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THE SECTOR MAGNET FOR THE IPCR SSC

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Abstract.- This report describes the design of the sector magnet for the IPCR SSC. The magnet system of this SSC consists of four sector magnets with sector angle of 50°, gap distance of 8 cm and the maximum magnetic field of 15.5 kG. Each sector magnet is 5.64 m long, 5.24 m high and 530 tons in weight. The detailed design of these magnets was based on measurements of the magnetic properties of the model magnet as well as results of the magnetic-field calculation and mechanical analysis.

1. Introduction.- The main characteristics and the status of the IPCR SSC are reported in this conference[1]. The major design characteristics of the sector magnets of this SSC remains the same as that previously reported[2]. More detailed design work for the trim coil system have been done after that report. The final design of the sector magnet are completed.

The first sector magnet will be delivered at the beginning of 1982.

2. Configuration of the sector magnet.- The profiles of the magnetic field should provide the focusing property and orbital stability for the beam in a wide range of energy and particles. In order to get desired field profile in the range of 7 kG to 15.5 kG, measurements of the magnetic field were carried out using 1/4 scale model magnets. Calculations of the magnetic field were also performed.

The final parameters of the sector magnets were determined from the results of the analysis of magnetic properties and the computation of beam dynamics based on the above measurements. Table 1 lists the design characteristics of the sector magnets.

Table 1. Characteristics of SSC Magnets

Number of Sector Magnet	4
Sector angle	50°
Gap width	8 cm
Injection mean radius	89.3 cm
Extraction mean radius	356 cm
Height of magnet	5.24 m
Overall diameter	12.6 m
Total Weight	2120 ton (530 ton/one sector)
Maximum magnetic field	15.5 kG
Maximum magnetomotive force	1.35×10^5 A·T
Maximum current	1000 A
Current stability	0.002 %
Maximum power	480 kW
Number of trim coils	29 pairs x 4
Maximum current	500 A
Current stability	0.05 %
Total trim coil power	200 kW

The main magnet system consists of four sector magnets with sector angle of 50° and gap distance of 8 cm. It can produce the field of 15.5 kG at maximum. The maximum magnetomotive force was estimated to be 1.35×10^5 ampere turns and maximum power consumption in the four sector magnets is estimated to be 480 kW. Each sector magnet is 5.64 m long, 5.24 m high and 530 tons in weight. The shape and geometrical size of the sector magnet is shown in figure 1.

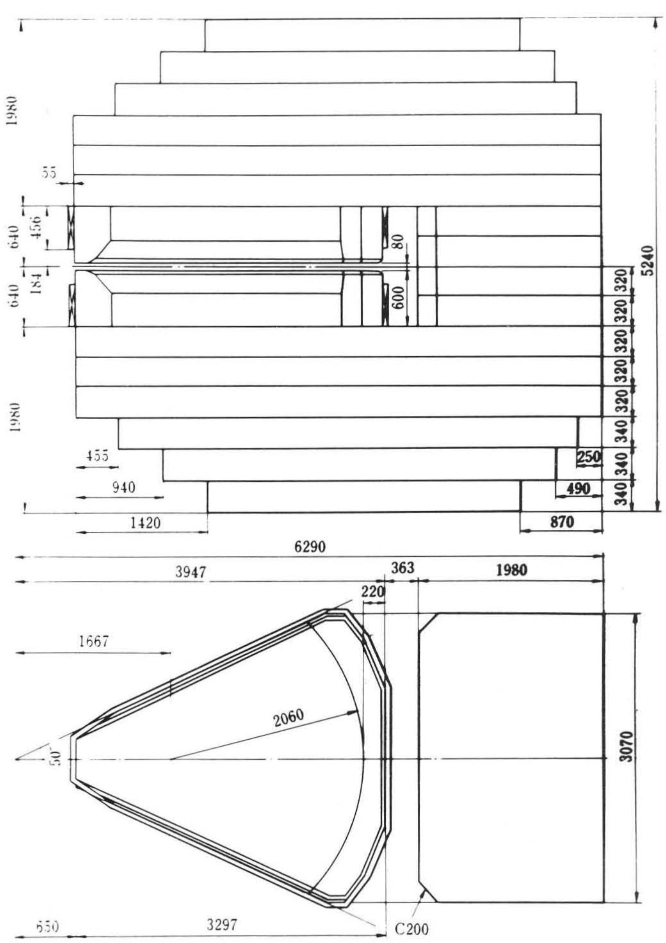

Fig. 1 : Shape and geometrical size of the sector magnet

For forming the required isochronous field and harmonic field, 29 pairs of trimming coils are mounted on the pole face. The trim coils and their returns are enclosed with the auxiliary vacuum chamber.

3. Pole edge profiles and pole tip contour.- The pole tip contour and pole edge profiles are shown in figure 2. The pole edge profile except the inner part is approximated by a B-constant profile. Resultant fringing field produced with these pole edge profiles have been investigated by the analysis of the magnetic field computed by TRIM code and the measured field of the model magnet. Radial dimension along the central line of the pole tip is 3.3 m. The pole tips extend in the radial direction by 3.5 gaps toward the machine center from the first equilibrium orbit and by 2.75 gaps outward beyond the extraction equilibrium orbit. The gas spacers and the elements for the injection and extraction will be inserted in these extended areas.

4. Yoke.- The yokes will be divided into 16 slabs for convenience of the construction and transportation as shown in figure 1. The ratio of the cross-sectional area of yoke to that of the pole base is 0.94.

5. Iron material.- The maximum field and the field profile of the sector magnet strongly depend on iron material. Very homogeneously forged steel with carbon contents of 0.02 % - 0.01 % was specified for the pole and rolled steel of 0.08 % - 0.1 % carbon contents for the yoke of each magnet. Two poles of each sector magnet should be prepared from a single ingot. Table 2 shows specification of the steel.

Table 2 Specified chemical composition of the low carbon steel (weight percent)

	C	Si	Mn	P	S	Cr	Ni	Cu
Pole	0.02	0.07	0.2	0.05	0.017	0.08	0.10	0.11
Yoke	0.08	0.25	0.35	0.013	0.017	0.08	0.10	0.11
	Al	Mo	N					
Pole	0.03	0.04	0.006					
Yoke	0.04	0.05	0.007					

6. Excitation characteristics and main coils.- In order to design the main coil, excitation characteristics of the magnet have been investigated based on the measurements for the model magnet and field calculation by using the specified permeability of the steel. The maximum magnetomotive force was estimated to be 1.35 x 10^5 ampere turns.

The design of the main coil has been completed. Final design, however, may be changed slightly according to the result of the design of the vacuum chamber. They consists of 66 turns of hollow copper conductor and will be formed in size of 5.0 cm in thickness and 45.6 cm in height to provide enough space for the RF-cavities which will be installed in the narrow space between two sector magnets. The coils are located outside of the vacuum chamber. The main coils of each sector magnet will be connected in series and excited with maximum current of 1000 A. Maximum current density in the copper conductor is 4 A/mm^2.

7. Mechanical analysis of the magnet structure.- The deformation of the magnet structure as a result of various forces acting on it was computed by FEM-2 code including three dimensional effect. The magnet consists of 16 separate parts as shown in figure 1. The results are shown in figure 3. The maximum displacement of the pole face becomes 0.35 mm vertically when 1 mm thick gap spacer is inserted between pole base

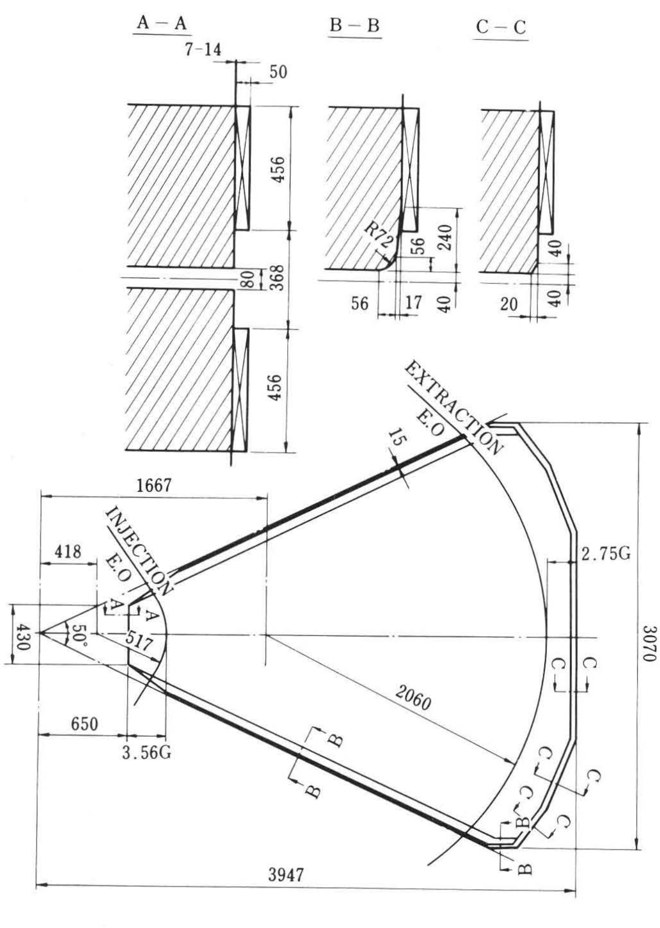

Fig. 2 : Pole edge profiles and pole tip contour

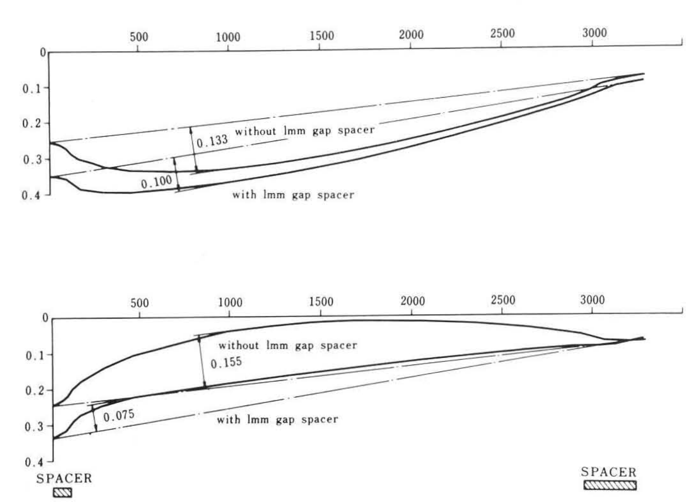

Fig. 3 : Computed vertical deflection of the pole faces and median plane along center line of the magnet

and yoke. The value of the deformation of the pole face can be reduced significantly by applying the gap. Such displacement introduces less than 0.4 mm shift of the median plane from the ideal plane, but such changes will entail no problem on the beam dynamics. For these reasons, we decided to introduce such a pole base gap in the present design.

8. Trim coils.- For the design of the trim coils, extensive calculations by TRIM code were performed. The radial widths and positions of the trim coils were determined by using computer optimization code developed by A. Goto. Figure 4 shows the fields produced by each coil when the same current is applied individually at base field of 15.5 kG. Figure 5 shows the comparison between field distribution formed with 29 trim coil pairs and theoretical isochronous field for the acceleration of C^{6+} to 134 MeV/u.

The trim coils of the SSC magnet consist of 29 pairs for isochronous field. 5 pairs of them are used also for harmonic field. They have a curved shape along the hard-edge equilibrium orbit. The lay-out of configuration of the trim coils is shown in figure 6. Total power of the trim coils is estimated to be 200 kW.

The trim coils will be mounted directly on the pole faces by bolts and enclosed with the auxiliary vacuum chamber. In order to reduce the magnetic perturbation due to bolt holes, we will use the special bolts of soft magnetic iron welded to stainless steel. The cross sectional view of the pole section is shown in figure 7.

The detailed design of the sector magnet for IPCR SSC are completed.

References

1) H. Kamitsubo, "IPCR SSC with K = 540", this conference.
2) S. Motonaga et al., "The Sector magnet for the IPCR SSC", Proceedings of 7th International Conference on Magnet Technology", Karlsruhe, 1981.

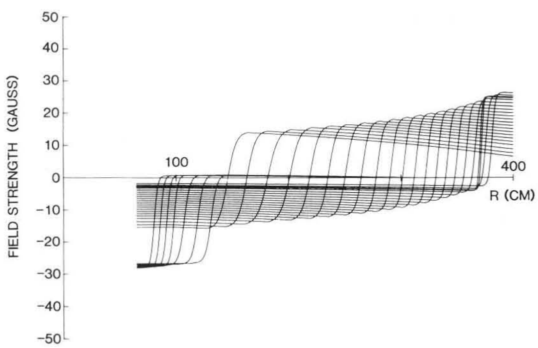

Fig. 4 : Caluculated magnetic field contribution of each trim coil at the base field of 15.5 kG when each coil current is 100 A.

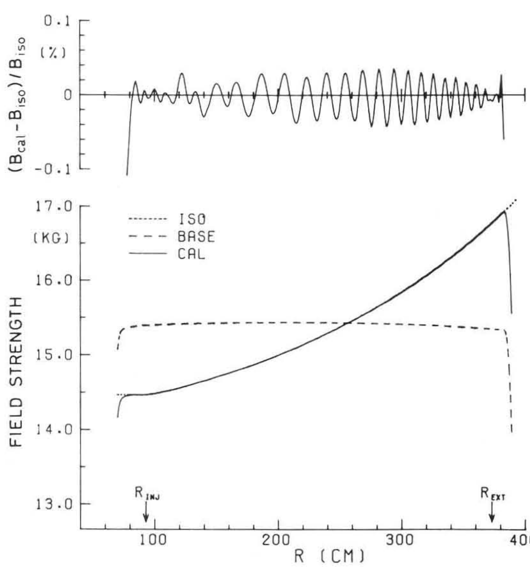

Fig. 5 : Comparison of magnetic field distribution formed by the trim coils with the isochronous field for acceleration of C^{6+} to 134 MeV/u.

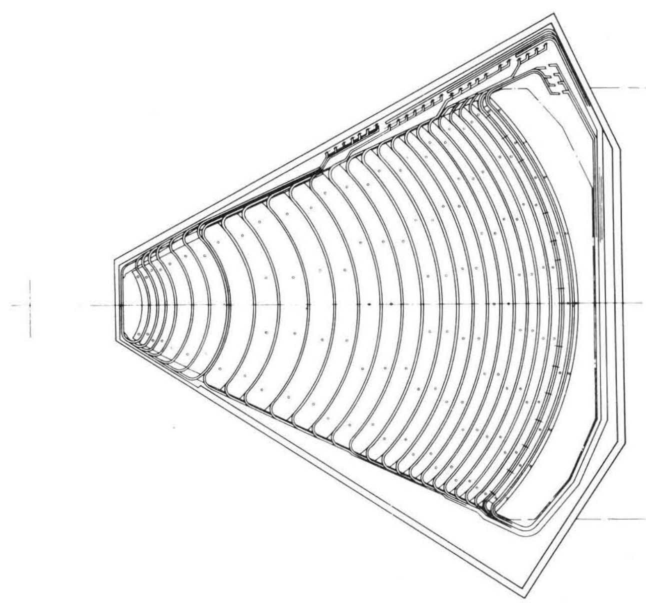

Fig. 6 : Lay-out of the trim coils for the sector magnet

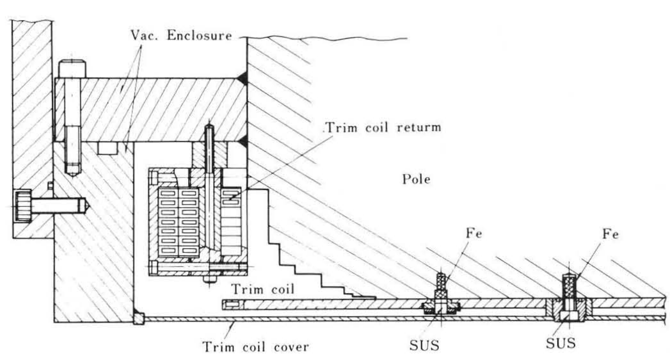

Fig. 7 : Detailed cross sectional view of the pole edge section