

## Calculations of Gabor Lens Having Two Glaser Field Distributions

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### Abstract

The present computational work is focused on investigating some properties of Gabor lens. The Gabor lens under consideration consists of two fields, electrostatic and magnetic. The Glaser field model is assumed to represent each field along the optical axis. Under zero magnification condition the trajectory of charged particles along the axis of Gabor lens has been computed. The results have shown that a lens of short focal length and hence high refractive power can be achieved.

**Keywords:**Electrostatic Lenses, Gabor Lens, under zero magnification, Glaser field

## Introduction

Gabor lens was proposed as an effective (space – charge lens) for positive ion beam [1]. It offers better control and focusing strength than both gas focusing and applied fields. This lens has been investigated by several research groups since its invention. It has been constructed at Fermilab and has been used to focus a 30 KeV proton beam with good optical quality. Palkovic used Gabor lens with 30 KeV  $H^+$  beam from an ion source [2,3].

Like in the previous experiments, in Russia and USA the Gabor lens has been operated with a gas discharge to obtain the desired non-neutral electron distribution in contrast to Gabor's original proposal of a pure magnetron type electron beam. Gabor's space – charge lens shows that this lens is capable of providing much stronger focusing than an equivalent electrostatic quadrupole doublet provided that a relatively “cold” electron beam is used which operates close to the ideal Brillouin – flow limit.

The Gabor Lens is only attractive if uniform electron density and hence force linearity can be achieved. The Fermilab experiment is an indication that strong nonlinear forces are acting on the  $H^+$  beam in that system. Such nonlinear force could be due to non-uniformity of the electron density to start with. But it could also develop due to the interaction between the space charge of the  $H^+$  beam and the electron plasma [4].

The properties of space charge lenses are very advantageous as they can theoretically provide a strong linear cylinder symmetric force on the beam particles. The space charge lenses investigated has been suggested and published by Gabor in 1947 [5].

## Electrostatic Lenses

Electrostatic lenses form part of ion sources and electron gun: the cathode shield and anode function as an electrostatic lens, focusing the electrons from the filament into a beam that is extremely high brightness. Electrostatic lenses are generally thick lenses produced by two or three electrodes of circular symmetry [6].

They are made of metallic discs with apertures of round shape, or pieces or round metallic tubes. The optical axis of the lens is formed by axes of symmetry of its electrodes. When the dimensions of the lens along the optical axis cannot be neglected in comparison with other characteristic dimensions, it is considered a thick lens. Its focal lengths must be measured from the geometrical mid-plane of the lens[6].

Magnetic lenses are often used in electron optics to avoid the high voltages required by electrostatic lenses. Magnetic lenses have rotational symmetry with the radial component of the magnetic field equal to zero along the lens axis[6].

Charged particles traveling on the axis are not deflected by the lens.

Charged particles traveling parallel to the axis are deflected across the axis at the focal point. The focal point can be adjusted by changing the current in the magnetic windings. Some magnetic lenses are asymmetric along the rotational axis. This provides space for deflectors, stigmators, and aperture behind the lens. Electron columns uses an asymmetric lens to de magnify the electron beam to its final spot size (2 to 200 nm).

Magnetic lenses can be classified into two basic categories: long lenses with distributed fields and short lenses with highly consented fields[6].

## The Structure of Gabor Lens

Figure 1 shows a Schematic diagram Gabor lens with magnetic and electric field s. Radial confinement is provided by a solenoidal magnetic field, axial confinement by the electric field of one or more electrodes [2].

The design concept of a Gabor lens for a positive ion beam is illustrated somewhat simplistically in figure 1. A solenoid with axial field strength  $B$  provides radial confinement

of the electron cloud. An electrode configuration like the one shown in the figure with a positive voltage of  $v_0$  on the center electrode provides the axial confinement for the electrons. A second shorter solenoid located on one side of the main solenoid producing a magnetic field in the opposite direction. Gabor placed a ring shaped thermionic cathode at the plane ( $B=0$ )[3].

### Trajectory Equation of Electromagnetic Field

The trajectory equation of an electron beam traversing combined electrostatic and magnetic fields in the non-relativistic case is given by [6]:

$$\frac{d^2}{dz^2} r + \frac{1}{2V} \frac{dV}{dz} \frac{dr}{dz} + \frac{1}{4V} \left[ \frac{e}{2m_0} (B_z)^2 + \frac{d^2 V}{dz^2} \right] \cdot r := 0 \dots \dots \dots (1)$$

Where  $V$  is the field distribution,  $r$  is the radial displacement of electron beam trajectory,  $z$  is the axial distance and axial flux density distribution  $B(z)$ .

In the present work equation (1) has been taken into account to determine the trajectory of the electron beam traversing Gabor lens.

### Glaser's Field Model

The axial density distribution in Glaser's field model is given by [7]:[8]

$$B(z) = \frac{B_m}{1 + \left(\frac{z}{a}\right)^2} \dots \dots \dots (2)$$

Where  $B_m$  is the maximum value of magnetic field,  $a$  is the width at half maximum  $B_m/2$ . The general shape of axial flux density distribution  $B(z)$  is shown in figure No. (2) curve (a).

### Magnification Condition

The magnification conditions depends on the trajectory of the charged – particles beam.

a) Zero magnification:

The beam enters the lens field parallel to the optical axis (i.e. object at infinity)  $z_0 = -\infty$  [9]; see figure No. (3).

b) Infinite magnification:

The beam leaves the lens field parallel to the optical axis (i.e. image at infinity)  $z_i = +\infty$  [7]; see figure No. (4).

c) Finite magnification:

$z_i$  and  $z_0$  are at finite distance [9]; see figure No. (5)

In the present work, the beam is assumed to enter the lens parallel to the optical axis.

## Results and Discussion

### -The Focal Length

In a magnetic electron lens the focal length is determined by the field strength in the lens gap and the speed of electrons, under zero magnification condition a Gabor lens of short focal length has been put forward which could be useful in electron-optical instruments.

### -Computer Program for Computing the Beam Trajectory

A computer program with Mathcad professional 2001, has been used for determining the trajectory of the electron with the aid of the second order Runge – Kutta method.

The program shows high ability of drawing the general shape of axial flux density distributions and high facility and proficiency of drawing the trajectory of the electron beam that is moving through a rotationally symmetric field.

### **-Computing the Electron Beam Trajectory and Field Distribution Under Zero Magnification Condition**

The electron beam path along Gabor lens and the field distribution under zero magnification condition have been found. Figures **No. 6 and 7** show the field distribution and the trajectory of an electron beam traversing Gabor lens field. The trajectory has been computed with the aid of equation 1.

Also the trajectory of electron beam of the Gabor lens converges towards the optical axes under zero magnification condition and there is no distribution aberration affected upon it.

Two different fields distribution are used in Gabor lens, the first one is Glaser distribution which is given by equation (2) which represents the magnetic field distribution, and the other is the rectangular field distribution which is given by equation (1) see figure No. (2) which represents the electrostatic field distribution.

Secondly when the Glaser distribution was electrostatic field distribution and the rectangular field distribution. The trajectory varies with change of the field.

### **Conclusions**

It has been found from the present computational investigation that it is possible to represent the two different fields of Gabor lens by the Glaser field model. The Glaser lens under investigation has been operated under zero magnification condition. A Gabor lens of short focal length has been put forward which could be useful in electron – optical instruments.

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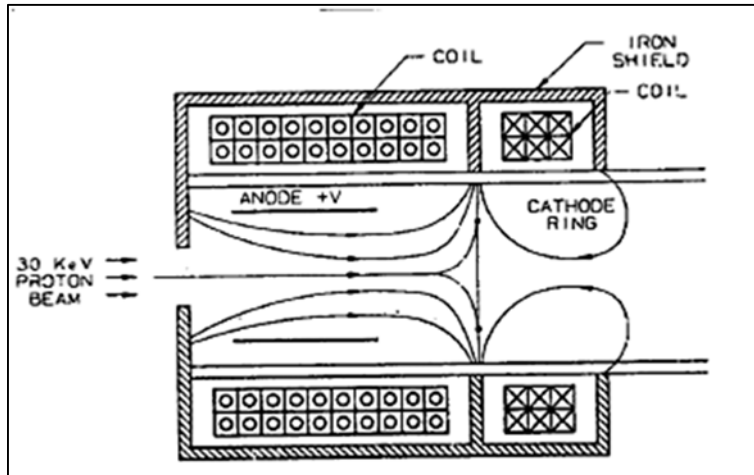


Figure No. (1): Gabor lens cross-section

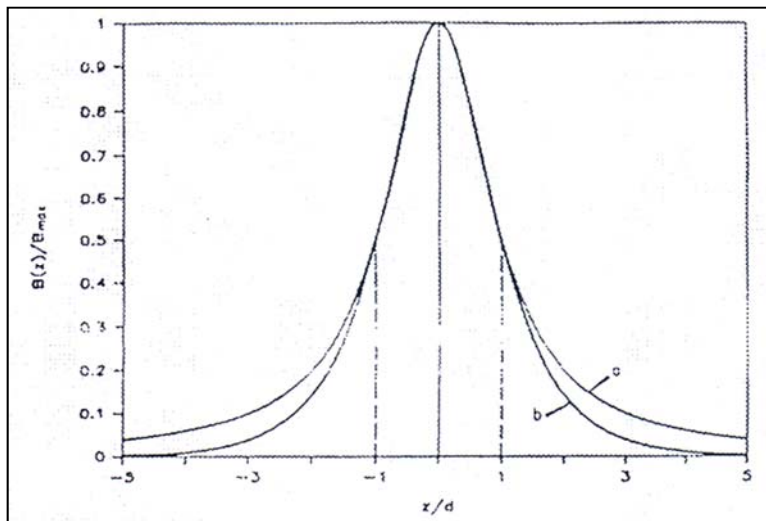


Figure No. (2): Glaser's model (curve a) and the Grivet-Lenz model (curve b).

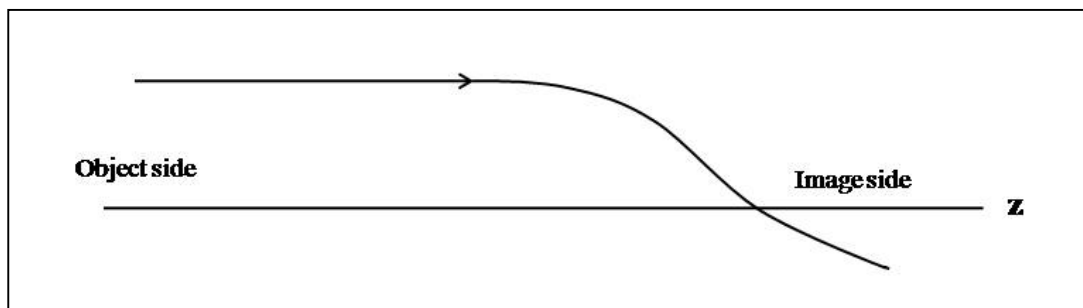
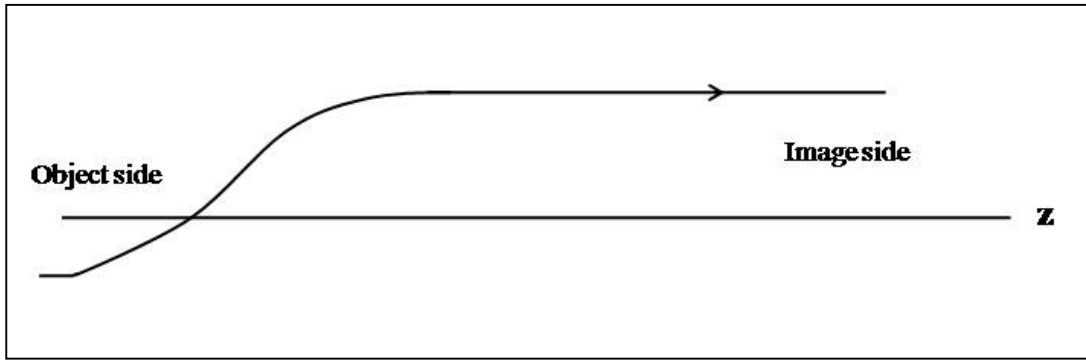
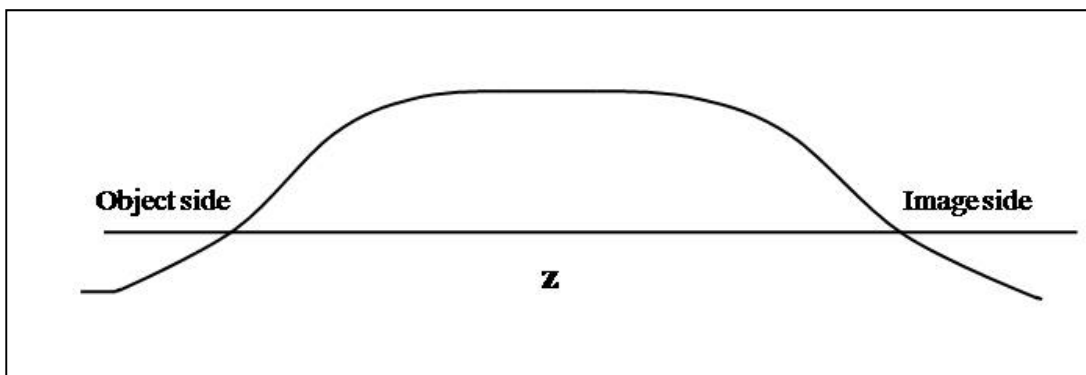


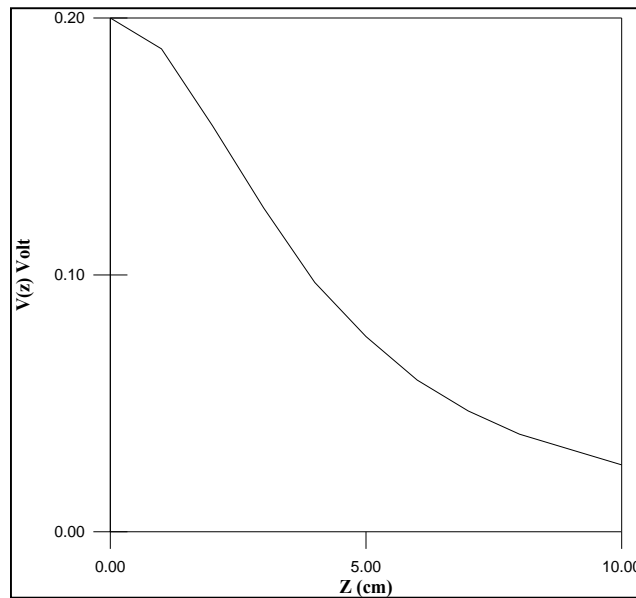
Figure No. (3): Zero magnification condition



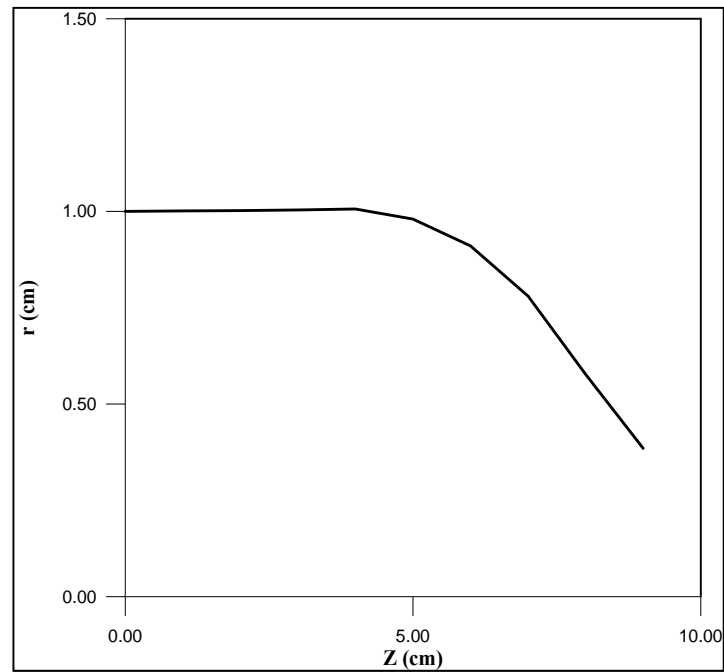
**Figure No. (4): Infinite magnification condition**



**Figure No. (5): Finite magnification condition**



**Figure No. (6): The field distribution  $V(z)$  as a function of the axial distance  $z$**



**Figure No. (7): The radial displacement  $r$  of the electron beam trajectory as a function of the axial distance  $z$**

## حسابات عدسة غابورتحوي مجالين من توزيعات كلاسر

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### الخلاصة

يركز هذا العمل الحسابي في التحقيق في بعض خصائص عدسة غابور. عدسة غابور تتألف من مجالين، الكهربائي والمغناطيسي. ويفترض هذا الانموذج مجال كلاسر لتمثيل كل حقل على طول المحور البصري. تم احتساب مسار الجسيمات المشحونة لمحور عدسة غابور بشرط التكبير تحت الصفر. وأظهرت النتائج انه يمكن تحقيق البعد البؤري القصير للعدسة والطاقة الانكسارية العالية.

الكلمات المفتاحية: العدسات الكهربائية، عدسة غابور، مجال كلاسر، التكبير تحت الصفر