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MAGNETS AND POWER SUPPLY SYSTEM OF JHF 50-GEV MAIN RING

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Abstract

The JHF 50-GeV main ring, very high-intensity proton synchrotron, for the JHF project has been designed.[1][2] The main ring consists of 96 bending magnets, 176 quadrupole magnets, 48 sextupole magnets and 176 steering magnets. The bending magnet is of a modified window frame type, whose maximum field is 1.9 T. Field gradient of the quadrupole magnet is 20 T/m in peak and the bore radius is 63 mm. The total active power of bending and quadrupole magnets is estimated to be about 100 MW in peak.

The recent progress of design studies of the magnets and the power supply system are described in this paper. The preliminary results of R&D study of the bending magnet, being now in progress, is also reported.

1 JHF MAIN RING MAGNETS

The principal parameters of the bending magnet and quadrupole magnet are summarized in Table 1.

Table 1. Main Parameters of JHF 50-GeV Main Ring Magnets

Bending Magnet		
	Magnetic Rigidity	12.76 - 170 Tm
	Field	0.143 T (for 3 GeV) 1.9 T (for 50 GeV)
	Useful Aperture (horizontal)	112 mm
	Gap Height	106 mm
	Length	5.85 m
Quadrupole Magnet (8 families)		
	Max. Field Gradient	20 T/m
	Aperture	126 mm$^{\phi}$
	Length	2 m and 1.5 m

The bending magnet has been designed to have the maximum field of 1.9 T. It was revised from the old design whose maximum field is 1.8 T [3], to make the magnet shorter. The electric resistance and inductance are estimated to be 40 m-ohm and 100 mH, respectively. The maximum ampere-turn is 92800 AT for the field strength of 1.9 T. The total weight is about 30 tons/magnet.

The quadrupole magnet, the sextupole magnet and the steering magnet have been also designed.[2]

2 R&D STUDY OF THE BENDING MAGNET

2.1 *Bending Magnet for R&D Study*

A short-size R&D bending magnet based on the original design, whose maximum field is 1.8 T, was constructed to study about field quality, end plate effect, problem of mechanical structure, and so on. It has the cross section of actual size and the length of about 1.7 m (nearly 1/4 of actual size). Figure 1 shows the cross sectional view of the R&D bending magnet.

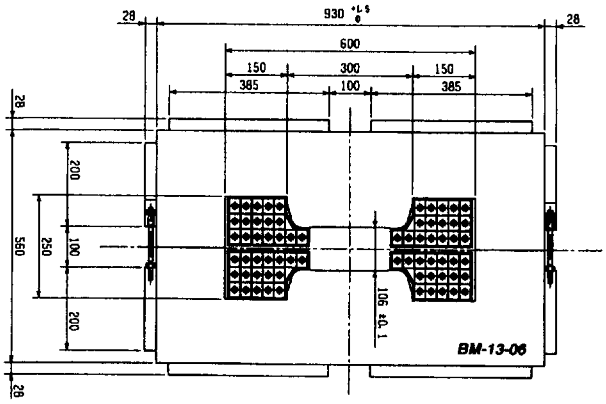

Fig. 1. Cross sectional view of the R&D bending magnet

The core material is 0.5 mm thick laminated silicon steel, 50RM600. The maximum ampere-turn is 84630 AT for the magnetic field of 1.8 T. The gap height of 106 mm is the same as that of the design of 1.9 T.

In order to investgate a cut shape of the magnet end, the magnet ends are cut with step shapes, approximating to a Rogowski curve and a B-constant curve. Rogowski curve and B-constant curve are described as follows:

$$z/d = 1+(2/\pi)\exp(\pi x/2d), \quad \text{and}$$
$$z/d = \cosh(x/d),$$

respectively. Here d is the half length of the gap and x is the position of the logitudinal direction.

2.2 Preliminary Results of Field Measurement

The field structure of the R&D bending magnet has been studied within the field range of up to 6 kG, because of the limitation of a DC power supply. The relative field strength is measured with a gauss meter equipped with a Hall probe, and an absolute value of the field is monitored with an NMR probe. The Hall probe is positioned three-dimensionally with the accuracy of 10 µm by a newly developed moving stand.

The measured field distribution in radial direction is shown in Fig.2, together with the result calculated with the program Poisson. The field strength of 1.43 kG is corresponding to the injection energy of the JHF 50-GeV main ring.

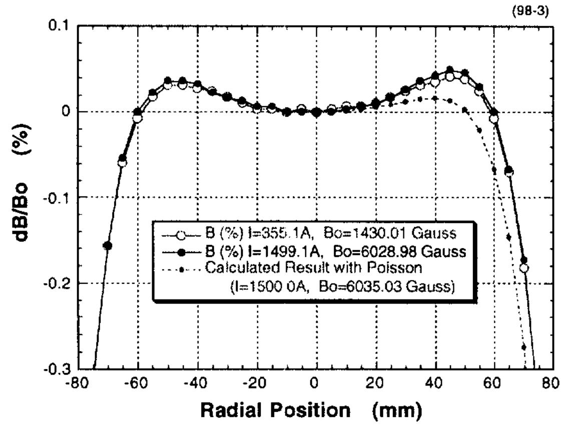

Fig.2. Radial distribution of field strength

As seen in the figure, the field deviation of less than 0.05% is obtained in the radial region of +- 60 mm. On the other hand, there is a slight difference between the measurement and the calculation results, whose cause is now under investigation.

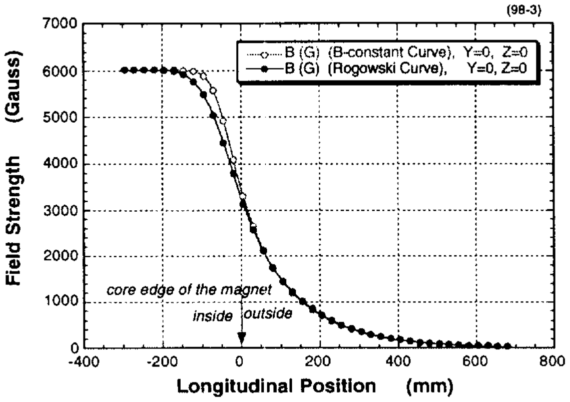

Fig.3. Longitudinal Field Distribution for both Ends

The field distributions in the longitudinal direction around both magnet ends are also measured. Figure 3 shows the measurement results of Rogowski curve end and B-constant curve end at the field level of 6 kG, for comparison.

In the figure, Y means the radial position and Z means the vertical position. The figure indicates that an effective length is different between two curves. Table 2 shows the effective lengths at some positions distributed within the magnet gap, measured at the field of 6 kG. In the table, the effective length means the length from the core edge to the outside of the magnet.

Table 2. Effective Length for both Magnet Ends

Rogowski Curve End (mm)

	Y=-60	Y=-40	Y=-20	Y= 0	Y= 20	Y= 40	Y= 60
Z=45				45.59			
Z=25				45.25			
Z= 0	44.38	44.81	45.08	45.13	45.05	44.75	44.29

B-constant Curve End (mm)

	Y=-60	Y=-40	Y=-20	Y= 0	Y= 20	Y= 40	Y= 60
Z=45				54.84			
Z=25				54.40			
Z= 0	53.15	53.72	54.00	54.10	54.02	53.71	53.24

The average values of the effective length are 44.92 mm and 53.91 mm for Rogowski curve end and B-constant curve end, respectively. The difference due to the position is very small, being less than +-1 mm.

On the other hand, at the field of 1.43 kG, the effective lengths at the position of Y=0 and Z=0 are 45.45 mm and 54.48 mm for Rogowski curve end and B-constant curve end, respectively. The change due to the excitation level is also very small in this field range.

The remnant field after exciting up to 6 kG is about 7 Gauss at the central orbit.

Measurement at field range higher than 6 kG will be done in near future with a new power supply mentioned in the section 3.2.2.

3 POWER SUPPLY SYSTEM

3.1 Power Requirement

The JHF 50-GeV main ring is operated with an excitation pattern of trapezoidal wave form. Most of required electric power is due to the bending magnet and quadrupole magnet. The total active peak power and dissipation power of the power supplies for both magnets are estimated to be about +120 MW (-60 MW) and 34.5 MW, respectively, including power losses generated in cables, transformers and power converters.

A power supply with a high-power output current of trapezoidal wave form described above usually generates cyclic variation of line voltage. In the case of the JHF main ring, the line voltage fluctuation is estimated to be about 15% or more due to the expected reactive power, and about 4.3% due to the variation of active power itself. This amount of fluctuation is not acceptable for the line condition in the KEK.

3.2 Configuration of power supply system

3.2.1 Rotating machine system

In order to absorb the cyclic fluctuation of line voltage and to keep line voltage constant enough, a rotating machine system, so-called 'double-fed adjustable speed fly-wheel generating system' is adopted. Figure 4 shows a conceptual block diagram of the power supply system with the new rotating machine system.

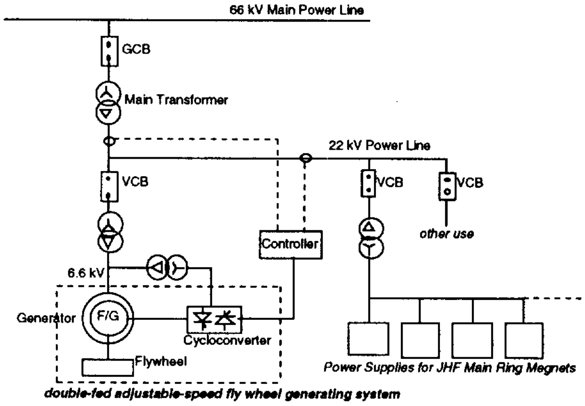

Fig.4. Conceptual Block Diagram of the Power Supply System

The generator is not equipped with a motor, as seen in the figure, and it is connected directly to the main power line in parallel with the power supplies of the JHF main ring magnets. The generator has the characteristics of an induction-type machine (AC machine), and the rotor is excited with AC current from the cycloconverter. With this characteristics, the system makes it possible to transfer electric power very quickly from the generator to the power line, and vice versa.

As the results, the very large amount of required electric power mentioned in the section 3.1 goes and returns between the magnets and the generator, and then the system does not give line voltage fluctuation to the main power line. Finaly, the system needs to take in only the average electric power dissipated in the whole system shown in the Fig.4, which becomes constant during the JHF excitation period, from the main power line.

The main characteristics of the generator for the JHF 50-GeV main ring is as follows;

type	vertical
output capacity	100 MW
rotating speed	600 rpm +- 5%
size	10 x 10 x 10 m^3
weight	300 tons.

3.2.2 Power Converter

It is investigated to use not only SCR but also GTO and IGBT as a converter element to generate a trapezoidal-wave-form current from AC power.

For the power supplies of the quadrupole magnet, IGBT is to be used as a converter. The current ripple of the power supply for the quadrupole magnet is required to be less than 10^{-6}. It is expected that adoption of IGBT makes it easy to construct a power supply with very low current ripple like that.

In order to study the possibility of using IGBT as a converter of a power supply having trapezoidal output with a power of about 5 ~ 10 MW, an R&D power supply with the peak power of 1 MW equipped with IGBT has been designed and constructed.[2] The specification is as follows;

converter	IGBT
output mode	trapezoidal and DC
repetition rate	~ 3.4 sec
active peak power	1 MW
max. current	3000 A
output current ripple	10^{-5} (without active filter)
stability	10^{-4}
tracking error	10^{-3}.

As for the power supply of the bending magnet, at present three selections are investigated. The first one is to use SCR, 2nd and 3rd ones are to use GTO and IGBT, respectively. SCR is very reliable element to convert very high-rate electric power, but it has a disadvantage of generating very large reactive power, as well known. Furthermore, a filter system to suppress output current ripple becomes very large scale, because its control speed is rather slow compared with GTO or IGBT.

Therefore, it is now investigated to use GTO for the power supply of the bending magnet of the JHF 50 GeV main ring, instead of SCR. The preliminary results of the simulation shows that the output current ripple is suppressed to 10^{-6} with passive and active filters of reasonable size. However, GTO has very large demerits of low efficiency and complexity of gate circuit.

Then, it is also investigated to use IGBT. Though the power rate per element is rather small, IGBT seems to be very easy in use, compared with both SCR and GTO.

4 REFERENCES

[1] To be reported elsewhere in this conference.

[2] The Design Group: 'JHF ACCELERATOR DESIGN STUDY REPORT' (To be published)

[3] M.Muto et al.: 'Magnets and Their Power Supplies of JHF 50-GeV Synchrotron', KEK Preprint 97-72 (1997), PAC97 Vancouver (1997).