CURRENT SHEET TYPE SUPERCONDUCTING MULTIPOLE MAGNET

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INTRODUCTION

The strength and homogeneity of fields in the current sheet magnet will be much more improved by using superconducting coils which have very high current density. By making small superconducting multipole magnet, we have studied various problems and searched optimum design.

DESIGN CONSIDERATION

Factors to be considered when we design the current sheet magnet are as follows,necessary field space, necessary current sheet, field strength, field homogeneity, and easiness for making. To optimize these factors we have analyzed various types of magnet theoretically, figure of merit which is defined as the field space devided by the total current is one of these criterions. In figure 1 various types of magnet are illustrated to show the figure of merit. For the field homogeneity, the errors from ideal current sheet field are generated from finite thickness of current sheet, finite permeability of iron and fringing field. To study the effects of finite thickness and of finite permeability, we have calculated the fields analytically when the single current was placed in the two dimensional area which is surrounded with iron of constant permeability. (figure 2) These results are limited to particular cases which have a relatively simple shape of boundary, we have found more generally from the conformal mapping that the boundary which has the least effect of finite permeability is the single line or equivalently the single circle, because it has a single image current for a single real current, and other boundaries which have several or infinite images will suffer non uniformly the changes of image strength by the finite permeability. For the finite thickness of current sheet, the errors should be made minimum by the numerical calculation because after adjustment the errors will not change by the field strength and have no ambiguity such as due to finite permeability. After above considerations we have searched most easy shape of magnet for making and designed the magnet showed in the figure 3. In the magnet, each coil pancake has multilayer coil windings to generate dipole, quadrupole, sextupole,and octupole field, but for sextupole and octupole field, it has only few windings, and it is only for field corrections. This magnet has many terminals to be able to test both dipole field and quadrupole field by changing coil connection Various dimensions of this magnet are showed in table 1.

As for the characteristic of superconducting wire, the critical thickness which is defined as the critical field intensity devided by the critical current density is a useful parameter, and is closely related to the figure of merit. Our test magnet was so small that the field strength was essencially limited by the allowable area for the current sheet, and the necessary area for the current sheet were given by the critical thickness corresponding to the field strength.

EXPERIMENTAL RESULT/CONCLUSION

The homogeneity for the guadrupole field was satisfactory and is fitted as follows

$$B=4.554\cdot x - 2.863\cdot 10^{-3}\cdot x^2 + 2.785\cdot 10^{-4}\cdot x^3$$

where B(kG) is a vertical component on the median plane.

$$-1.4(\mathrm{mm}) \leqq x \leqq 1.4(\mathrm{mm}) \qquad =2.29\cdot 10^{-3}(\text{standard deviation})$$

For the dipole field, a saturation effect was observed and the maximum field was greatly reduced. From this result, we have concluded that for a strong field current sheet magnet, it is necessary to make a coil winding with window flame type or like that, and optimize the shape from the figure of merit. As for the sextupole and the octupole field, each of these field alone are not measured, for these high order fields are very weak in the center of magnet, and residual field are dominant in that region. For the guadrupole fields, a saturation effect was not appeared this is due to the fact that the yoke has larger cross section area for the dipole field

length of the flux line. Considering these we have realized that the dipole and the other multipoles are quite different, and should be made in different magnet to optimize the desig .

REFERENCE

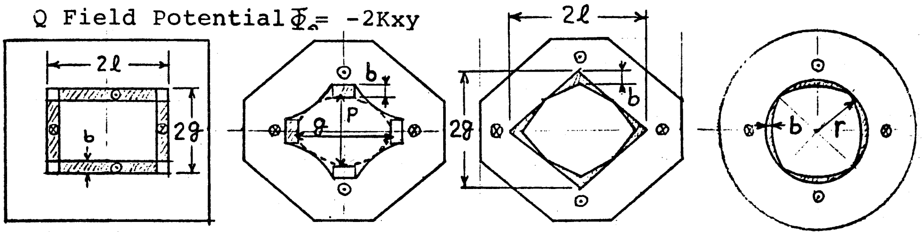
1) H. Ikegami RCNP ANNUAL REPORT 1976, P137
2) L.N. Hand and W. K. Panofsky, Rev. Sci. Instr., 30(1959)927

Table 1 Magnet dimensions

Yoke inner diameter ; 86(mm) Coil material ; NbTi
Yoke outer diameter ; 230(mm) Number of coil pancake;40
Yoke axial length ; 120(mm)
Inner diameter of field area ; 38(mm)
Number of turns for Q-Field in each pancake (Symmetric 1/4 part)
10, 28, 44, 56, 62, 56, 44, 28, 10

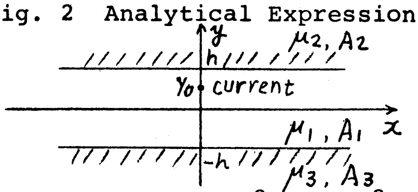
F = Figure of merit = Available Field Area / Total Current

Q Field Potential $\Phi_n = -2Kxy$



$F = (1-b/g)/(4K)$ $F = \pi/(8k)$ $F = (1-b/g)/(2k)$ $F = (\pi/8k)(1-2b/\pi r)$

Fig. 2 Analytical Expression of field with single current in the area which has three kind of region with different permeability. Expression is given by vector potential A normalized by $2\pi I$; I:current



$$A1(xy) = (1/2)\ln(x^2+(y-y0)^2) + \int_0^\infty (1/k)\,Q1(k)\cos kx\cdot\exp(-ky)\,dk$$

$$+\int_0^\infty (1/k)\,P1(k)\cos kx\cdot\exp(-ky)\,dk$$

$$A2(xy) = \int_0^\infty (1/k)\,Q2(k)\cos kx\cdot\exp(-ky)\,dk$$

$$A3(xy) = \int_0^\infty (1/k)\,Q3(k)\cos kx\cdot\exp(-ky)\,dk$$

where

$$Q1(k) = (\exp(-kh)/D)(\mu 1/\mu 3-1)(\cosh k(h-y0)+(\mu 1/\mu 2)\sinh k(h-yo))$$

$$P1(k) = (\exp(-kh)/D)(\mu 1/\mu 2-1)(\cosh k(h+y0)+(\mu 1/\mu 3)\sinh k(h+y0))$$

$$Q2(k) = (-2\exp(kh)/D)(\cosh k(h+y0)+(\mu 1/\mu 3)\sinh k(h+y0))$$

$$Q3(k) = (-2\exp(kh)/D)(\cosh k(h-y0)+(\mu 1/\mu 2)\sinh k(h-y0))$$

with

$$D(k) = ((\mu 1/\mu 2)(\mu 1/\mu 3)+1)\sinh 2kh+(\mu 1/\mu 2+\mu 1/\mu 3)\cosh 2kh$$

Fig. 3 Superconducting multipole magnet and cryostat