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SI/Note MAE/70-2
30.1.1970

THE PSB MULTIPOLE MODEL

DESIGN AND MAGNETIC MEASUREMENTS

M. Giesch

PS/48

1. Introduction

The parameters for the correcting lenses (octupole, sextupole and skew- or normal quadrupole) are given by C. Bovet and K.H. Reich in SI/Int. DL/69-3.

A model was constructed, tested and measured magnetically in order to verify the calculated values.

2. Design of the multipole model

Fig. 1 shows a cross-section of the model with the main dimensions of coils and conductors. Octupole, sextupole and quadrupole are superimposed on each other. The coils are mounted on aluminium cylinders, which are water-cooled on both ends.

Current densities of up to 2.7 A/mm^2 could be obtained for a maximum coil temperature of 65° C. The outer cylinder is made of mild steel and serves as a magnetic screen.

With the coil geometry of the model, the field distribution inside the lenses is given for the quadrupole by :

$$B = {}^{2}/_{\pi} \sin({}^{\pi}/_{3})\, \mu_o\, j\, F \left\{ \ell_n \frac{a_2}{a_1} + \frac{1}{4} \left[\left(\frac{a_2}{b}\right)^4 - \left(\frac{a_1}{b}\right)^4 \right] r \right. \quad (1)$$

$$\times \cos 2\varphi$$

and for the sextupole and octupole by :

$(m = 3,4)$

$$B = {}^{2}/\pi \sin({}^{\pi}/3)\, \mu_o\, j\, F \left[\frac{1}{m-2} \left(\frac{1}{a_1^{\,m-2}} - \frac{1}{a_2^{\,m-2}} \right) + \frac{a_2^{\,m+2} - a_1^{\,m+2}}{(m+2)\, b^{2m}} \right] r^{m-1} \cos m\varphi \qquad (2)$$

where a_1, a_2 inner and outer radius of the coils

b inner radius of the iron shield

j uniform current density per coil section

F filling factor of coil section.

With the dimensions given in fig. 1, one obtains for the field distribution and gradient strength for $\varphi = 0$, $I = 40$ A .

$$B_{quad} = 0.17\ r_{[m]} \quad [T]$$
$$g = 0.17 \quad [T/m] \qquad (3)$$

$$B_{sext} = 3.2\ r^2_{[m]} \quad [T]$$
$$g' = 6.4 \quad [T/m^2] \qquad (4)$$

$$B_{oct} = 36.5\ r^3_{[m]} \quad [T]$$
$$g'' = 228 \quad [T/m^3] \qquad (5)$$

The more interesting integral field distribution cannot be calculated to an accuracy of a few percent and has to be found from magnetic measurements.

3. Result of magnetic measurements

The radial field distribution in the centre of the lenses was measured with a Hall probe, the integral field distribution with a long coil (~ 1 m).

The measuring precision is limited by the positioning of both devices which is about ± 0.2 mm with respect to the centre of the lenses.

The results of the integral field distribution are given in Fig. 2 for quadrupole and octupole, and in Fig. 3 for the sextupole measured for $\varphi = 0$. Measurements for $\varphi = \pi/2$ are in good agreement with the plotted curves.

One can write for the integral field distribution

$$(\int B \, dl)_{\varphi=0} = K_n \; r^n \qquad [\,Tm\,]$$

and for the field distribution inside the lenses

$$(B)_{\varphi=0} = C_n \; r^n \qquad [\,T\,]$$

with $n = 1,2,3$ quad, sext, oct.

The equivalent field length is

$$\ell \, eq = \frac{K_n}{C_n}$$

K_n and C_n are calculated from the individual points measured (see fig. 2 and 3).

The following results are obtained :

(skew-) Quadrupole	: K_1	= 0.049	[T]	± 1 %
	C_1	= 0.15	[T/m]	± 1 %
	ℓ_{eq}	= 0.33	[m]	
Sextupole	: K_2	= 1.08	[T/m]]	± 0.7 %
	C_2	= 3.02	T/m^2]	± 1 %
	ℓ_{eq}	= 0.36	[m]	
Octupole	: K_3	= 12.9	[T/m^2]	± 1.5 %
	C_3	= 35	[T/m^3]	± 2 %
	ℓ_{eq}	= 0.37	[m]	

The errors given for the K_n and C_m are maximum deviations from an average value and represent directly the deviation of the measured field distribution from the theoretical distribution. They are partly due to measuring errors which could only be reduced by a more sophisticated measuring equipment.

4. Conclusion

The integral field distribution obtained from magnetic measurements deviates from the theoretical distribution by less than ± 1 °/o for the quadrupole, ± 0.7 °/o for the sextupole and ± 1.5 °/o for the octupole.

The absolute values measured for sextupole and octupole are a few percent smaller than calculated. The rather big difference for the quadrupole of about 15 °/o is due to the fact that the ratio of diameter to length is $d/\ell = 0.7$ instead of $d/\ell \ll 1$ as assumed for the calculations.

When the obtained precision for the field distribution is acceptable, the results from the model measurements can be taken into account for the final design and the construction of a prototype would not be necessary.

Acknowledgement :

I would like to thank Mr. M. Battiaz who constructed the model and Mr. G. Colini for the execution of the magnetic measurements.

Distribution :

A. Arn
A. Ašner
M. Battiaz
C. Bovet
G. Brianti
K.D. Lohmann
K.H. Reich
C. Rufer
G. Schnell

Cross Section of Correction Multipole Modell

	Conductor [mm²]	Section [mm²]	I [A]	Filling Factor	j [A/mm²]
Octupole	2,2 × 8 N = 16 2 Layers	16,7	40	0,7	2,4
Sextupole	2,2 × 7 N = 42 3 Layers	14,5	40	0,71	2,76
Quadrupole	1,7 × 9 N = 30 1 Layer	14,7	40	0,73	2,72

Length of coils 0,36 m

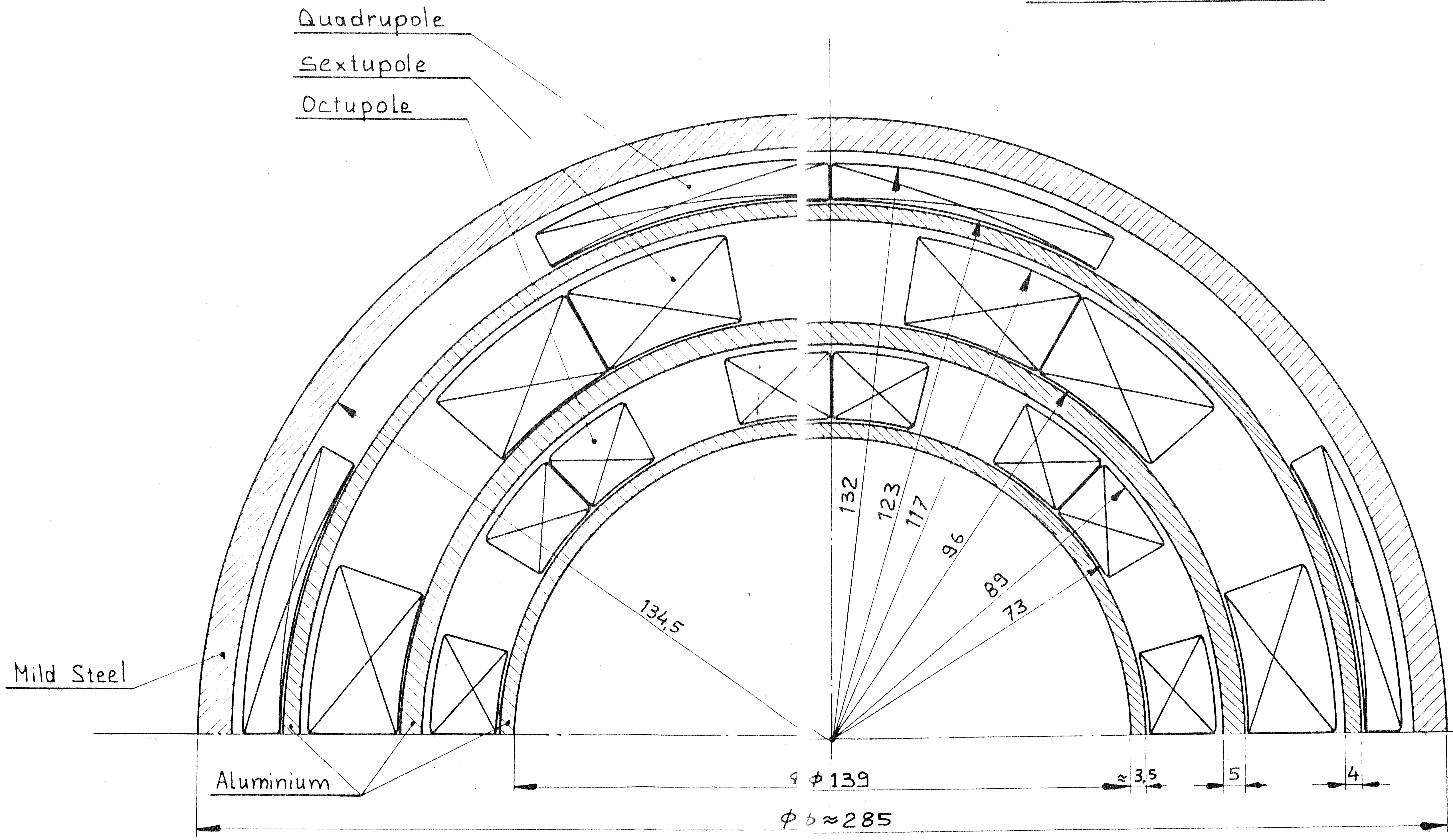

Fig. 1