New magnetic cusp lens and tracking of charged particle within

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Introduction

Magnetic cylindrical lens is used mostly in beam lines to focus low energy beam. It is well known that focusing power of a magnetic lens is dependent on its mass and momentum of the particles. The magnetic solenoid rotates the ion beam and the phase space areas of the beam in x- and y-plane get entangled and increased.

The paper reported here describes an effort to design a cusp field solenoid lens for the first time using some formulated analytical equations to generate the realistic Glaser type of scalar magnetic potentials and fields along the central axis. Thereafter particle tracking is done using the combined field of a pair of solenoids energized oppositely or similarly. Required focusing power of a lens system for a beam of given beam rigidity, Bρ can be achieved.

Potential and Field Evaluation

The sketch of the magnetic cusp lens, formed from two Glaser solenoids; kept attached or at small gap 2G, along the beam line and energized oppositely, is shown in Fig. 1. The hatched area is the iron yoke confirms the bell shaped field for the Glaser solenoid magnet. The diameter D and pole-to-pole distance S is given for the structure of the Glaser solenoids. These parameters together with the magneto-motive force NI set the design of Glaser lens for certain focal lengths individually for a beam of given rigidity. Design and test of Glaser type of solenoid magnet have been presented in InPAC 2009 [1]. We assume that O is the origin, then the centre of the two solenoids are at d=(S/2+G) from the origin. The magnetic scalar potentials for the cusp lens are defined by eq. (1) below, where subscript i stands for 1, 2 and 3, based on eqs. (1), (2) and (3) in reference [1]. The '-' sign between the potentials on the RHS of eq. (1) is replaced by '+' for similarly energized solenoids. More apparent and straight forward potential form $\psi_4(z)$ can be written as in eq. (2) cusp field. These potential formula, $\psi(z)$'s for the magnetic cusp lens are used to evaluate analytically the magnetic field along the central axis through $\psi'(z)=-\mu_0 d\psi(z)/dz$. The net axial field B_i for the cusp magnet is obtained using eq. (3) and $B_4(z)=-\mu_0 d\psi_4(z)/dz$. The evaluated fields of the oppositely (cusp) and similarly energized lens for S=0.1, D=0.1, G= 0.1m and NI=37000A-turn are shown in Fig. 2.

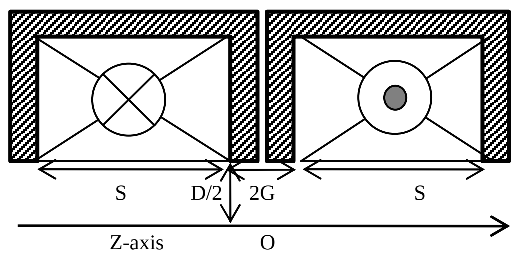

Fig. 1 Cylindrically symmetric cusp lens where ⊗ and ◉ shows electric current out and into the page.

$$\psi_i(z) = NI/2 + \varphi_i(z-d) - \varphi_i(z+d) \qquad (1)$$

$$\psi_4(z) = \frac{NI}{2} - \frac{NI \cdot D}{2\pi S}\left[\begin{array}{l}\{Z_+ \cdot \tan^{-1}(Z_+) - z_+ \cdot \tan^{-1}(z_+)\} + \\ \{Z_- \cdot \tan^{-1}(Z_-) - z_- \cdot \tan^{-1}(z_-)\}\end{array}\right]$$
$$Z_+ = 2(z+G+S)/D, \quad z_+ = 2(z+G)/D \qquad (2)$$
$$Z_- = 2(z-G-S)/D, \quad z_- = 2(z-G)/D$$

$$B_i(z) = \Psi_i'(z-d) - \Psi_i'(z+d) \qquad (3)$$

Cardinal Points and Particle Tracking

A particle of Bρ=0.064 T-m is projected at r=5, 3 and 1cm parallel to the central axis at different conditions G=0, 10 and 20 cm when the coils of the pair are energized likely (similarly) or unlikely (oppositely). The magnetic field is calculated using only one potential form ψ_4 as above. Motion of the particle is tracked using the same matrix method for the thin lens as described in reference [1]. The crossing point of the particle track with the z-axis gives the point of focus which help in finding the principal focal length f_p, mid-focal length f_m and the position of the principal plane z_p.

The extreme trajectories represented by G0 lines in Fig. 3 correspond to G=0 when coils are energized similarly and oppositely. The initial values of the distance and angle of the particle are r=3cm and r'=0 respectively. As the gap G increases the paths move in between extreme trajectories. The combined lens become stronger or weaker respectively when G is increased as individual solenoids are energized oppositely or similarly, keeping other parameters constant.

Beam rotation depends on G, S, D, NI and configuration of the fields depending on the direction of current in the two coils. The rotation of the beam during the flight is shown along the z-axis in Fig. 4. It is independent of the gap G. Net rotation at the exit of the field of the lens is 0 for symmetric cusp field but there is essentially a non-zero value for similarly energized solenoids.

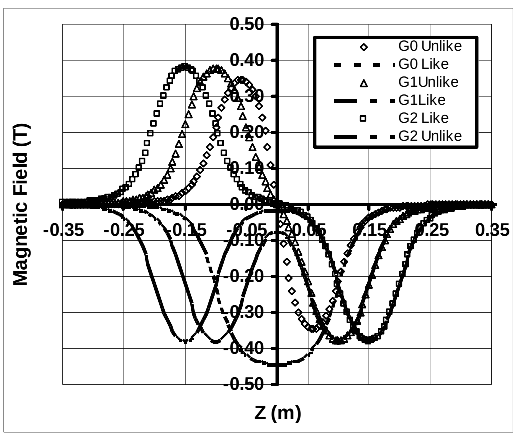

Fig. 2 Magnetic field calculated from ψ_4. G0 to G2 indicate G=0, 10 or 20 cm respectively.

Table 1: The cardinal points of the solenoid lens under study using the calculated field above.

Gap G cm	$\mathbf{f_a}$ cm	$\mathbf{f_p}$ cm	$\mathbf{f_m}$ cm	$\mathbf{z_p}$ cm	**θ** deg.
0 -like	43.3	46.7	46.3	-0.37	-44.4
0 -unlike	85.3	89.3	89.0	-0.30	0
10-like	55.8	62.2	61.2	-1.1	-44.4
10-unlike	59.2	65.7	64.7	-1.0	0
20-like	57.2	66.8	64.4	-2.3	-44.4
20-unlike	57.7	67.3	65	-2.3	0

The cardinal points of the lens comprising both the solenoids are listed in Table 1. The analytical focal length from standard formula, principal focal length, mid-focal length and position of the principal plane are represented by f_a, f_p, f_m and z_p respectively.

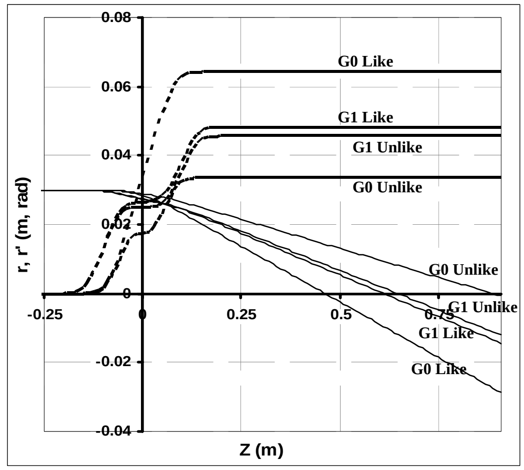

Fig. 3 The distance r and angle r' of the particle are given by solid and dotted lines respectively at different gap G.

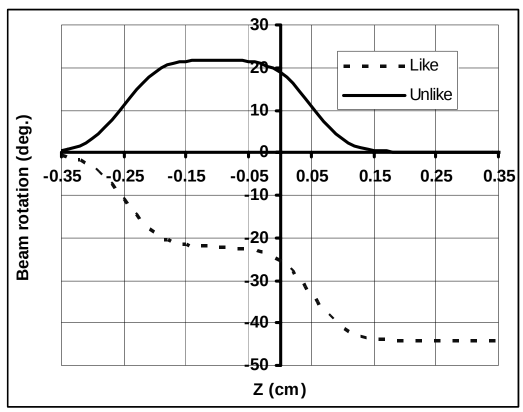

Fig. 4 Beam rotation of the given particle of Bρ=0.064 T-m in the calculated above field.

References

[1] M.H. Rashid, C. Mallik and R.K. Bhandari, Proc. DAE-BRNS Indian Particle Accel. Conf. at RRCAT, Indore, **InPAC-2009**, Manuscript No. 115, Feb. 2009.