The 6th Symp. on Accelerator Science and Technology, 1987, Tokyo, Japan (© Ionics, Tokyo, 1987)

CONFIGURATION OF GRADIENT MAGNET WITH LARGE USEFUL APERTURE

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Abstract

Configuration of combined function type gradient magent is discussed from a view point to realize a magnet with a useful aperture as large as possible. Consideration is focussed on the low field region of the magnet. It is shown to be feasible that constant gradient of field extends to the vanishing point of field over the pole width without introducing any shims onto the pole face.

In the design of the guide magnet of synchrotron, separated function type magnet system, which is combination of dipole and quadrupole magnets, is extensively used owing to its flexibility in function. On the other hand, combined function type gradient magnet has high space factor as the guide magnet of synchrotron in compensation for the lack of flexiblity. In rapid-cycling synchrotron, the guide magnet system is excited usually by means of a resonant network

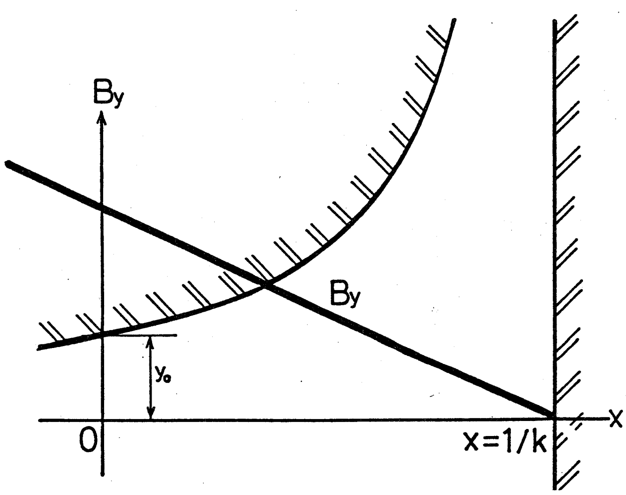

Fig.1 Ideal configuration of gradient magnet.

system including resonant capacitors and choke transformers for DC bias current. If the guide magnet system in the rapid-cycling synchrotron is composed of dipole and quadrupole magnets, the system should not be excited by independent, separate power supplies but by a single power supply from the techinical view point of phase control of the resonant network system and the economical reason. This means that the dipole and quadrupole magnets are connected in series electrically, and hence the advantage on the flexibility of separated function type magnet will be lost. Therefore, the combined function type gradient magnet is useful as the guide magnet especially in the rapid-cycling synchrotron.

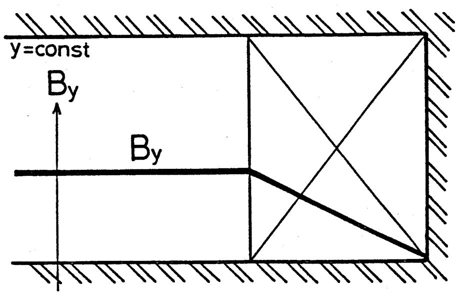

Fig.2 Geometry realizing a linear field in coil.

In order to realize a gradient magnet with a large aperture, we concentrate the consideration on the low field region of the gradient magnet. Pole profile and magnetic field on the median plane of gradient magnet are given by

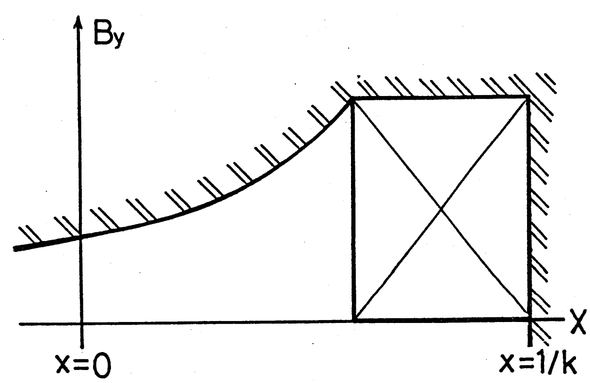

Fig.3 The configuration to be tested for the search of ideal linear field.

$$y = y_0/(1-kx)$$

and

$$B_y = B_0(1-kx) \quad ,$$

where y_0 is the half magnet gap at the position of central orbit $x = 0$. The contour of the pole face asymptotically approaches to a straight line $x = 1/k$. If the pole face extends to $x = 1/k$, $y = \infty$ and the region of $x > 1/k$ is filled by iron, linear field is perfectly realized up to the position of the boundary at $x = 1/k$. In practice, the magnet pole is cut at a position of $x < 1/k$, and the deviation from linear field is partially compensated by introducing shims onto the pole face. Even with such a procedure, however, it is very difficult to keep the field linearity within a practical level of tolerance, i.e., 0.5% of the field gradient, over the whole width of pole. On the other hand, it is well known that a linear field is realized within a coil conductor, which is set in a uniform gap as shown in Fig.2. If the field gradient in both cases shown in Fig.1 and 2 is adjusted so as to be equal, the region of constant field gradient may extend to the point of $B_y = 0$, which corresponds to the position of the asymptotic line $x = 1/k$ in Fig.1. The configuration of pole face and coil arrangement shown in Fig.3 seems to fulfill such a condition.

In order to confirm the above-mentioned idea, computor calculations have been carried out. Results are shown in Fig.4 to 7. The most striking result among those is a fact that an ideal field configuration

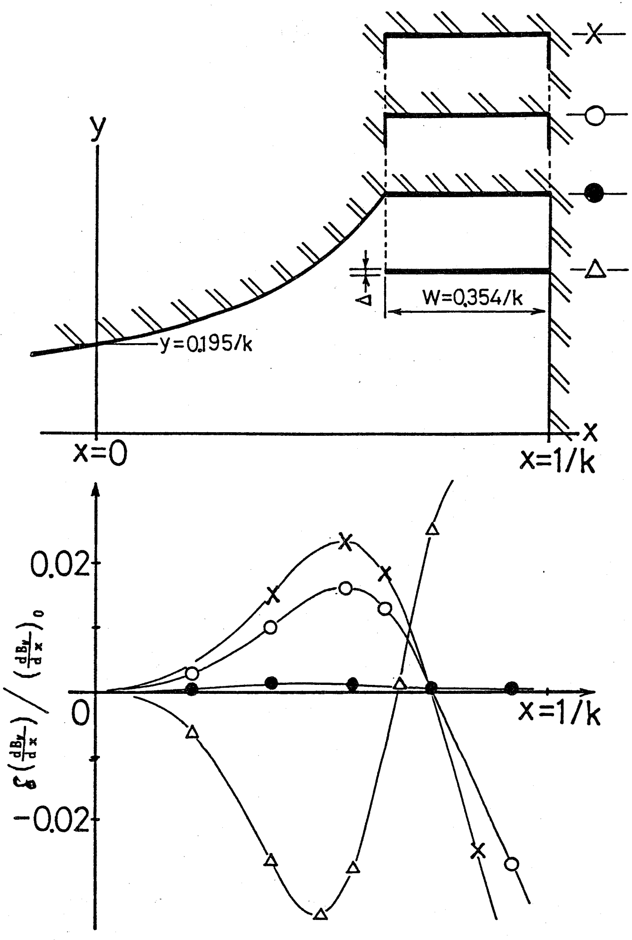

Fig.4 Field gradient distribution induced by very thin current sheet. (thickness $\Delta = 0.0035/k$)

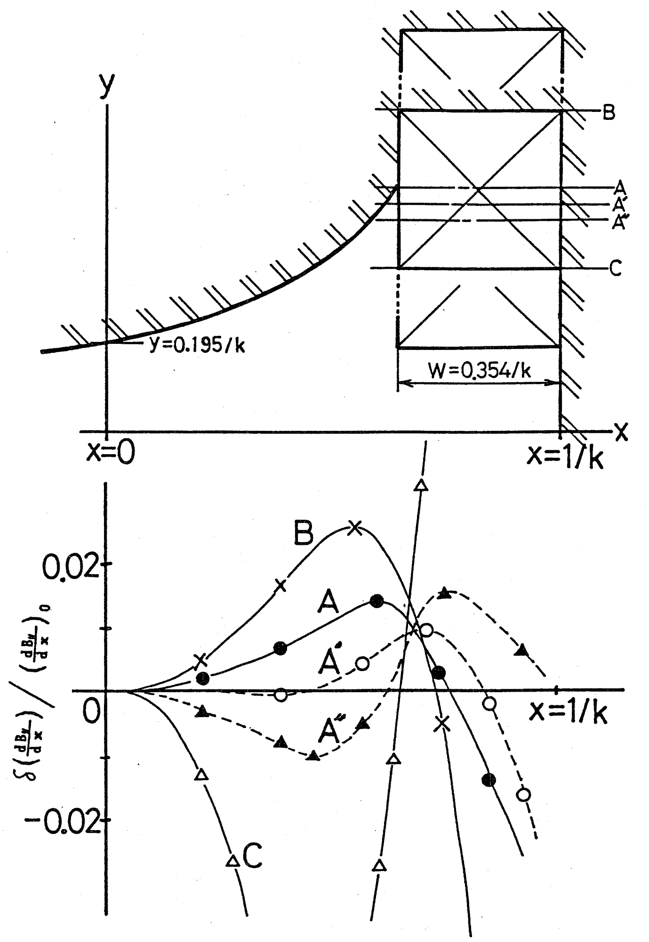

Fig.5 Field gradient distribution of the gradient magnet excited by a coil with square cross section. Case A' and A" correspond to the coil shifted downward by $\delta = 0.035$ and 0.070 from the case A.

is attained with an infinitely thin coil attached to the surface in the uniform gap portion and the region of constant field gradient extends to the position of the asymptotic line. However, this configuration is not realistic because of the requirement of infinite current density to the coil conductor. Figures 5 and 6 show the effect of the position and the thickness of the coil with finite size. Even with a finite thickness of coil, the field gradient keeps constant within 1% over the region x=0 to x=1/k without introducing any shims onto the pole face. If the useful region is limited to the range of the curved secion of pole, the field gradient can be within a tolerance of 0.5% in contrast to usual shimming method.

However, this method has a drawback that the field configuration is sensitive to the position of the coil because the considerable contribution to the field gradient comes from directly the exciting current in the coil. Figure 7 shows the change of field gradient caused by the position error of the coil of finite size.

It has been shown that constant field gradient at low field region in gradient magnet can extend over a wide range, i.e., even to the vanishing point of field without introducing any shim. Therefore, the useful aperture of the gradient magnet is practically determined only by the configuration of the magnet at high field region, which depends on the electro-magnetic properties of used material and the geometry of pole, and it is not necessary to take care of the configuration at low field region of the magnet.

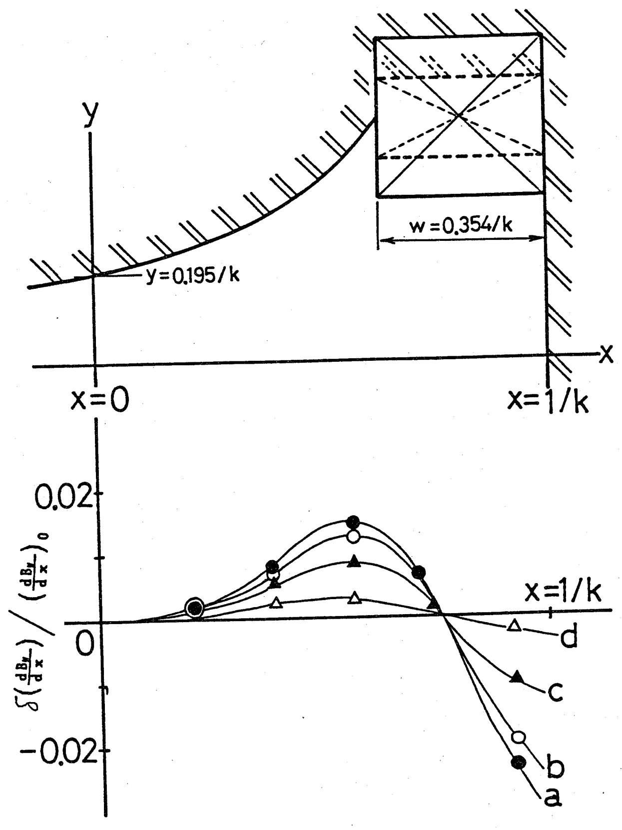

Fig.6 The coil-thickness dependence of field gradient distribution. Case a,b,c and d correspond to a full size square coil, half, 1/8 and 1/32 size in thickness, respectively.

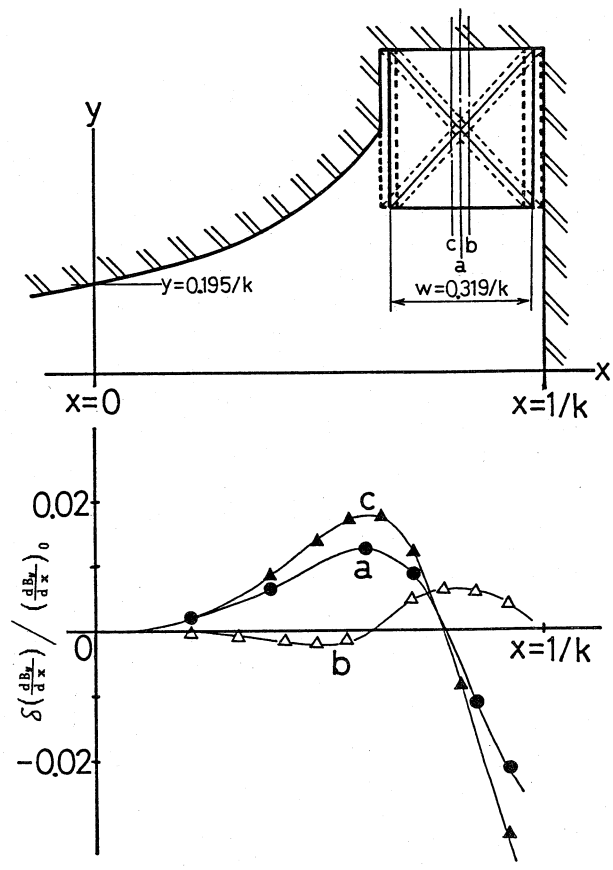

Fig.7 Dependence of field gradient distribution on the horizontal position of coil. Case a is with the coil centered in coil window. In case of b and c, the coil is shifted from the center to right and left by δ = 0.018/k.