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Compensating Solenoid for Fringe Field Reducing

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The proposed small compensating solenoid with diameter of 30mm and length of 20cm is designed to reduce a fringe field depolarization of muon around the upstream hole of the iron yoke. Its axis coincides with the central axis X = Y = 0 of the magnet and its upstream edge placed near area of maximum radial field.

Introduction

D.E. Lobb proposed an additional shield coil (SC) for reducing of muon depolarization in the fringe field area of a magnet. One can see his result by comparison of curves "a" and "c" on Fig. 4 [1]. Value of $v_\perp / v$ changes from ≅ 0.07 ("c") to ≅ 0.03 ("a"). The "v" is total velocity, and "$v_\perp$" is radial velocity of muon. It means the reducing of the muon depolarization in $(0.07/0.03)^2 \cong 5$ times because $1 - P_\mu = 1 - \cos(v_\perp/v)$. This method works! Idea of the D.E. Lobb's method was <u>to increase a B_z field</u> at the upstream edge (UE) of SC by the SC switched on the same as the main magnet polarity. I would like to suggest a <u>same compensation of a fringe field</u> at the UE by a SC switched on opposite polarity. In an ideal case, if $B_r(Z, r, SC) = - B_r(Z, r)$, the fringe field depolarization will be zero inside the UE area. But the same field distribution $B_r(Z', r)$ appears around the downstream edge (DE) of the SC. More exactly say the $B_r(Z', r)$ is mirror reflection of the $B_r(z, r)$. The field $B_r(Z', r)$ will create a new area of fringe field. Muon spin depolarization in the area of the $B_r(Z', r)$ will be less than in the area of $B_r(Z, r)$ because B_z component in the DE area has a greater value than in the UE area. Value of the B_z will change after the compensation because

$$B_r(r,Z) \cong - (r/2)\cdot(\partial B_z(0,Z)/\partial Z).$$

It means that $B_z(0,Z) = \text{const}$ if $B_r(r,Z) = 0$. The rough illustration of the compensation is presented in Fig.1.

Estimation of fringe field depolarization

Below one can see an attempt to estimate by hand the muon depolarization at different values of B_r and B_z . Angle ϑ of muon momentum deflection in magnetic field **B** is defined as:

$$\cos\vartheta = \cos^2\theta + \sin^2\theta\cdot\cos(\Delta\varphi); \quad \Delta\varphi = (\omega_H\cdot\sin\theta)\cdot\Delta Z; \quad \tan\theta = B_r/B_z .$$

ω_H is cyclotron frequency of surface muon, ΔZ is length of fringe field area. B_z = const., B_r = 100G = const, ΔZ = 50cm. The values of ΔZ = 50cm and B_r = 100G were taken from Fig.2 [2]. Muon with $P_\mu = 1$ moves originally along Z axis. Value of $\cos\vartheta$ will oscillate between $\cos\vartheta = \cos^2\theta + \sin^2\theta \equiv 1$ and $\cos\vartheta = \cos^2\theta - \sin^2\theta$. It was suggested the average value $\langle\cos\vartheta\rangle = \cos^2\theta$. Values of $\langle\cos\vartheta\rangle$ and $\langle 1- P_\mu\rangle$ after crossing by muon the distance of 50cm are shown in Table.

Table

B_r = 100G; ΔZ = 50cm

B_z, kG	0	5	10	20
$\langle\cos\vartheta\rangle$	0.99884	0.9996	0.9999	0.999975
$\langle 1- P_\mu\rangle$, (10^{-4})	11.6	4.0	1.0	0.25

The above by hand estimations show the remarkable decreasing of the $\langle 1- P_\mu\rangle$ from increasing of the B_z . Computer calculations are needed to optimize the SC configuration. Some suggestions for the optimization are done below.

Suggestion and procedure

We need to compensate the B_r inside muon beam area only. It is a cylinder with central axis at X = Y = 0 and with radius r < 30mm because more than 99.9% of beam particles have r < 18mm for tune1 [2] {$\sigma_x(\theta)$ = 6.1mr, $\sigma_y(\theta)$ = 7.6mr, σ_x = 4.0mm, σ_y = 3.2mm} and r < 31mm for tune2 [2] {$\sigma_x(\theta) = \sigma_y(\theta)$ = 19.1mr, $\sigma_x = \sigma_y$ = 1.73mm} at ΔZ < 400mm from a focal plane. That means we can use a compensating solenoid (CS) with diameter of 60mm instead of the big SC with diameter 400mm [1]. We can provide the needed value of $B_r \cong -$ 100G at r $\cong$ 10mm [2] by a small value of B_z of the CS because radius of the CS is small also. Furthermore the small CS with the small radius and magnetic field will distort a magnetic field on the chamber assembly less than the big SC with diameter 400mm.

• First step of the optimization:

The CS has diameter of 60mm. Its UE placed around Z = 150cm (the maximum fringe field area [2]). Its DE placed at Z = 0. Magnetic field of the CS has opposite direction to magnetic field of the main magnet (MM) with the iron yoke. Value of the B_{CS} is selected to have the same as for MM integral of $|B_r|$ at r = $\sigma_{x,y}$ = 3.5mm. The requirement

$$\int B_r(Z, r = 3.5\text{mm, CS})dZ = -\int B_r(Z, r = 3.5\text{mm})dZ$$

is not so correct because the two field distributions along Z are different. That requirement can be used as an initial step.

• Second step:

Muon depolarization at Z = 0 is calculated at different Z positions of the UE and the beam focus. The above integral must be conserved during the Z changing.

• Third step:

Muon depolarization at Z = 0 is calculated at different Z positions of the DE. Again the above integral must be conserved at the Z changing. The Z position of the DE is increased till a remarkable worsening of the P_μ value. After that a distortion of magnetic field inside the working volume is checked.

I believe the optimization could be done for 2D geometry and without a matter inside the magnet in order to estimate the fringe field depolarization effect itself.

A different kind of the optimization can be suggested also. Originally a short CS is selected with length of 20cm for example. Its diameter can be ≅ 30mm because the beam radius of the above both tunes is r < 14mm at Z < 10cm from a focal plane. Three degrees of freedom are for the optimization: position of the UE along Z axis, position of the beam focus along the Z axis, and value of magnetic field of the CS. <u>We could overcompensate the fringe field inside the UE area in order to compensate again the muon polarization inside the DE area.</u> A rough illustration of the overcompensation method is shown on Fig.2. Arrangement of the CS relative to the iron yoke is shown on Fig.3. Convenient way of the optimization is calculation of the $\langle P_\mu \rangle$ or $\langle 1 - P_\mu \rangle$ at Z=0 for several points of the CS on a grid placed near points proposed to be optimal. Position of the beam focus is not so crucial moment for the optimization because the beam size (tune1) changes very slowly. Initial value the B_{CS} could be selected to have equality of the above integrals. Subsequent values of the B_{CS} could grow with step + 5% for example to overcompensate the fringe field inside the UE area. Analysis of the Fig.2 [2] lets to suggest Z = 120cm as the initial point of the UE for the optimization. Subsequent increasing of Z with step of + 5% seems to be convenient. Initial position Z = 120cm of the beam focus could be convenient also.

Fringe field depolarization can not be reduced to zero level of course because that means $B_r(Z, r) \equiv 0$ and $B_z(Z, r) \equiv 2T$ inside the full space. But the reducing of the B_r in 3 times (from 100G to 30G) in area of weak B_z will reduce the $1 - P_\mu$ in $3^2 = 9$ times.

References

1. D.E. Lobb. Methods of Reducing the Azimuthal Momentum Created During Axial Injection into a Strong Axial Field, Third European Accelerator Conference (EPAC92), Berlin 24-28 March 1992, p.1524
2. R. Ramadanovic, D.H. Wright. Optimization of Muon Polarization in the M13 Beamline and E614 Detector, E614 Technical Note TN – 31, 1999