EXPERIMENTAL RESULTS OF THE SHIFT BUMP MAGNET IN THE J-PARC 3-GEV RCS

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Abstract

The shift bump magnet produces a fixed main bump orbit to merge the injection beam into the circulating beam. In order to control the injection beam for the short injection time (500 microseconds) with sufficient accuracy, the shift bump magnet needs a wide uniform magnetic field and the high speed exciting pattern of the high current. The magnetic field design and the structural analysis of the shift bump magnet have been performed using the three-dimensional electromagnetic analysis code and the mechanical analysis code, respectively. The magnetic field distributions were measured with a long search coil, thus giving a BL product over the magnet gap area. The temperature distributions at the various points of the magnet were measured by the thermocouples over 24 hours till they saturated. General trend of these measurements agrees well with calculations.

INTRODUCTION

The beam injection system of the J-PARC (Japan Particle Accelerator Research Complex) 3-GeV RCS (Rapid Cycling Synchrotron) consists of four shift bump magnets that produce the closed bump orbit to merge the injection beam into the circulating beam [1] [2] [3]. The shift bump magnets are located at the long straight section in the 3-GeV RCS injection area. The four shift bump magnets connected in series, so that the tracking of the power supply can be dispensable.

In the first stage, the energy of the injection beam and the extraction beam is 181MeV and 3GeV, respectively. And the extraction beam power is 0.6MW at a repetition rate of 25Hz. In the second stage, the injection beam energy and the extraction beam power are to be upgraded to 400MeV and 1MW, respectively. All bump magnets were designed corresponding to 400MeV injection beam design. All power supplies of the bump system are operated by the design of 181MeV injection at the first stage, and they can be upgraded to 400MeV injection design at the second stage. The production of all magnets and power supplies will be finished by November 2006. Installation of them will be finished by January 2007.

The power supply for the shift bump magnet is not available yet, so that of the preceding machine of the paint bump power supply has been used for the measurements that the magnetic field and the temperature distributions of the shift bump magnet.

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SPECIFICATIONS OF THE MAGNET

The parameters of the shift bump magnet are shown in Table 1. The shift bump magnet has a longitudinally split structure to insert a foil between the magnet core for H0 beam stripping. The machine acceptance of the magnet gap area is 486πmm-mrad, and the core and the coil of the shift bump magnet have been designed for a wide uniformed good field region. The uniformed good field region to cover the injection beam from the Linac and the circulating beam stay area of the RCS is 370mm in width and 224mm in height. To make core loss small, window frame core of the shift bump magnet is made from laminated silicon steel cores, the thickness of which is 0.15mm.

The decay time of the excited current is to be less than 150 microseconds in order to protect the charge exchange foil against the excessive foil hits by the circulating beam [2]. When the maximum exciting current of 32.2kA is decaying, 6kV maximum voltages are applied to the magnet against ground.

The beam injection period is 500 microseconds. Power supply with IGBT chopper units is controlled by a switching frequency over 60kHz and the deviation of the actual current to the programmed current is less than 1%.

Table 1: Parameters of the shift bump

Parameter	Value
Number of magnets	4
Structure	W- frame
Core Length [mm]	400 - 400
Turns per Coil	2
Gap Height [mm]	310
Coil Inside Distance [mm]	616
Maximum Current [kA]	32.2 (20.0)*
Maximum Field [T]	0.26 (0.17)*
Maximum Magnet Voltage [kV]	6
Inductance [H]	13.6×10^{-6}
Beam Stay Area [mm] (Horizontal / Vertical)	370 / 224
Lamination thickness [mm]	0.15

(181 MeV injection beam design)*

CURRENT MEASURMENT

The current pattern of the shift bump was excited by the preceding machine of the paint bump power supply, and the magnetic field distribution of the shift bump was measured. The measurement result of the exciting current waveform of the shift bump for closed bump orbit is shown in Fig.1. The maximum excited current is 20kA that corresponds to 181MeV beam injection design. The exciting current was measured by PEARSON CT (model 1423). Preliminary test of long-term operation for 24-hours was performed, and the result is shown in Fig.2. The deviation of the exciting current to the programmed current pattern was confirmed less than 1%.

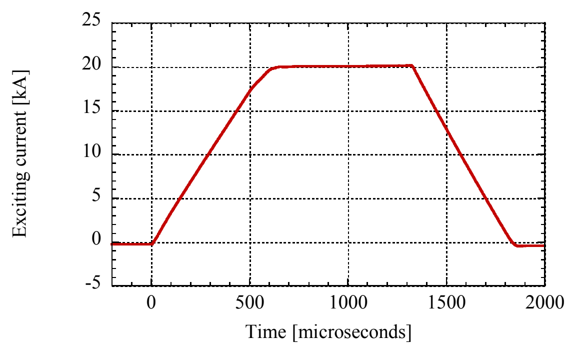

Figure 1: Exciting current waveform of the shift bump design at the experiment.

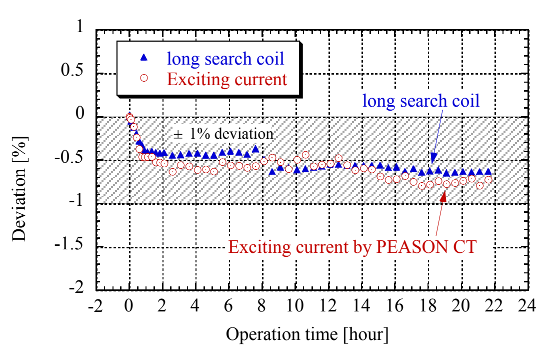

Figure 2: Long-term operation test result for 24-hours.

MAGNETIC FIELD MEASURMENT

The design of the core and the coil in consideration of a magnetic field distribution has been performed using three-dimensional analysis code, TOSCA [3]. By the optimization of the coil and the core shape, a uniform field with less than 0.35% in homogeneous distribution, which is 400mm in width and 270mm in height, has been achieved.

The distributions of the integrated magnetic field were measured by the long search coil. The picture of the set-up for magnetic field measurement is shown in Fig.3. The flexible bar is applied to connect the coil with the cross bar for countermeasure of the thermal expansion [3]. The long bar in the center of the magnet gap area is the long search coil that is made of the epoxy resin. The coil loop line of the long search coil is wound with 0.1mm enamelled wire, and the loop size is 3mm in width and 2500mm in length by 3 turns.

The raw data of the experimental results of the long search coil and the integrated waveform are shown in Fig.4. The BL in the figure means the numerical value that the result divided by the loop area and the coil turn numbers.

The integrated magnetic field distribution is shown in Fig.5. This result shows the realization of the uniform field with less than 1% inhomogeneity over a wide area, which is 400mm in width and 270mm in height. This good field region is enough to cover the 486πmm-mrad circulating beam and injection beam from the Linac.

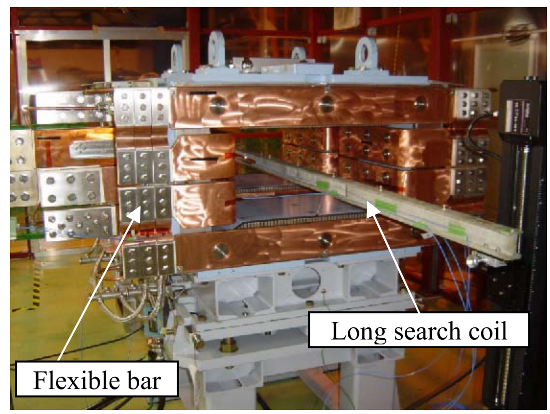

Figure 3: Setup for the field measurement.

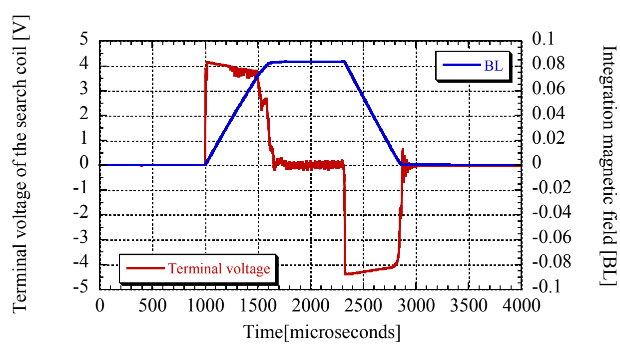

Figure 4: Raw data of the experiment results of the long search coil and the integrated wave form by using that raw data.

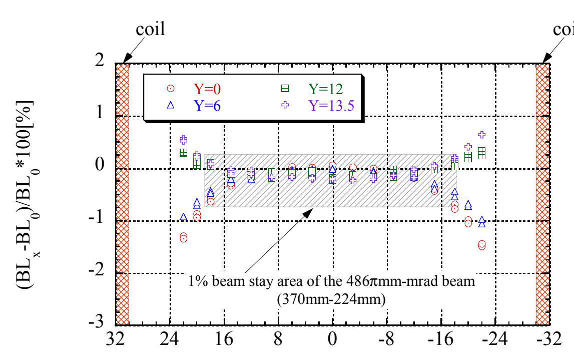

Figure 5: Integrated magnetic field distribution.

TEMPERATURE MEASURMENT

Calculation Result

The magnet core of the shift bump is laminated by 0.15mm thin steel sheets in order to decrease the iron loss by an eddy current. The end plate made of SUS 316 is 25mm thick due to the hold up to the laminated pressure of 2 MPa. The end of the core and the end plate are applied by the slit cut. The slit cut is given for 2mm width at intervals of 10mm and the incised height is 35mm and the depth along the beam axis is 30mm.

The temperature of the end plate, the core and the coil were calculated using the EMSolution and the ANSYS analysis at the 400MeV beam injection design of the shift bump magnet. The calculation results are shown in Fig.6. The temperature of the end plate is 102 degrees C and the core is less than 100 degrees C. The maximum temperature of the coil with cooling is 155 degrees C and the water temperature rises up by 3 degrees C. In any case, it calculated at 30 degrees C room temperature. The cooling water pipe is only applied at the cross bar because the pipe in the magnetic gap gives the influence to the magnetic field distribution and the electric field.

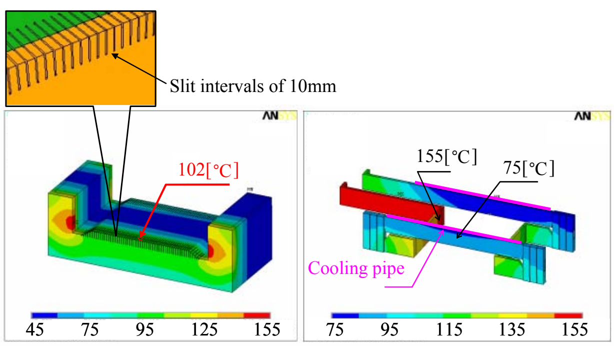

Figure 6: Calculation results of the temperature of the end plate, the core and the coil.

Experimental Results

The temperature distributions of the end plate, the magnetic core and the magnetic coil were measured by the thermocouples at the 181MeV injection beam design. The long-term operation for 24-hours was performed, and the temperature distributions were shown in Fig.7. The temperature of each point was about saturated after 20 hours.

The temperature of each part of the magnet has been estimated from the measurement results in preparation for the upgrade to 400MeV beam injection. The exciting current parameters of the experiment were 10kA, 15kA and 20kA, and the estimated temperatures are shown in Fig.8. It became the temperatures that the estimated results by the experimental results were higher than the calculation results. It has been considered that the effective value of the excitation current waveform of the calculation becomes 30% smaller than the actual current waveform. Because the paint bump power supply is used, it can't excite the actual current waveform of the shift bump magnet design. Although the temperature of the coil becomes as high as 100 degrees C, it is satisfactory in order to use Rika-Lite of heat resistant material [4].

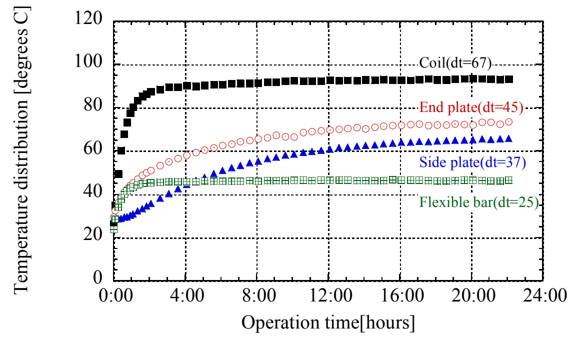

Figure 7: Temperature distributions of the long-term operation for 24-hours.

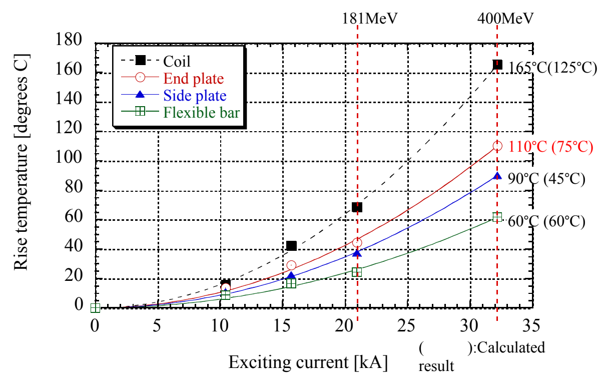

Figure 8: Experimental results and estimated temperatures of 400MeV operation design.

SUMMARY

The magnetic field distribution less than 1% deviation of the shift bump magnet was wide enough to cover 486πmm-mrad beam. The good performance at the 181 MeV injection beam design was confirmed. Furthermore, the prospect of being equal also to generation of heat load in the case of 400MeV injection beam design was acquired.

REFERENCES

[1] T.Takayanagi, et al, "Design of the pulse bending magnets for the injection system of the 3-GeV RCS in J-PARC", PAC'05, Knoxville, Tennessee, May 2005, p. 1048.

[2] T.Takayanagi, et al, "Design of the injection bump system of the 3-GeV RCS in J-PARC", MT, September 2006.

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[4] Rika-Lite, NIPPON RIKA KOGYOSHO CO., LTD.