COLLECTION OPTICS WITH THE HORN TYPE FOCUCING ELMENT MADE WITH SEPARATE CONDUCTORS

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Abstract

We describe the device for focusing of charged particles by the system of separated conductors which follow the parabolic profile. Basically this is a horn-type focuser, but with the individual conductors instead of continuous surface. This device allows substantial reduction of fabrication cost with the same focusing properties as the continuous parabolic surface. We recommend this "bird-cage" type system for focusing pions/muons in the projects under discussion in many Laboratories around the World.

OVERVIEW

Necessity for good quality secondary beams is well argumented topic for the high energy physics [1]-[3]. The horn-like focusing elements (lenses) are broadly in use in many laboratories for collection of secondary particles in the proton lines. One example of usage of miniature copy of such lens for collection of positrons is known from Budker INP [4]. For collection of pions the horns reach sized of ~0.5 m in diameter and ~2 m long [5].

Fabrication of thin wall parabolic surface of this scale represents substantional technological difficulties. Typically it is fabricated from solid billets of 40-6061-T6 Aluminum with typical lengths of 40 cm [5]. Three segments are electron beam welded together. Typical thickness of the parabolic wall is around 2mm. In all horn-like focusing devises the secondary beams running through material of paraboloid.

In this publication we made a proposition to approximate continuous surface of paraboloid with limited number of separate conductors. This approach delivers significant simplifications in technology of fabrication. The payoff for this-a distortions of trajectories can be made acceptable as the angular spread of secondary beams is significant. Any way it is comparable with divergences obtained as a result of multiple scattering in material of paraboloid.

THE CONCEPT

Idea of a horn-like device has a long story. The horn with conical surfaces was proposed in [6]. It was recognized soon after [7] that the *parabolic* profile of the surface allows excellent (practically ideal) performance of such device for the focusing.

Magnetic field from linear current drops as a reverse distance, $H = 0.4\pi I / 2\pi r = 0.2I / r$. If one can arrange quadratic dependence of the distance of interaction on the transverse coordinate, $s = kr^2$, the integral

$$\int_{-\infty}^{+\infty} H ds = \frac{0.2I}{r} 2krdr = 2 \cdot 0.4Ikr \,, \qquad (1)$$

where k –is a parameter of parabola. So the deflection angle comes to

$$\alpha = \frac{\int H ds}{(HR)} = \frac{0.8Ikr}{(HR)} \,, \qquad (2)$$

where (HR) –is a magnet rigidity of the particle.

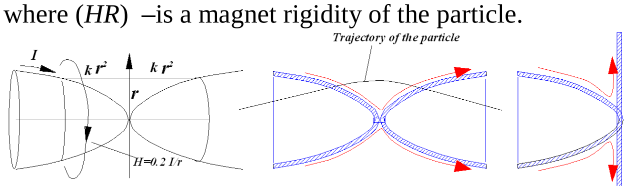

Figure 1: Magnetic horn, or X-lens. Current back way covering the cylinder, serving for reduction of inductance, is not shown here (see it in Fig.2).

So the device has ideal dependence for linear focusing. The focal distance of this lens goes to

$$F \cong (HR)/0.8Ik \,. \qquad (3)$$

As the particles here are going through the material of the horn, it manufactured usually from Aluminum ($X_{Al} = 24.3 g/cm^2 [\cong 9cm]$) or from Beryllium ($X_{Be} \cong 66 g/cm^2 [\cong 35.8cm]$). Necessary fixtures must be designed so that the stray fields are minimal, Fig.2.

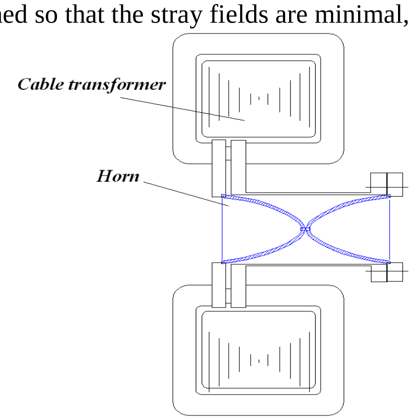

Figure 2: Magnetic horn or X-lens incorporated in a transformer.

NUMERICAL MODEL

We investigated technological possibilities for such lens here. We made a model for calculation with 3D code MERMAID [8].

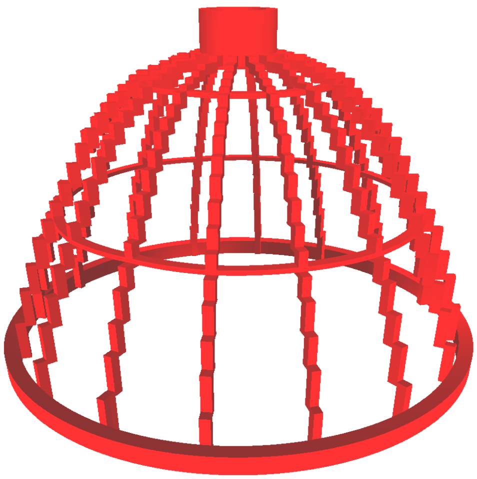

Figure 3: The model of the horn as it appears in the 3D MERMAID model. Sixteen conductors approximate a parabolic surface.

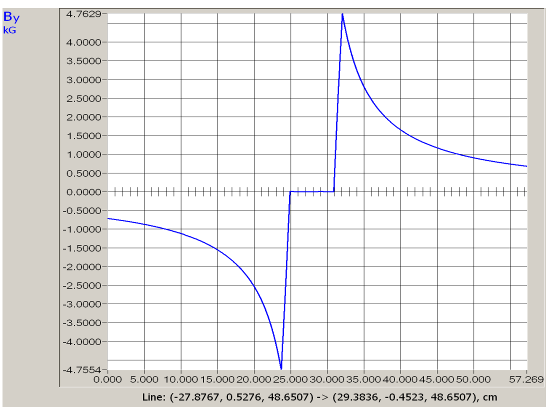

Figure 4: The field across the horn in end region (at a waist).

In Fig. 4 the y-component of the field is represented as a function of transverse coordinate. The stiff rise of the field is explained by crossing over the area occupied by conductor. From Fig.5 one can see, that the field flips ant the distance ~2cm i.e. comparable with the size of conductor. The field drops ~1/r as it should be for a centered conductor. In Fig.6 the fields as functions of transverse coordinate are shown. Again the perturbation of the field lasts at the distances of the order of ~3 cm i.e. of the order of the distance between conductors.

For cooling of conductors a water or Liquid Lithium flow can be used. In the last case the area occupied by Lithium conducts current also. Temperature of Lithium flow >156°C does not create much problem. Pumping system for liquid Lithium is well known technique (see for example [9]).

Transverse ring type conductors (Figs.3,10,11) serve for reinforcement purposes only; the current is not running through (just parasitic currents could be created by the broken symmetry).

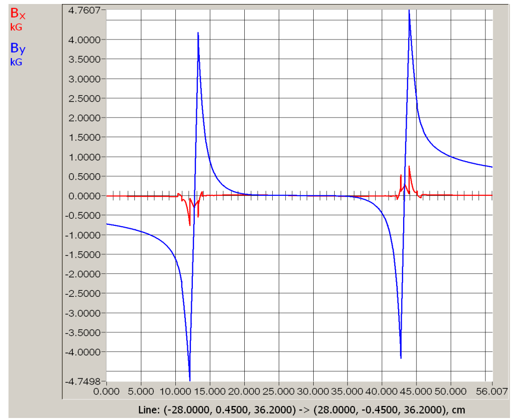

Figure 5: The field across the horn in a middle of the model region. Two components of the field are represented B_x and B_y values as functions of transverse coordinate.

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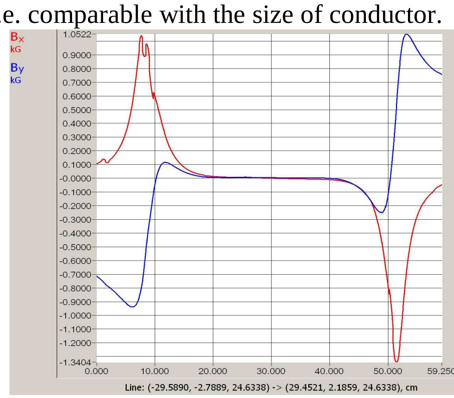

Figure 6: The field across the horn at the same longitudinal coordinate as in Fig 5, but in transverse direction between the conductors.

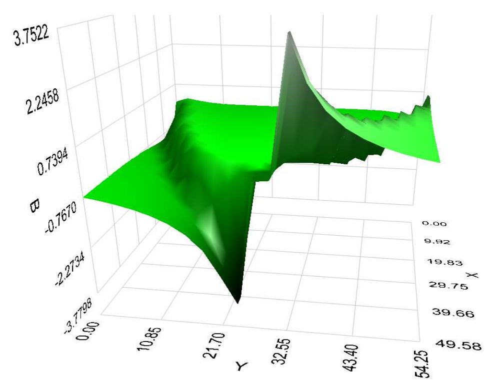

Figure 7. 3D visualization of B_y in a plane which runs sightly below the medial plane.

CONCEPTUAL DESIGN

We investigated model of such lens with Beryllium or Aluminum conductors, Figs.10, 11.

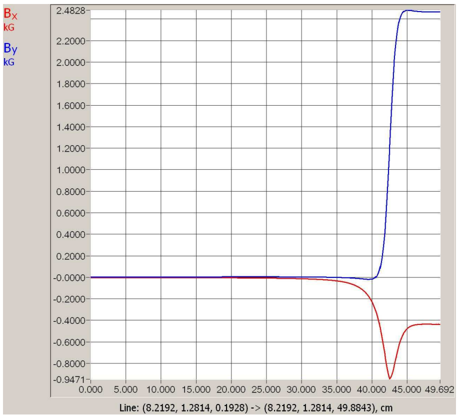

Figure 8. Field dependences as functions of longitudinal coordinate. In case of continuous surface here should be a step-like function.

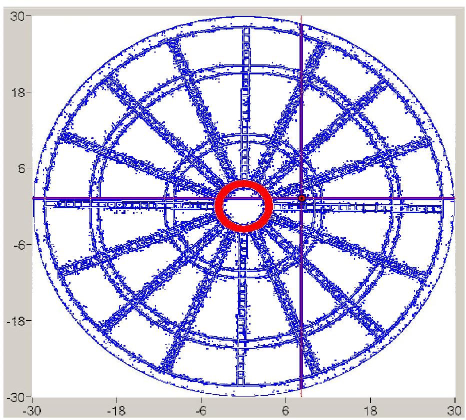

Figure 9. The graph in Fig.8 runs in z-direction across the transverse coordinates marked by small red dot with cross.

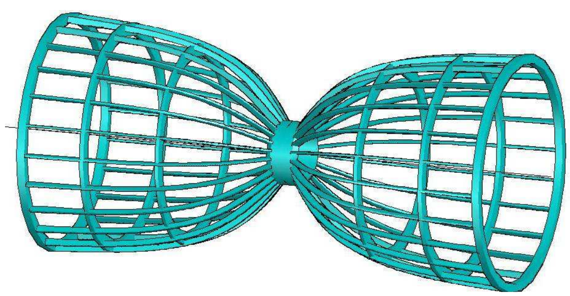

Figure 10. A Conceptual design of the lens. Double paraboloid type. Conductors jointed by welding. Cooling tubes are running in a body of each conductor.

SUMMARY

Usage of separated conductors allows creation of focusing lenses with very complicated profile necessary for powerful optics, which is difficult and expensive for the lens with continuous surface.

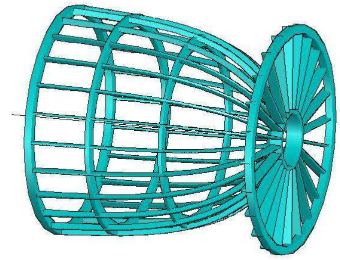

Figure11: Half of paraboloid

Some distortions associated with particle passage between conductors remain smaller, than the ones due to scattering in the material, so the efficiency of this construction might be higher. The number of individual conductors in the lens can be determined by the maximal allowable distortion. However, as this lens installed typically right after the target, where the angular divergence and the energy spread are substantional, these effects could be masked even with limited number of conductors.

Conductors can be manufactured with ordinary equipment and the lens can be assembled with welding. Cost is much less, than the one made with traditional approach. Cooling of conductors can be provided by the tubing implemented into conductors. Cooling by water or by liquid Lithium might be arranged adequately to the current running in the horn.

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