SPLIT-POLE PM DIPOLES AND QUADRUPOLES WITH VARIABLE FIELD

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Abstract

Several possibilities to replace electromagnets on beam transport channels by permanent magnet (PM) lenses are considered. The main attention is concentrated on a design and features peculiar to dipoles and quadrupoles with variable field in rather wide range of adjustment. A PM dipole sample on Nd-FE-B alloy with 0.64 T at the center of the magnet and about 100% field adjustment range is presented. It is shown that the alloy with 1.4 T coercivity and 1.0 T remanent field is able to give appropriate field uniformity (or linearity for quadrupole lens). The design is considered as supplementary choice for transport line among tanks of high intensity driver of the ITEP "Neutron Generator" [1].

1 INTRODUCTION

PM multipoles, their features and fields of application were considered many times. Several investigations were perfomed to study the field distribution and harmonic content in two main multipole designs: segmented- and rod-type, as well as in proposed but not yet used ring-type [2-4]. It was shown the first of them is the most suitable for application when small number of units is required due to its compactness and high accuracy of the field configuration.

Split-pole PM qadrupoles have wide application as focusing elements in accelerators and in transport systems. Here the PM dipole is considered for transport system as a bending magnet which manipulate an ion beam into one or several channels. This purpose can be achieved when an accelerator operates on each channel for a long time and for automatical regime of adjustment.

In the paper PM dipole with variable field for wide range of adjustment is described. The main two questions studied were: a) the field longitudinal distribution in the dipole with different length of movable layers and b) the influence of the field magnitude on the PM magnetic state in median plane for Nd-Fe-B alloy.

2 PM DIPOLE DESIGN

The dipole consist of two movable layers (Fig.1). In logitudinal direction each layer contains three blocks of 24 Nd-Fe-B segments with the magnetization oriented correspondig to the rule $\varphi=\psi$, where φ-angle of magnetization vector **I** of a segment, ψ-its centre azimuth in a cylindrical coordinate system. The first layer has inner radius R_1=20 mm, outer - R_2=29.5 mm, length L_1=80 mm and the second - R_3=33.5 mm, R_4=49.4 mm, L_2=120 mm, respectively.

To take an angle reading a scale is attached so that it is possible to adjust a layers turn angle required and to fix the dipole in outer device at appropriate position. For automatical adjustment the dipole must be complemented by two motors remotely controlled and magnetic measurement system for right field orientation. The design provides fixing of the layers each other by special screw on the scale.

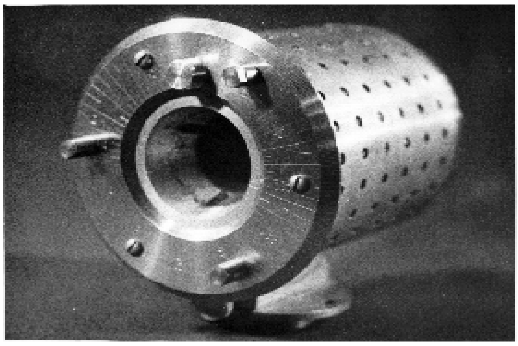

Figure 1. The PM split-pole dipole with variable field.

The dipole has the 30° conical bell-ended aperture on both sides to provide beam injection and extraction at an appropriate angle respect to dipole axis.

3 MAGNET MEASUREMENTS

Magnet measurements were carried out by device with small Hall probe, which can be moved along three rectangle directions inside dipole aperture and fringe field regions included, with field measurement accuracy of 1% and positioning error ~ .5 mm. The longitudinal distribution of the field was measured on the geometrical axis for maximum field adjusted. It was found that the form of the distribution little differ from calculated one which can be got taking into account the following expression for the field B(z) on the axis of a half-infinite split-pole lens with continuous (rule: $\varphi=\psi$) magnetization distribution:

$$B(z) = \frac{\mu_o I}{4}\left(\frac{z}{\sqrt{R_2^2+z^2}} - \frac{z}{\sqrt{R_1^2+z^2}} + 2\ln\frac{z+\sqrt{R_2^2+z^2}}{z+\sqrt{R_1^2+z^2}}\right), \qquad (1)$$

where R_1, R_2 - dipole inner and outer diameters, respectively, with origin z=0 placed at the lens geometrical side. When $z \to -\infty$, the formula (1) reduces to well known expression for infinite length dipole.

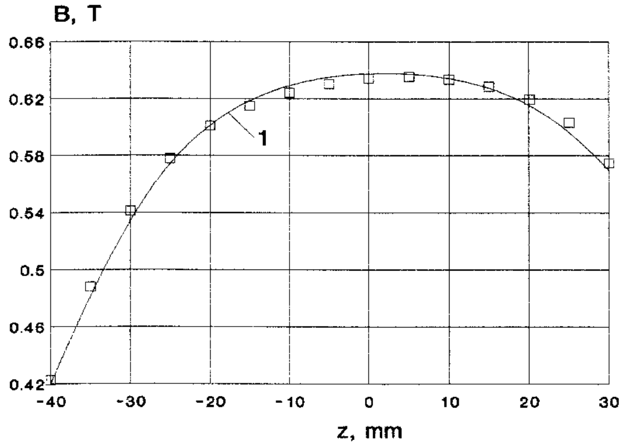

Figure 2. Dipole field z-dependence near its geometrical centre; measured data - (points), calculated curve - (1).

Calculations of the field distribution for measured dipole were made taking into account that layers have different geometrical sizes and magnetizations. Fig.2 shows the data measured near magnet centre z=0 (experimental points) and curve 1 calculated using (1).
The discrepancy can be estimated by r.m.s deviation of ~0.6 % of the field value in maximum 0.64 T.

Field distributions in pole and median planes (xz and yz, respectively) were measured with step of 5 mm for 7 cross-sections z=[-15 mm,15 mm] with 5 mm appart. The first of them is shown on Fig. 3 and the second - on Fig. 4. There is obvious minimum of the field

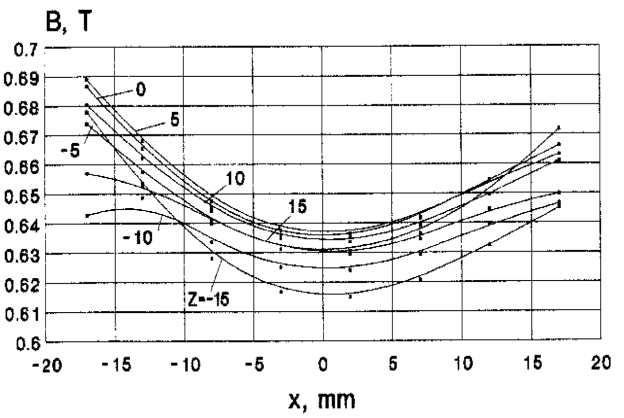

Figure 3. Field distribution in the pole plane of the dipole for 7 cross-sections; points - measured data, curves - smooth approximation lines.

dependence in xz-plane, which is a consequence of fringe field effects, and no exhibition of demagnetization factor as it must be. In contrast to that in yz-plane one can watch the significant decreasing of the field near the aperture surface. It can be estimated by 10% of maximum field value in the magnet centre. The value is almost equal to the field decreasing in the pole plane.

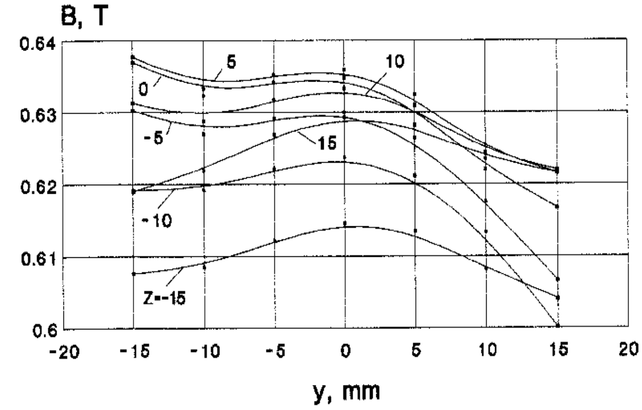

Figure 4. Field distribution in the median plane of the dipole for 7 cross-sections; points - measured data, curves - smooth approximation lines.

By turning layers each other in the angle range of ψ^*=360° the $\mathbf{B}^2 = \mathbf{B}_1^2 + \mathbf{B}_2^2 + 2\,\mathbf{B}_1\mathbf{B}_2\cos\psi^*$ dependence, where B_1,B_2 - fields of the first and the second layers, respectively, was verified to be convenient enough to describe the field variation in such deep range of adjustment. Because in measured dipole the geometrical sizes of layers were chosen so that $B_1 \cong B_2$, the formula $B=2B_1|\cos\psi^*|$, which follows from mentioned above in the case, gives discrepance with measured not greater than 0.5 % for ~85 % of the whole adjustment range.

3 CONCLUSIONS

Measurements for PM dipoles and quadrupoles made from Nd-Fe-B materials with coercivity not less than 1 T shows that demagnetization effect reduces accuracy of field configuration not greater than ~5% in 75% of aperture with maximum field up to ~6.5 T. It is possible to provide the field adjustment range to 100%. The theoretical formulaes gives good accuracy of spatial field distribution; they can be used for beam simulations.

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