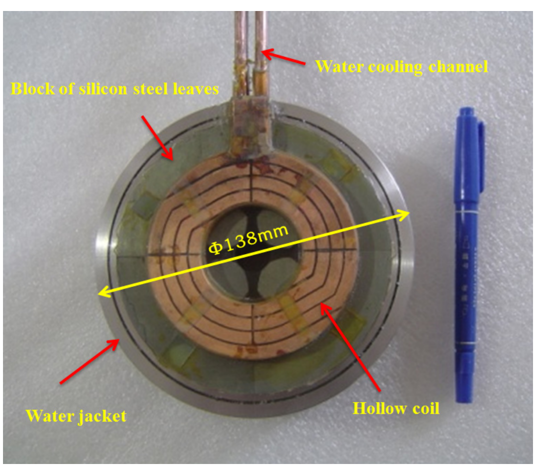

Figure3: The EMQ assemblies.

QUADRUPOLE MEASURMENTS

After the assembly of quadrupole being finished, the field measurements were carried out. The excitation property, magnet field gradient in transverse plane and the effective length were measured by Hall probe. Figure 4 (a) shows comparison of magnetic field gradient as function of excitation-current for measured and analyzed data. It indicates that the designed gradient of 75T/m can be achieved with an excitation current of 495A, which is lower than that from 3D simulation. Figure 4 (b) shows the measured effective length .The measured effective length is 42.8mm and slightly longer than the design one about 3.7%.

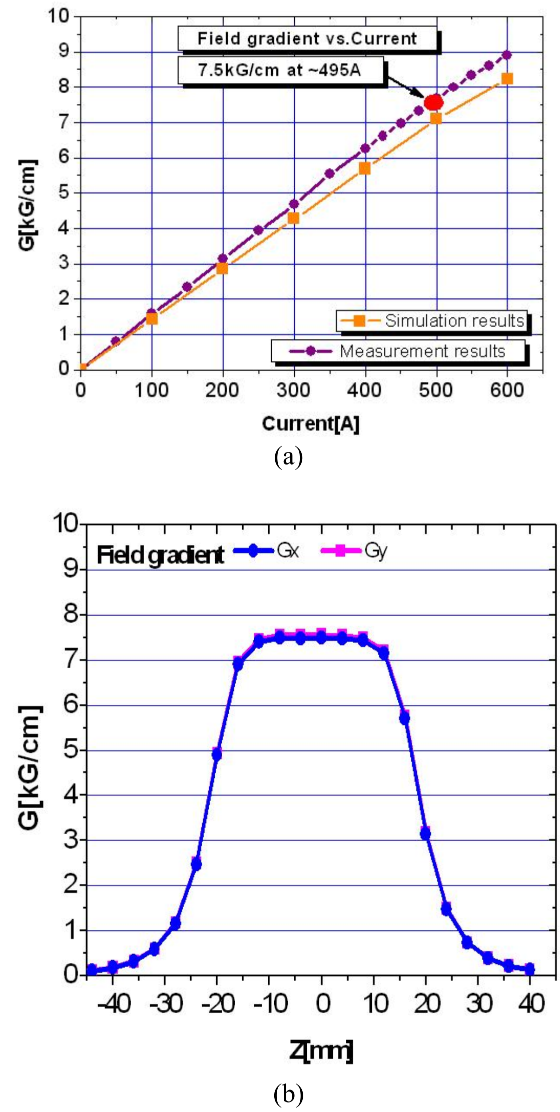

Figure 4: The excitation property of the magnet field gradient in transverse plane (up) and the measured effective length results (down).

Because the quadrupole will be operated in DC mode, the temperature rise of cooling water should be concerned enough. The temperature rise of the cooling water was measured on the DT prototype. In the coil for the measured pressure drops are 4.8kg/cm2 and the water flows of 1.1 Liter/minute, the average water temperature rise at DC current 495A was 8.6 °C. For stable operation consideration, we also measured the temperature rise at higher DC current 600A for three hours. Figure 5 shows the temperature distribution photo of the coil surface at DC 600A. It can be funded that the highest temperature 36℃ occurred at the outlet of water cooling channel, 11.2℃ correspondingly the temperature rise, which was approximately equal to the calculate value11.8°C..

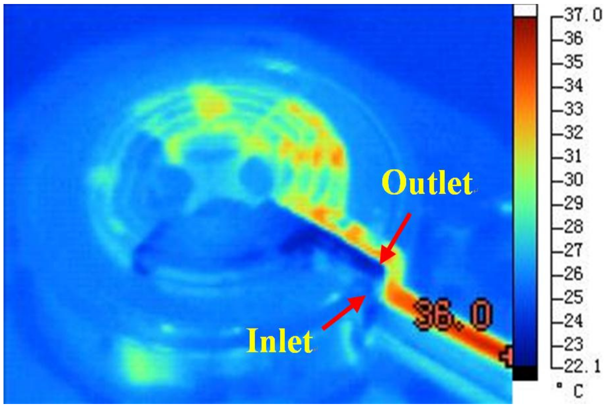

Figure 5: The temperature distribution of the coil at DC 600A.

The EMQ installed into drift tube has a concentric tolerance of less than ±30μm error. A small rotating coil measurement system (Figure. 6) was developed to detect if the deviation between the magnetic field center and the drift tube center is within the required accuracy. On the supporting structure of the measurement system, the drift tube was adjusted in accordance with the magnetic field center which was defined as the position with a minimum dipole component being less than 0.3% in comparison with the quadrupole component. And then the mechanical center of the beam pipe and outer diameter of the drift tube were machined according the measurement results. Furthermore, the higher order multipole components in the magnetic field center are also measured by the rotating coil simultaneously, as shown in Figure 7.

The first prototype of DT has been successfully completed in this January (as shown in Figure 6). The discrepancy between the drift tube mechanical center and the magnetic field center is 12μm. The ratio of the dipole component and the quadrupole component is 0.16%. From Figure 7, it can be obtained that the higher-order multipole components were sufficiently small, being less than 0.3% in comparison with the quadrupole component.

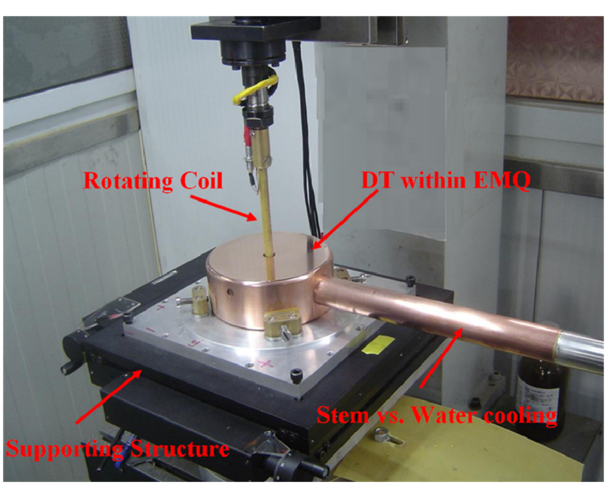

Figure 6: The first prototype of drift tube and the rotating coil measurement system.

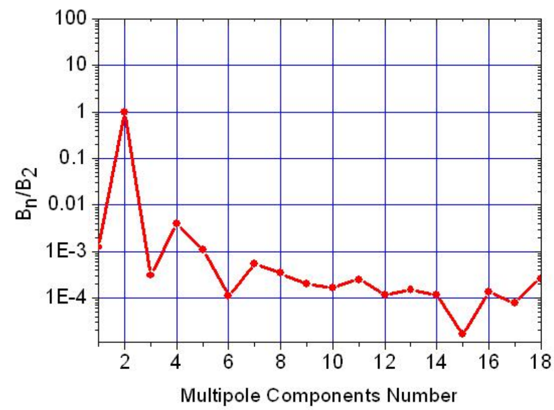

Figure 7: The measured higher-order components of EMQ.

CONCLUSIONS

A prototype of the electromagnetic quadrupole for 324-MHz DTL has been successfully developed with a hollow coil in IHEP. The Measurements of the magnets' properties were carried out with the Hall probe and the rotating coil measurement system. The measured effective length agreed with the design one within approximately 3.7%, and higher-order multipole components in the magnetic field center were sufficiently small, being less than 0.3% in comparison with the quadrupole component. The results are found to be consistent with computer calculation and satisfy the requirements for the low-energy part of the DTL.

ACKNOWLEDGEMENTS

We acknowledge the support of the Chinese Academy of Sciences and the staff of IHEP.

We also wish to acknowledge the fruitful discussions with the KEK and JAERI colleague, especially Prof.F.Naito and Dr.K.Hasegawa.

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