Construction and Measurement of the Bending Magnets for the SRRC Transfer Line

C.H. Chang, C.S. Hwang, M.H. Huang, F.Y. Lin
Synchrotron Radiation Research Center, Hsinchu, Taiwan
G.J. Hwang
Department of Power Mechanical Engineering, National Tsing Hua University, Hsinchu, Taiwan
P.K. Tseng
Department of Physics, National Taiwan University, Taipei, Taiwan

Abstract

Four horizontal and two vertical bending magnets have been constructed and installed in a 70 meter long transfer line between the 1.3 GeV synchrotron booster and the storage ring. The H type bending magnet is a straight and solid iron yoke with 4 flat pancake type coils. The same pole profile with gap 36 mm is designed to create a uniform dipole field of 0.9461 Tesla at nominal 1.3 GeV energy. The transverse field distributions are calculated and measured for achieving the field deviation Δ B/B within 0.02 % in a required range of 60 mm. Next, the AISI 1006 low carbon solid steel is used for easily constructing the horizontal and vertical magnet core. Also, the field permeability of the core material is measured and improved after the annealing heat treatment via various temperature rise for relieving the internal stress. Furthermore, the field mappings are performed by using the Hall probe along the ideal orbit in a curvilinear and a straight trajectory. The deviations of integrated field strength are within 0.1 % in a range of 42 mm among all magnets.

1. INTRODUCTION

The 70 m long SRRC transfer line is connected from the booster to the storage ring. The booster is located outside of the storage ring building and has an elevation difference of 4 m between them. The synchrotron booster is a full energy operation for ejecting the electron beams through the transfer line to the storage ring which is operated between 1.0 to 1.5 GeV energy. The BTS (Booster to Storage ring) transfer line consists of 6 bending magnets (four horizontal and two vertical), 17 quadrupole magnets and 8 steering magnets.

According to the beam dynamics calculations for the transfer line [1], the maximum 2 sigma beam size is 9 mm in the horizontal plane and 6 mm in the vertical plane. The magnet gap of 36 mm is determined to conserve the power requirement and the aperture of the vacuum chamber. In considering the errors from the sagitta, field and misalignment effect on the beam size, the requirements of the integrated dipole field uniformity must be less than 1 x 10^{-3} in a range of 40 mm. The main parameters of the BTS bending magnet are listed in Table 1.

Table 1
Main Parameters of the BTS Bending Magnet

		B_2B_6(H)	B_3(H)	B_4,B_5(V)
Quantity	ea	3	1	2
Bending angle	deg	10	11.5	15
Bending radius	m	4.583	3.918	3.918
Magnetic length	m	0.8	0.8	1.2
Nominal field	Tesla	0.9461	0.9461	1.088
Magnet gap	mm	36	36	36
Good field width	mm	60	60	60
Good field height	mm	20	20	20
Field uniformity	%	0.1	0.1	0.1
Current	A	396	455	396
Number of turns		72	72	72
Current density	A/mm^2	3.5	4.0	3.5
Voltage drop	V	10.6	12.2	14
Power consumption	kW	4.2	5.5	5.6

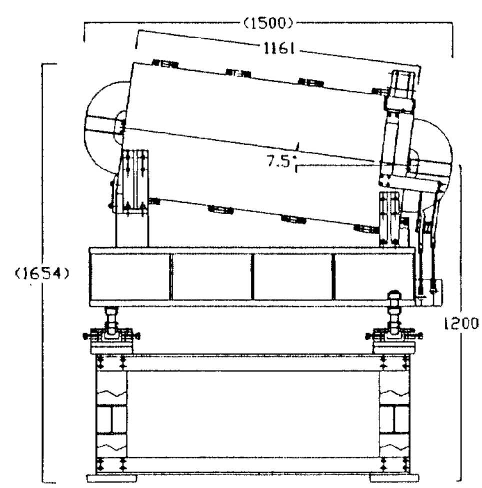

Fig. 1 The vertical bending magnet

2. MAGNET DESIGN

Four 0.8 m long horizontal bending magnets, i.e. a bending angle of 10 degrees for three of them, 11.5 degrees for one of them, and two 1.2 m long vertical bending magnets with bending angle 15 degrees are required for bending the electron beam in a designed curved orbit. In following the ideal beam curvature, the curved magnet has some merits in minimizing the stored energy as well as conserving the power consumption. However, the operation time of magnets for the transfer line is brief and a more thorough analysis of the production cost is provided than a straight magnet. For simplifying production, the H type rectangular magnet with four flat pancake coils is designed for the BTS transfer line. The H type magnet provides the symmetric magnetic circuit and has a minimizing effects of iron permeability with minimal remnant fields. The 1.2 m long curved bending magnet has a total sagitta of 39.2 mm. Taking into account the sagitta, the field homogeneity has to be more wider over a maximum sagitta range.

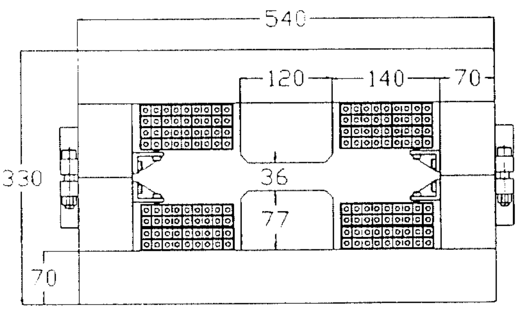

Fig. 2 The cross section of bending magnet

To produce a more compact and economically feasible magnet, two families of bending magnets were designed for the same gap profile with two different lengths. One family is 0.8 m long bending magnets with a horizontal bending angle of 10 and 11.5 degrees. Another one is 1.2 m long bending magnets with a vertical bending angle of 15 degrees. The bending magnet is required to produce a maximum field strength of 1.09 Tesla in the gap center. The gap height of 36 mm is selected for limiting the costs associated with the magnet production and the power supply. The pole width was minimized to roughly three times that of the gap height. The cross section of the bending magnet is presented in Fig. 2. The two dimensional field calculations were performed by using the computer code "MAGNET". The pole profile was designed to satisfy the field uniformity between 1.3 to 1.5 Gev energy operation. The pole was shimmed with 0.32 mm x 10 mm shims for attaining the wider good field region. The field uniformity $\Delta B/B$ was calculated less than 2×10^{-4} over a range of 60 mm which includes an additional sagitta and accommodates an orbit displacement from the nominal beam position and is shown in Fig. 4.

3. Magnet Construction

The magnets of transfer line were operated at constant energy. Ramping the magnetic field was not deemed necessary . A cost analysis indicated the solid core was easier to construct and conserved the production costs for a small quantity. The yokes were constructed by the AISI 1006 low carbon solid steels as provided by the China Steel Cooperation. Since 75 mm thick steel was fabricated through means of the hot rolling process, the internal stress remained in the steel and affected the magnetic permeability. The permeability field strength curves were measured and the characteristic curves were presented in Fig. 3. In order to relieve the stress and improve the magnetic property, the materials were annealed via different heat treatments with a respective 800^{o} C, 850^{o} C and 900^{o} C core temperature rise in the gas mixture of nitrogen and hydrogen during a 4 hour time constant. The permeability level was measured and higher values were attained at 850^{o} C as displayed in Fig 3.

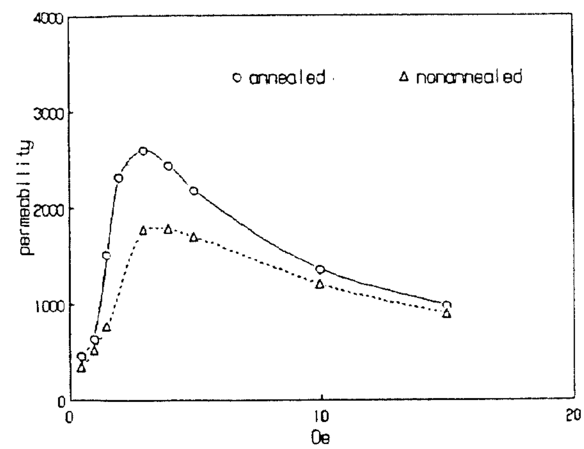

Fig. 3 The permeability curves of low carbon steel

For the installation of a vacuum chamber and four pancake coils, the bending magnet could be split in a horizontal mid-plane. The half of a yoke was assembled through means of four blocks steel and pins. The block steel was machined much cheaper and with more accuracy than the lamination core. The pole faces were flat and parallel to 0.02 mm and with a length deviation of 0.1 mm. The precise alignment of two half magnets were undertaken through usage of dowels. The vertical bending field was generated by making a ninety degree rotation of the midplane and tilting the magnet fifteen degree. The vertical bending magnet is illustrated in Fig 1. The vertical bending magnet was mounted in a fixed angular blocks and prealigned on a precision surface of support table for easy installation and survey alignment.

The same bending angle magnets were connected via a power supply. The simple racetrack coils were designed to satisfy a commercial and reasonable power supply requirements. 12 x 12 mm square hollow copper conductor with a 6 mm diameter cooling hole was selected to meet the current density requirement of approximately 4 A/mm^2. Each pancake includes two layer winds with a total of 18 turns without joints. The coils were insulated by 0.5 mm thick fiber glass tape and impregnated with the DER 732 and 332 epoxy resin in a vacuum mold. The appreciable hysteresis effects in the solid yoke may yield an insignificant effect on the integrated field strength. The solid core can not shuffle to complete an averaging of steel magnetization. Additional coils added to each pole yielded a five percent dipole field strength for modifying the variance of magnets. The additional winding should avoid the appreciable saturation of the yoke. 2 mm diameter copper conductor with 0.5 mm thick glass fiber insulator was winded for the correcting coils.

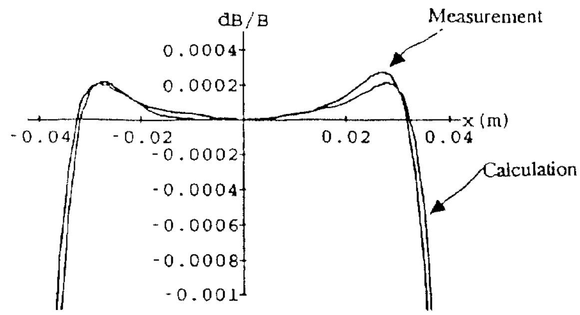

Fig. 4 The dipole field deviation in the central magnet

4. Field Measurement Results

The field measurement was performed by using the Hall probe mapping system.[2] The transverse field distribution was measured in the midplane along the transverse direction at the magnet center. The measurement results of two dimensional dipole field were quite close to the calculated value as shown in Fig. 4. The electron beams pass through the magnet along the ideal curvilinear trajectory. The mapping trajectory was performed along both straight and curvilinear trajectories for to verify the good field region. If the edge focussing effect has not taken into, analysis, measurements taken indicated a slight difference of the integrated field strength distributions between along a curvilinear and a straight line trajectory as shown in Fig. 5. The field homogeneity was within 0.1 % in a range of 42 mm. The good field region would reduced to correspond with the requirements because of considerable contributions of the sextupole fields at the magnet edge. The field saturation takes place at the integrated field strength larger than 1.25 T-m in the gap of the magnet. The integrated sextupole field error would beyond 0.1 % caused by the field saturation at the magnet edge. The deviations of integrated dipole field strength were measured within 2×10^{-3} as shown in Fig 6. The field errors of six bending magnets were satisfied within the specified requirements. All BTS bending magnets have been installed in the transfer line.

5. Concluding Remarks

A more economically feasible and precise solid and straight bending magnet for the SRRC transfer line was introduced in this study. The pole profile of soiled yoke was machined and assembled more easier than the lamination core to achieve a mechanical tolerance within 0.02 mm. Results of the transverse field distribution was obtained within 2×10^{-4} in range of 60 mm and closely correlated with the designed value. The integrated good field region would shrink because of the sextupole field contribution at the end of magnet. A slight difference of integrated field distribution was found between along a curvilinear and a straight line trajectory.

6. Acknowledgements

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7. References

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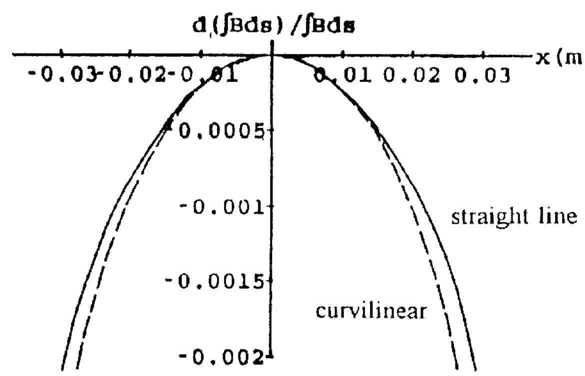

Fig. 5 Deviations of integrated dipole field distribution

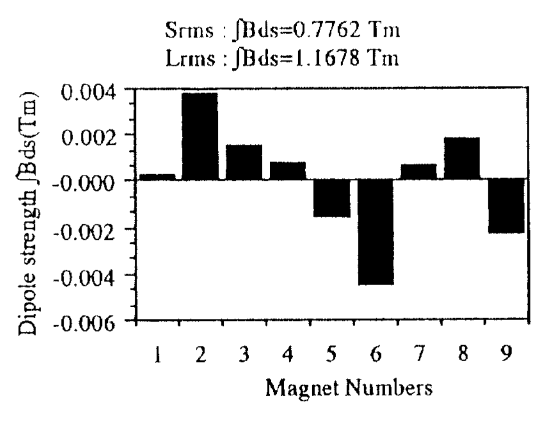

Fig.6 Deviations of the integrated dipole field among 9 magnets