FABRICATION AND TESTS OF THE DTL HOT MODEL IN THE R&D WORKS FOR THE BASIC TECHNOLOGY ACCELERATOR (BTA) IN JAERI

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Abstract

A hot model of a DTL has been developed to examine the cooling capability and the RF characteristics for the Basic Technology Accelerator (BTA) in Japan Atomic Energy Research Institute (JAERI). Quadrupole magnets were installed in the drift tubes after the measurements of the magnetic field strength and distribution. The hot model was assembled and the cold test was performed to examine the RF characteristics. The cooling capability was also studied through the high power test with feeding RF power. The results of the tests satisfy our object in the R&D study.

Introduction

A proton linear accelerator (BTA) with an energy of 10 MeV and an average current of 10 mA has been developed to provide high-current and low-emittance proton beam[1]. In the BTA system, 2 MeV protons accelerated by the RFQ are injected to the DTL and accelerated up to 10 MeV. In the development of the BTA-DTL, the field strength of the quadrupole magnet and the heat removal problem are the key issues especially in the low energy portion (E_p~2MeV) to achieve high transmission rate and high duty factor. In the R&D stage of the BTA, a hot model with 9 cells which is a mockup of the low energy portion of the BTA-DTL have been fabricated by Mitsubishi Heavy Industries, Ltd.

The specifications and the cross sectional view of the hot model are given in Table 1 and Fig. 1, respectively. Electromagnetic quadrupole magnets have been installed in the #1 drift tube and the one at the front end plate (DT#1 and #0 in Fig. 1, respectively). The magnetic field strength and distribution were measured prior to installation. The hot model was assembled and cold test was performed to examine the RF characteristics. The cooling capability was also studied in the high power test.

Magnetic Field of the Q magnet

In this R&D work, we developed electromagnetic quadrupole magnets (DTQ#0 and #1) which are hollow conductor type to improve the cooling capability provided for future cw operation. Figure 2 illustrates the cut view of the magnet in the drift tube. The poles and yoke are made of Fe-Co alloy to obtain required field gradient (80 T/m) in the limited space. To examine the magnetic characteristics, following issues were measured; (1) the excitation function, (2) the field distribution, (3) displacement from the mechanical center to the field center, and (4) the intensity of the higher harmonic components.

Magnetic field as a function of exciting current is measured with a Hall effect transducer and a 3-dimensional positioning machine. Designed field gradient of 80 T/m has been obtained at current of 785 A and 753 A for the DTQ#0 and #1, respectively. The field distribution in the transverse

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TABLE 1
Specifications of the DTL hot model

Cavity			
Resonant frequency	:	201.25	MHz
RF duty factor	:	12	%
Average field strength	:	2	MV/m
Quality factor	:	50634	(100% Q)
Wall loss	:	176 kW	(60% Q)
Number of cells	:	9	
Tank diameter	:	893	mm
Tank length	:	1005.5	mm
DT inner diameter	:	20	mm
DT outer diameter	:	200	mm
Quadrupole magnet (in DT#0 & #1)			
Hollow conductor type (5×5 mm²)			
Field gradient	:	80	T/m
Excitation current	:	780 A	(DC)
Number of turn	:	5.5	Turns
Pole & yoke	:	Fe-Co	Alloy

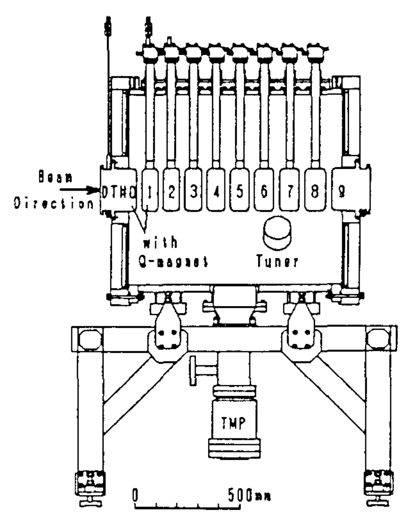

Fig. 1 Cross sectional view of the DTL hot model

direction has been confirmed to have good linearity over the adequate range of −15 ~ +15 mm, which satisfies the specification of the magnet since bore radius is 10 mm.

A conventional rotating search coil and the Fast Fourier Transformer (FFT) technique[2] was used to measure the magnetic center position and higher harmonic field components. A fine adjusting stage with positioning accuracy of 1 μm was used for the magnet positioning. The induced voltage in the search coil was fed to a signal analyzer to obtain frequency spectrum. The displacements from the mechanical center to the magnetic center are 12 and 27 μm for the DTQ#0 and #1, respectively.

The harmonic voltage spectrum was obtained in the series of the measurements. Figure 3 shows the typical harmonic spectrum for the DTQ#1. The magnitudes of the higher multipoles are less than 1 % of the quadrupole components, and will not cause significant effects to the beam dynamics.

Assembling and Cold Test

The hot model was assembled for the cold test and the high power test. About 2 weeks were needed for assembling and drift tube alignment. The drift tube alignment was made with a laser telescope, a reflecting target and a precise longitudinal scale. Alignment errors in the transverse plane and the longitudinal direction are within 0.1 and 0.08 mm, respectively.

The cold test was performed to examine the RF characteristics, i.e., resonant frequency, Q value and electric field distribution on the beam axis. The resonant frequency of the TM_{010} mode was measured to be 201.178 MHz when the tuner displacement was 100 mm. Figure 4 shows measured frequency shifts as a function of tuner displacement compared with the calculation by the MAFIA code[3]. The measured frequency shifts are in good agreement with those by the calculation. Total frequency shift was about ±200 kHz, which is enough to compensate the frequency change due to RF heating. The measured Q value was 42000, which is 83 % of the calculated one by the SUPERFISH code. The result indicates that the RF power of 130 kW is required to obtain the prescribed average field strength of 2 MV/m.

Electric field distributions on the beam axis were measured by the bead perturbation method with an aluminum spherical bead of 7 mm in diameter. Figure 5 shows typical field distribution, where vertical scale was normalized to designed field strength using the stored energy calculated by the SUPERFISH code. An average field strength over the whole region has been deduced to be 2.03 MV/m which is in good agreement with the designed value of 2 MV/m. Deviation of an average field in each cell has been deduced to be within ±2.3 %.

High Power Test

The high power test was carried out to examine the

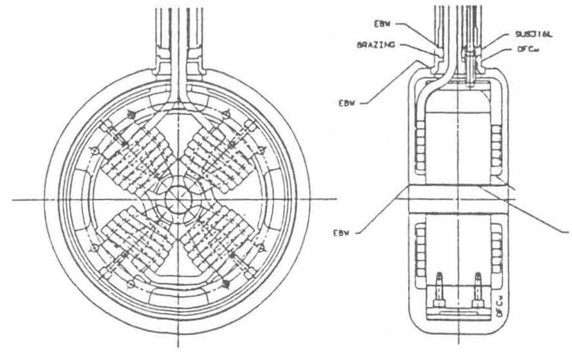

Fig. 2 Cut away view of the quadrupole magnet in the drift tube

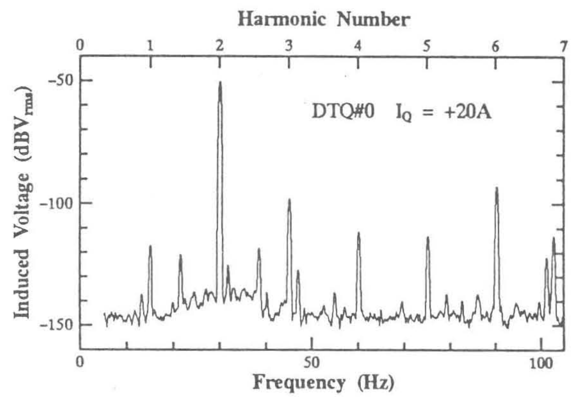

Fig. 3 Harmonic spectrum of the DTQ#0

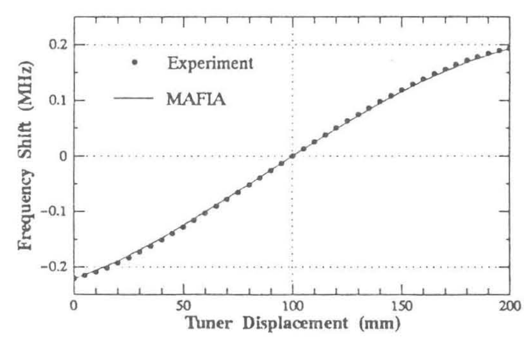

Fig. 4 Measured frequency shifts as a function of tuner displacement

cooling capability. Prior to the cooling capability test, high power conditioning has been done with monitoring RF signals from a pickup loop and a directional coupler, temperatures of the cooling water, total vacuum pressure by ionization gauge, partial pressure by quadrupole mass spectrometer and bremsstrahlung X-ray spectrum.

In the high power conditioning, we observed the input RF power up to 154 kW with duty factor of 12%, which exceeds the prescribed power of 130 kW described above. Figure 6 shows bremsstrahlung X-ray spectra measured with a HP-Ge detector. In this measurement, a collimator and a shield were set up carefully to detect X-rays only from a gap region between DT#0 and #1. In Fig. 6, both energy and yield of X-rays increase as the input power rises. Maximum energy in the X-ray spectrum called end-point energy in Fig. 6 represents gap voltage, since electrons are accelerated by the RF field[4]. The end-point energies were measured at the several conditions of input RF power. The relation between input power from the RF monitor and gap voltage from the X-ray spectrum agrees well to the calculation by the SUPERFISH code.

The cooling capability was examined by feeding the prescribed RF power of 130 kW. To obtain the distribution of the power dissipation, temperature rise and flow rate of cooling water through each path were measured by platinum resistance thermometers and a flow meter, respectively. Figure 7 shows the distribution of power dissipation obtained experimentally in comparison with the calculated values by the SUPERFISH code. Circles in Fig. 7 represent the experimental results when only RF power was fed, which are in good agreement with those by calculation except for the DT#0, #9 and downstream end plate. Since DT#0 and #9 are attached to the end plates, it is considered that disagreement between the experiment and the calculation is caused by heat transfer from end plate to drift tube. Triangles in Fig. 7 represent the experimental results when both RF power and excitation current of the quadrupole magnets were fed. In comparison between circles and triangles in Fig. 7, the cooling water of the drift tubes (#0 and #1 in Fig. 7) removed only a few percent of the magnet heating and most of the heating was confirmed to be removed by the magnet cooling water (Q mag in Fig. 7), which satisfies our cooling design. The temperature rise of the magnet cooling water was around 25℃, which agrees our designed value[1].

Summery

In the R&D works of the BTA, the hot model of the DTL has been developed and the magnetic field of the electromagnetic quadrupoles, the RF characteristics and cooling capability have been examined to be satisfactory results. The methods of design and fabrication developed in this work are applied to the fabrication of the BTA-DTL.

Acknowledgement

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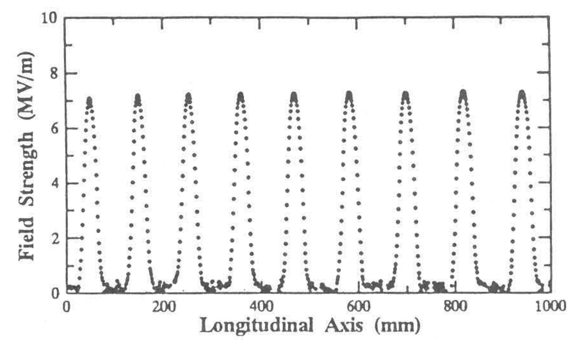

Fig. 5 Electric field distribution on the beam axis measured by bead perturbation method. The vertical scale is normalized to prescribed field strength using the stored energy by the SUPERFISH code.

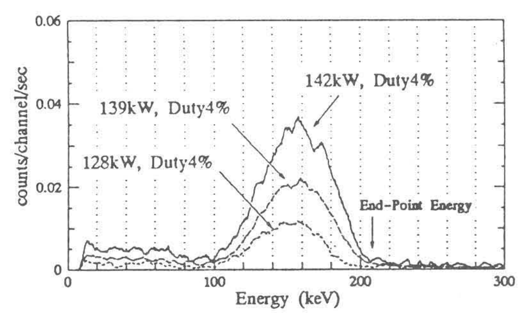

Fig. 6 Bremsstrahlung X-ray spectra measured by a HP-Ge detector.

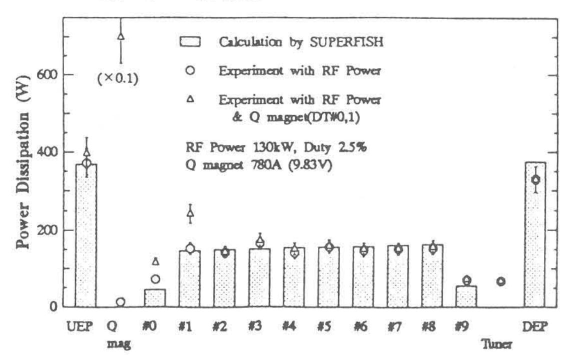

Fig. 7 Distribution of power dissipation.
#0~#9: drift tube and stem,
UEP : upstream end plate,
DEP : downstream end plate.