Computational Optimization of the Radial and Spiral Aberration Coefficients of Magnetic Deflector Distortion

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Abstract:

The optimum design of the magnetic deflector with the lowest values of the radial and spiral distortion aberration coefficients was computed. The optimized calculations were made using three models, Glaser bell-shaped, Grivet-lenz and exponential models. By using the optimum axial field distribution, the pole pieces shape which gave rise to those field distributions was found by using the reconstruction method. The calculations show that the results of the three models coincide at the lower values of the excitation parameter. In general the Glaser- bell shaped model gives the optimum results at the whole range of the excitation parameter under investigation.

The negative values of the spiral distortion aberration coefficient appears in the results at the same case, therefore the designer can use it as corrector in other optical systems which suffer from this type of aberration.

Key words: Magnetic deflector, Spiral distortion, radial distortion.

Introduction:

The analogy between electron optics and light optics extended into the domain of deflection systems [1]. The most common and classical type of deflection is used in cathode ray tubes, lithography machines, scanning electron microscopes, electron accelerators, electron-beam manufacturing technologies and some other analytical instruments[2]. Compared with electrostatic lens and deflector, the magnetic lenses and the deflectors have some advantages as high stability, low aberration and high sensitivity [3]. In many electron beam instruments, such as scanning electron microscopes and scanning electron beam lithography systems are usually use a magnetic lens to focus a(charge) particle beam , and magnetic deflection coils mounted within the lens. For both the intermediate and projector magnetic electron lenses, radial and spiral distortions are the most important. In general one can tolerate about 1% of radial distortion and 29% for spiral distortion [4]. In order to find a lens shape giving zero radial and zero spiral distortion at the same excitation, radial and spiral distortions were calculated for an asymmetrical triple pole-piece projector lens with varying dimensions, by using axial field distributions obtained by the finite element method [5]. The numerical analysis of magnetic deflector in electron-beam lithography system was carried out by [6]. Magnetic deflectors and radial and spiral distortion aberration coefficients were studied be many researchers [7-10].

Theory

Fields Distribution

Let B(z) be the axial flux-density distribution for the lens and D(z) be the deflection flux density required at the axis. Then, the following relation holds [11]and[12]:

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$$D=(1/2)d\, B'(z) \qquad (1)$$

where d is the displacement by the first deflector and $B'(z)$ is the derivative of the field distributions.

Three models are used to find the best distribution of magnetic deflector field which gives the optimum radial and spiral distortion coefficient, there are the Glaser′s Bell-shaped, Grivet-Lenz and Exponential models.

The axial flux density distribution of a typical symmetric short magnetic lens is a bell-shaped curve. The Glaser′s Bell-shaped model is given by[2]:

$$B(z) = B_{max} / 1 + (z/a)^2 \qquad (2)$$

where B_{max} is the maximum flux density distribution and a is the field width at half maximum $B_{max}/2$

For the representation of unsaturated lenses the axial flux density distribution of Grivet-Lenz model has been proposed which is given by:

$$(3) \quad B(z) = B_{max} / \cosh(z/a)$$

According to the exponential function the axial flux density distribution of the third model is given by :

$$B(z) = B_{max} \exp - (z/a)^2 \qquad (4)$$

The pole piece shaps are calculated for three models of field distribution using the reconstruction technique of [13] for constructing the electrodes of an electrostatic lens to reconstruct the pole piece shape of magnetic deflector and electrode shape of electrostatic deflector. According to this technique the equation of equipotential surfaces (the pole piece in case of magnetic deflector) is:

$$R_P(z) = 2\left[\left(V_z - V_P\right)/V_z''\right]^{1/2}$$
(5)

where R_P is the radial height of the pole piece, V_Z is the axial potential distribution, V_Z'' is the second derivative of V_Z with respect to *z* and V_P is the value of the potential at any one of the two pole pieces or electrodes

Radial and Spiral Distortion

The spiral and radial distortion aberration coefficients of an axially symmetric magnetic optical element are given by [5]:

$$Dsp(Vr) = \left(\frac{1}{16.V_r}\right).\left(2.\frac{q}{mq.V_r}\right)^{1/2} \int_{-\infty}^{\infty} D(z).\left[\left(3.\frac{q}{8.mq}\right) + D(z)'^{2} + Vr.\left(\frac{Yd}{Y}\right)^{2}\right].Y^{2}dz \qquad (6)$$

$$Drad(Vr) = \left(\frac{3}{8.fp^{2}}\right).\left(2.\frac{q}{16.mq.V_r}\right) \int_{-\infty}^{\infty}\left[D(z)'^{2} + \left(3.\frac{q}{8.mq.Vr}\right).D(z)^{4} - D(z).\left(\frac{Y'}{Y}\right)^{2}\right].Y^{3}.Xdz$$

(7)

where X and Y are two independent solutions of paraxial- ray equation with an initial condition depending on the operation modes, the prime denote derivative with respect to z, mq is electron mass, V_r is relativistic corrected accelerating voltage, q is electron mass and fp is the projector focal length.

Results:

The deflector flux density distribution D(z) which is computed by the three models is shown in figure (1).

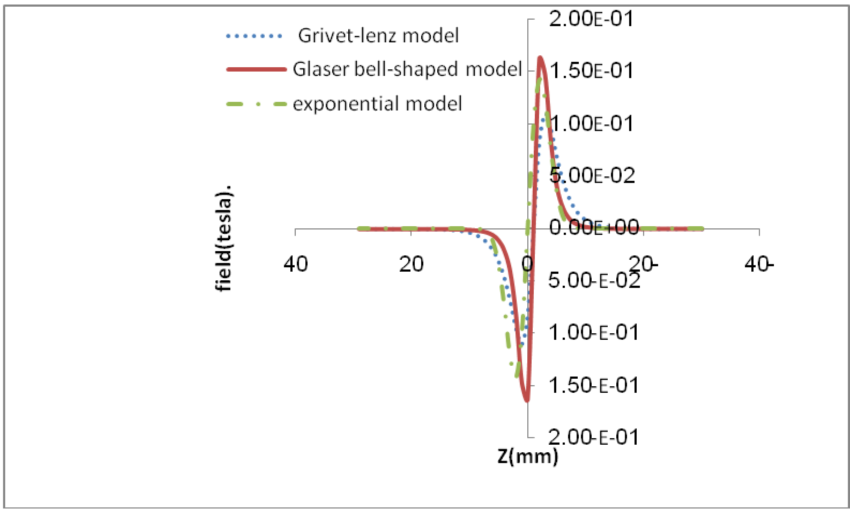

Figure (1): The field distribution of magnetic deflectors for three models of D(z).

The results of the pole piece shaps for three models of field distribution are shown in figures (2), (3) and (4).

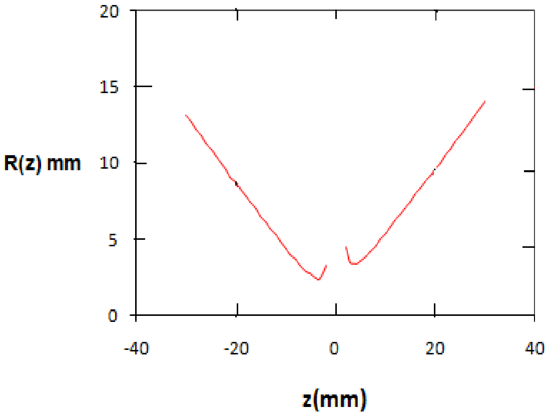

Figure (2): The pole piece shape for magnetic deflector with field distribution of Glaser's Bell-shaped model.

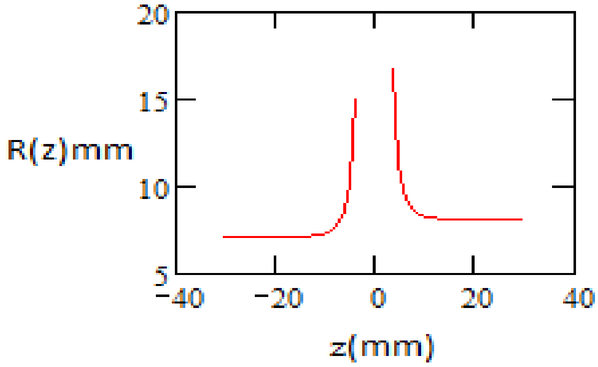

Figure (3): The pole piece shape for magnetic deflector with field distribution of Grivet-Lenz model.

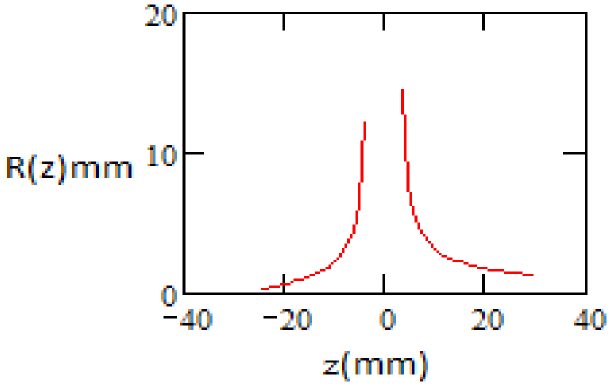

Figure (4): The pole piece shape for magnetic deflector with field distribution of exponential model.

The field distribution of Glaser's Bell-shaped model is used and the deflection flux density is found and both the radial and spiral distortion aberration coefficients are computed and the results are shown in figure (5) as a function of excitation parameter.

The relation between the radial and spiral distortion coefficient remains constant at law value of excitation parameter $NI/(V_r)^{0.5}$ and approach to zero, then in the region of excitation parameter greater than 7 amp. turn / $(volt)^{0.5}$ the radial distortion increases and spiral distortion decrease as the excitation parameter increase higher than 7 amp. turn / $(volt)^{0.5}$.

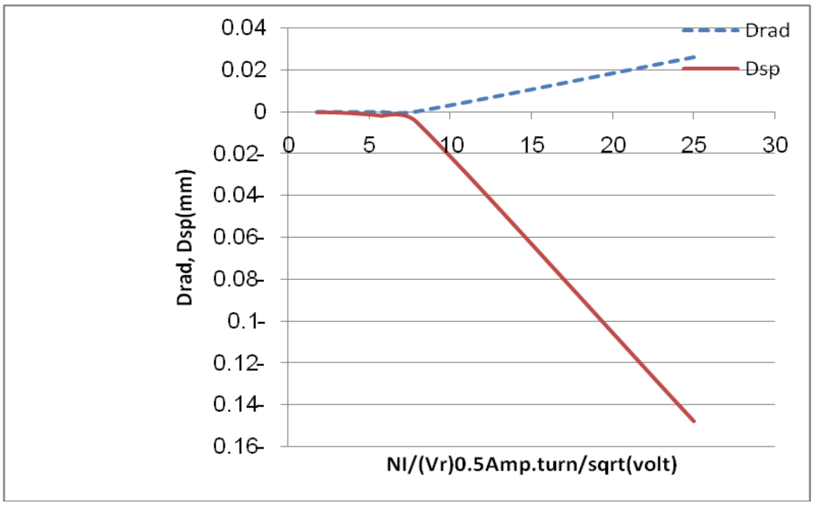

Figure (5):The radial and spiral distortion for magnetic deflector with the field distribution of Glaser′s Bell-shaped model.

The results of the field distribution of Grivet -Lenz model shows that the radial and spiral distortion aberration coefficients having the same behavior of the Glaser´s-bell shape model at low values of excitation parameter, but the spiral distortion aberration coefficient has the opposite behavior to that of Glaser´s-bell shape model, where the values of spiral distortion aberration coefficient is increasing with excitation parameter increases. While the values of the radial distortion aberration coefficient has the same behavior at the whole range of excitation parameter value as shown in figure(6).

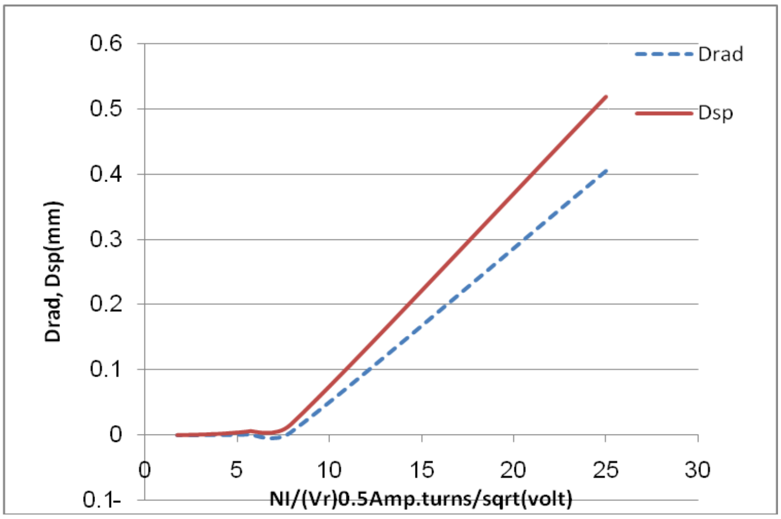

Figure (6):The radial and spiral distortion for magnetic deflector with the field distribution of Grivet -Lenz model**.**

The results of calculation of the calculations of the radial and spiral distortion aberration coefficients for the exponential distribution model as a function of excitation parameter are shown in figure (7). The radial and spiral distortion aberration coefficients having the same behavior of the Glaser´s-bell shape model which are remains constant at law value of excitation parameter NI/$(V_r)^{0.5}$ and approach to zero, then in the region of excitation greater than 7 amp. turn / $(\text{volt})^{0.5}$the radial distortion increases and spiral distortion decrease as the excitation parameter increase higher . than 7amp. turn / $(volt)^{0.5}$

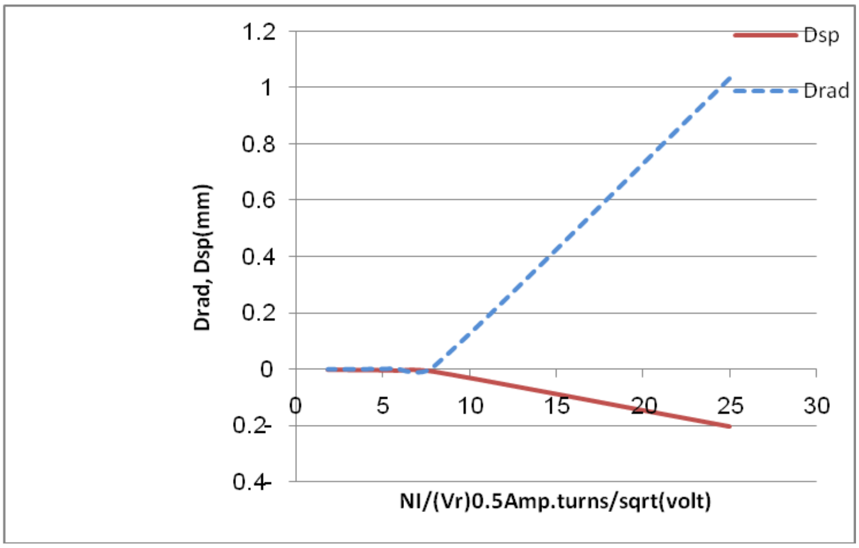

Figure (7):The radial and spiral distortion for magnetic deflector with the field distribution of the exponential distribution model.

The comparisons of the three models for spiral and radial distribution aberration coefficients are shown in figure (8) and (9) respectively. It is clear that at lower values of excitation parameter the value of radial and spiral distortion aberration coefficients are constant and reach to zero for all models.

The values of spiral distortion aberration coefficient for Grivet-lenz model increase with excitation parameter while the value for Bell-shape and Exponential models decreases and have negative values at excitation parameter greater than 7 amp. turn / $(volt)^{0.5}$the as shown in figure (8). In this case the deflector which design using this model can be used as corrector of spiral distortion aberration coefficient in the other optical systems. At excitation parameter higher than 7 amp. turn / $(volt)^{0.5}$, the radial distortion aberration coefficient for exponential model rises rather rapidly relative to the radial distortion aberration coefficient of Grivet-Lenz and Glaser′s-Bell model as shown in figure (9). The Glaser´s-bell shape model gives the best result for radial distortion aberration coefficient at the whole range of excitation parameters, while the values for both Grivet-Lenz and exponential models are increasing with excitation parameter increases at the values of exaction parameter greater than 7 amp. turn / $(volt)^{0.5}$.

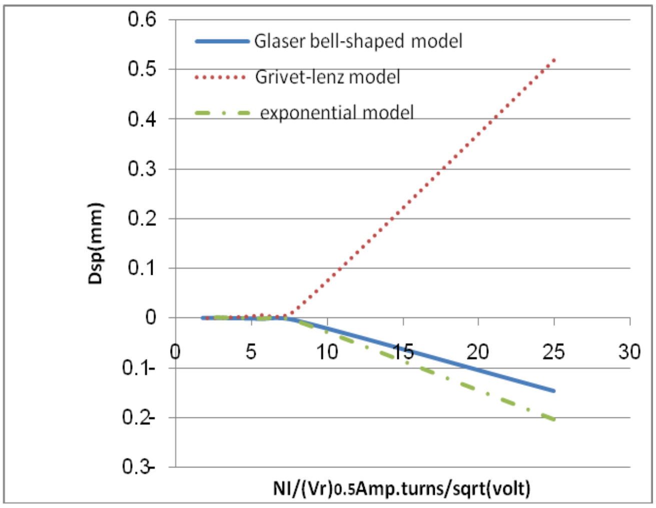

Figure (8): The spiral distortion for three models of field distribution of magnetic deflector.

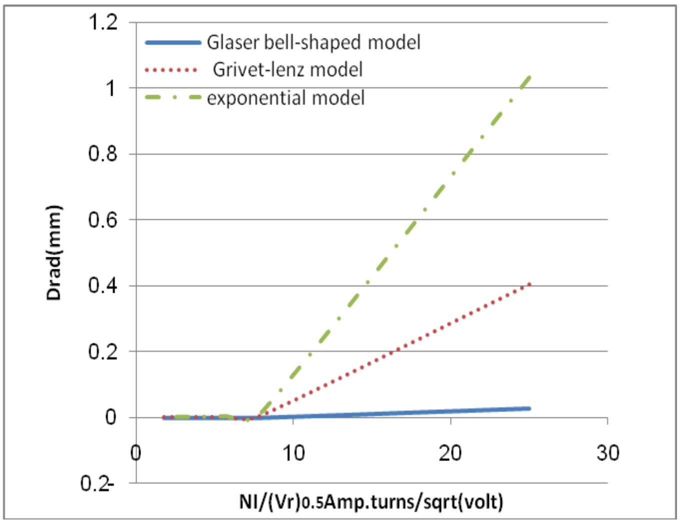

Figure (9): The radial distortion for three models of field distribution of magnetic deflector.

Conclusions:

1. It appears from the present work that it is possible to use any one of these results to find an optical system without any radial and spiral distortion aberration coefficient at the lower values. of the excitation parameter.
2. The designer can use the bell-shape and exponential models to design the corrector for the distortion aberration coefficient in the optical systems which contain this type of aberration values of aberration coefficients.
3. The calculations show that the bell-shape model gives the best results of radial and spiral distortion aberration coefficients at the same time.

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التصميم الامثل لمعاملات زيغي التشويه الشعاعي والتشويه الحلزوني للحارف المغناطيسي

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الخلاصة:

تم ايجاد التصميم الامثل للحارف المغناطيسي الذي يعطي اقل قيم لمعاملات زيغي التشويه الشعاعي والتشويه الحلزوني. ان حسابات الامثلية اجريت باستخدام ثلاث نماذج مختلفة هي أنموذج جرس كلازر (Glaser bell) وأنموذج (Grivet-Lenz) والأنموذج الأسي (exponential distribution) . بأستخدام التوزيع المحوري الأمثل للمجال تم ايجاد أشكال الأقطاب التي تمثل هذه التوزيعات بأستخدام طريقة أعادة التركيب. ان الحسابات بينت أن نتائج الثلاث نماذج تتطابق عند قيم التهيج الواطئة التي تقترب من الصفر. وبصورة عامه فأن أنموذج Glaser bell يعطي النتائج الأفضل لمعظم مدى معاملات التهيج موضع البحث. أن القيم السالبة لزيغ التشويه الحلزوني التي ظهرت بالنتائج يمكن استخدامها كمصحح للأنظمة البصرية الأخرى التي تعاني من هذا النوع من التشويه.