INVESTIGATION FOR THE PROJECTIVE PROPERTIES OF THE SYMMETRIC THE TAPERD CYLINDRICAL DOUBLE POLE PIECE MAGNETIC LENS

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Abstract

The Finite Element Method (FEM) has been used for investigation of design a symmetrical lenses with double tapered cylindrical polepieces. The axial magnetic flux density distribution has been calculated for a bore size of the polepiece at different values of air gap and for different bore diameters . The data of the axial magnetic flux density distribution have been used in computing the projector focal properties. The importance of this work lies in the possibility of designing symmetrical electron lenses with double tapered cylindrical pole pieces used as an projector lens with lowest distortions in transmission electron microscope (TEM)and scanning transmission electron microscope(STEM). In the present work a set of programs wnten by Munro(1975) and Maria(1977) have been used to suggest a new design of magnetic projector lens .Also, the result of the this work are in agood agreement compared with other investigations .

الخلاصة

في دراسة تصميم العدسات (FEM) استخدمت طريقة العناصر المحددة الالكترونية ثنائية القطب الاسطواني الناقص المتناظرة، حيث أمكن منها حساب توزيع كثافة الفيض المغناطيسي المحوري لكل فتحة في قطبي العدسة ولقيم مختلفة من الفجوة الهوائية وقطر الفتحة بين القطبين .لقد استخدمت المعلومات الناتجة من توزيعات كثافة الفيض المغناطيسي المحوري لحساب الخواص البؤرية المسقطة .إن أهمية هذا البحث تكمن في إمكانية تصميم عدسات الكترونية متناظرة ثنائية القطب الاسطواني الناقص والماسح (TEM)تعمل كعدسة مسقطة بأقل تشويه ممكن في المجهر الالكتروني النفاذ . والذي عالجه بحثنا الحالي حيث صممت هذه العدسة وفق برامج (STEM)النفاذ Munro(1975) و Maria(1977) وكانت النتائج جيدة توافق جيد مع الدراسات الأخرى .

1.Introduction

In the field of electron and ion optics ,there are two different optimization approaches namely, analysis and synthesis. A computational study has been carried out to describe the optimization for the symmetrical double pole piece magnetic lenses, under the absence of magnetic saturation by analysis. the analysis approach is based on trial and error . where, designer

starts with a certain set of given electrodes and polepiece and tries to improve their performance by analyzing the optical properties and vary the geometrical dimensions as well as the electric and magnetic parameters of the system until a set is factory performance is achieved [Szilagyi , 1988] .

It is necessary to reduce the most important defects of projective magnetic electron lenses namely, spiral and radial distortion . The radial and spiral distortion coefficients can be calculated with the aid of the following formula [Marai,1977] .

$$\mathbf{D}_r = \frac{3}{8f_p^2} + \frac{e}{16m\mathbf{V}_r}\int_{-\infty}^{\infty}\left[B_z'^2 + \frac{3}{8}\frac{e}{m\mathbf{V}_r}\mathbf{B}_\mathbf{z}^4 - \mathbf{B}_\mathbf{z}^2\left(\frac{r'_\alpha}{r_\alpha}\right)\right] r_\alpha^3 r_\gamma \, dz \text{ ....} \quad (1)$$

$$\mathbf{D}_S = \frac{1}{16\mathbf{V}_r}\left(\frac{2e}{m\mathbf{V}_r}\right)^{\frac{1}{2}}\int_{-\infty}^{\infty} B_z \left[\frac{3}{8}\frac{e}{m}B_z^2 + \mathbf{V}_r\left(\frac{r'_\alpha}{r_\alpha}\right)^2\right] r_\alpha^2 dz \text{ ....} \quad (2)$$

where Dr and Ds are the radial and spiral distortion coefficients respectively , fp is the the projective focal length , V_r is the relativistically corrected accelerating voltage , B_z is the axial flux density distribution , r_α and r_γ are the independent solutions of the paraxial-ray equation , B'_Z is first derivative of the axial flux density distribution , e and m are the charge and mass of the electron .
There are several attempts to reduce the spiral and radial distortion of the projective magnetic lenses.
[Al-Nakeshli , 1986] , [Lencova,1999] , [Al-Obaidi et. al,2001] , [Al-Batat,2001] , [Al–SaadyA.k.et al , 2004] , [Chalab.2009] ,
Al-Bahrani [2004], has been studied four symmetrical double pole piece magnetic lenses. The pole piece of different geometries, namely; the cylindrical ,the tapered cylindrical, spherical and the tapered spherical and developed by Chalab [2009] to deals with the optical properties of the tapered cylindrical and the tapered spherical pole piece magnetic lenses that proposed and compared with that of a conical pole piece magnetic lenses that proposed by Munro [1975] . The importance of this work lies in the possibility of designing symmetrical electron lenses with double tapered cylindrical pole pieces used as an projector lens with lowest distortions in transmission electron microscope(TEM) .

2-Test lens

In the present work, the test lens of the symmetrical tapered cylindrical double polepiece magnetic lens is shown in figure (1). The axial bore diameter (D_1=D_2=10mm), air-gap width (S=10mm) and lens excitation(NI=500 A.t). In this work, the most important properties the spiral and radial distortions .have been investigated in details .

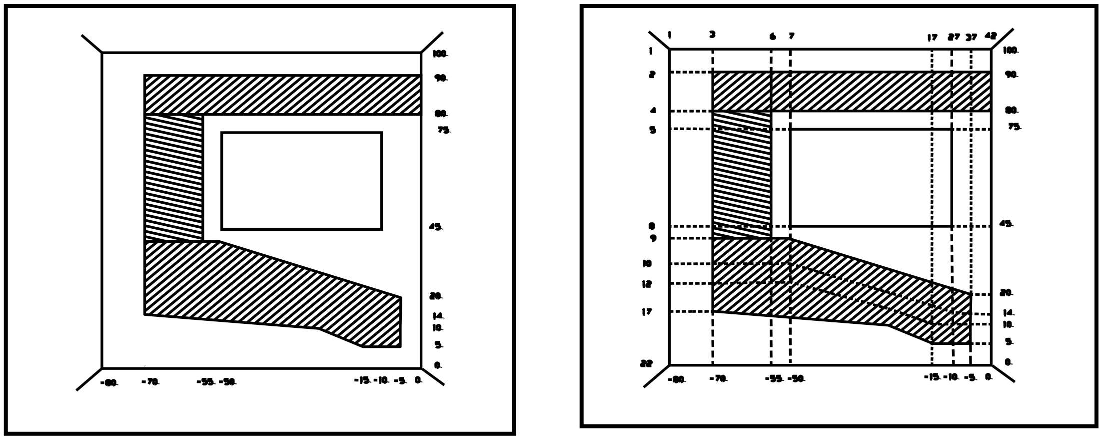

Figure (1): The left higher quarter with symmetrical the tapered cylindrical double pole piece magnetic lenses **. [Al-Bahrani, 2004].**

3- Results and Discussion

In order to study magnetic flux density distribution and the projective focal properties for example the projective focal length, spiral distortion coefficient, radial quality factor, spiral distortion coefficient and spiral quality factor as a function for excitation parameter for different parameters. In the present work, the symmetrical double pole piece magnetic lenses: conical and the tapered cylindrical have been studied under the effect of different optimization parameters.

3-1 The tapered cylindrical polepiece

3-1 -A Influence of air-gap width

1 - The axial flux density distribution Bz

The axial magnetic flux density distribution B_z along the optical axis z are plotted in figure (2) for different values of air-gap, where five values of air-gap have been chosen ranging from 6mm to 14mm, when the axial bore diameter and the lens excitation were kept constant at D = 10mm and NI = 500 A. t.

It is clear that for small values of air-gap width field distribution has a large peak magnetic flux value.

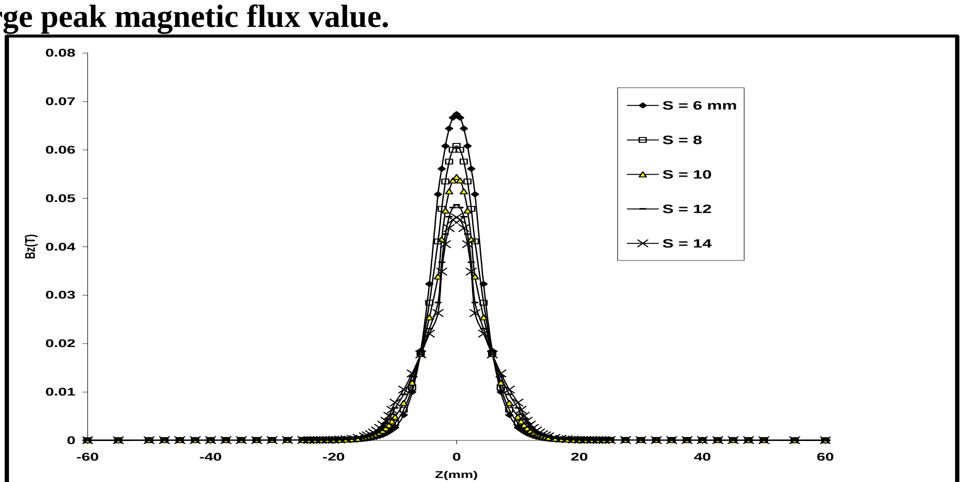

Figure (2): The axial magnetic flux density distributions for different values of

S at D= 10 mm , NI=500 A.t , for the tapered cylindrical polepiece

2- The projective focal length fp

Figure (3) shows the varying of the projective focal length as a function of the air-gap S. It is clear that as long as S decreases the properties become raising better. This means that, a magnetic lens of small projective focal length f_p can be designed when the air gap chosen to be smaller.

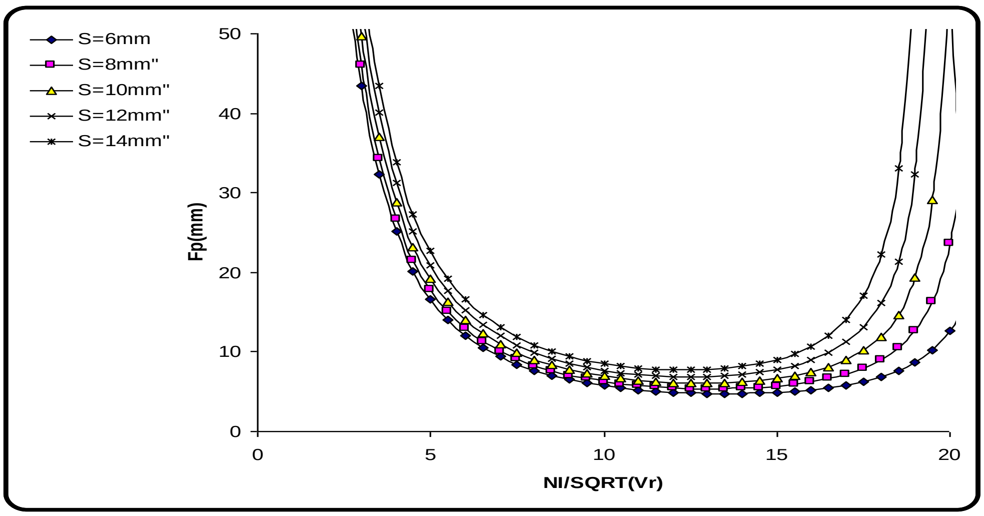

Figure (3): The projective focal length (fp) for different values of the air-gap at D= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

3 - The distortion coefficient

The spiral distortion coefficient and its corresponding the spiral quality factor versus the excitation parameter are plotted in figures (4) and (5) respectively . The radial distortion coefficient and its corresponding the radial quality factor versus the excitation parameter are plotted in figures (6) and (7) respectively .Where

figure (4) shows the decreasing of air-gap width s affected the spiral distortion coefficient Ds . for all values of S = 6 mm to 14 mm . Should be noted that ,the spiral distortion coefficient D_s improves as the air gap width increases. Also for all values of the air gap width S , the values of the quality factor Qs are chose to unity as shown in figure (5) which is the accepted value.

The radial distortion coefficient and the radial quality factor are plotted in figures (6) and (7) respectively for different values of air-gap.

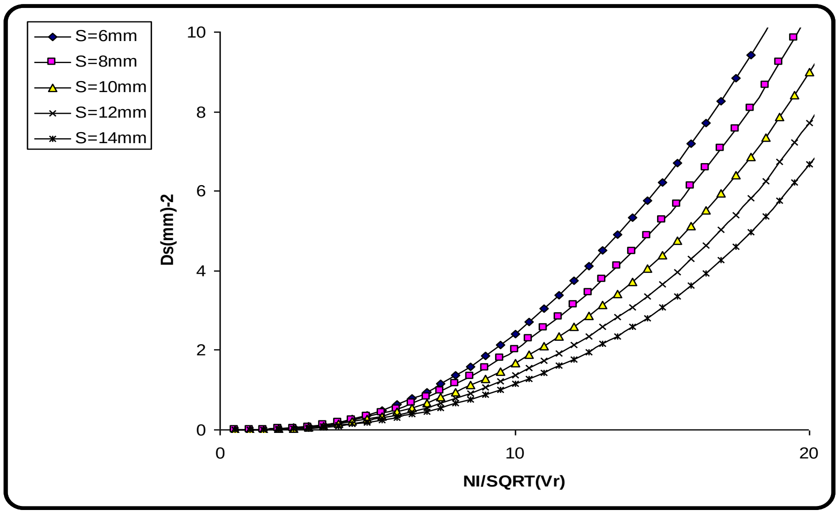

Figure (4): The spiral distortion coefficient (Ds) for different values of the air-gap at D= 10(mm) , NI=500(A.t), for the tapered cylindrical pole piece

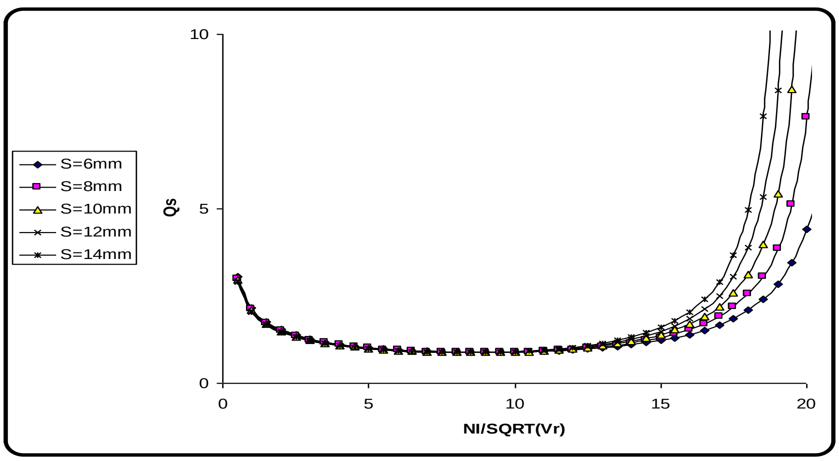

Figure (5): The spiral quality factor (Qs) for different values of the air-gap at D= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

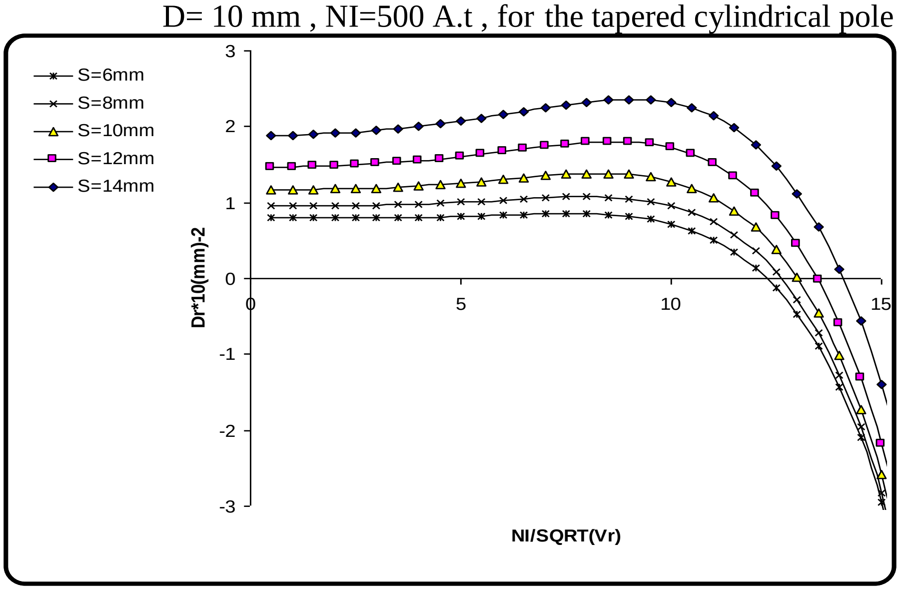

Figure (6): The radial distortion coefficient(Dr) for different values of the air-gap at D= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

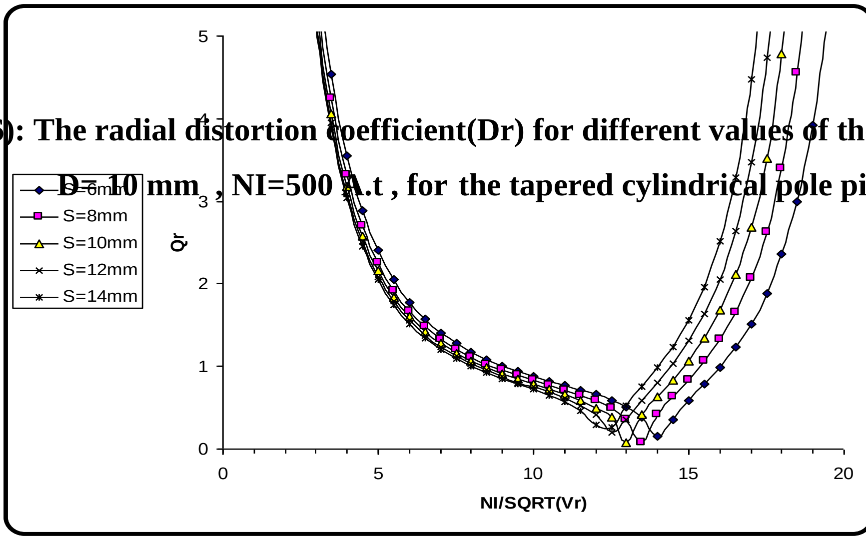

Figure (7): The radial quality factor (Qs)for different values of the air-gap at D= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

3-1-B Influence of axial bore diameter

1 - The axial flux density distribution Bz

The effect of axial bore diameter D on the axial field distribution and the projector focal properties has been investigated for chosen values D=(6,8,10,12,14) mm keeping the other parameters constant S=10mm and NI =500A.t. Figure 8 shows the axial field distribution along the optical axis for different values of the axial bore diameter . One can see that , the field distribution becomes more localized as the bore diameter D decrease, accordingly , the peck value of a field generated for small D value becomes greater then that for large D value .

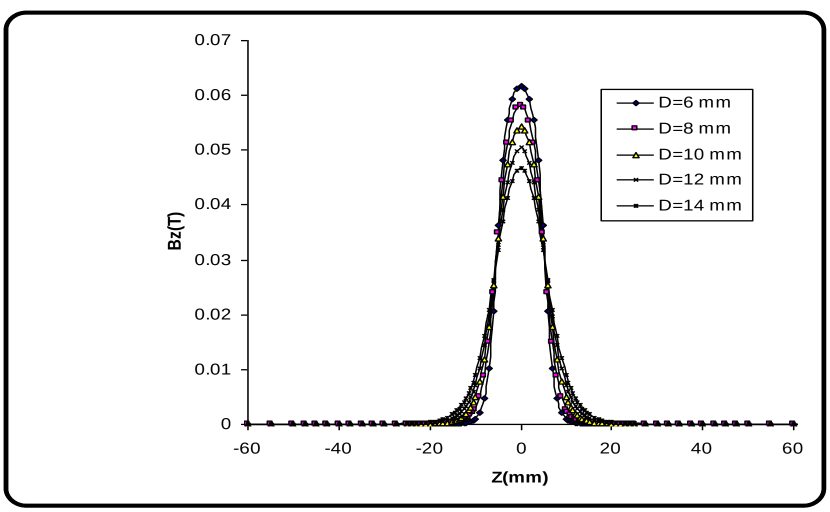

Figure (8): The axial magnetic flux density distributions for different values of the D at S= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

2 - The projective focal length (fp)

Figure 9 shows the variation of the projector focal length a function of the excitation parameter for deferent values of D . It can be seen that magnification for the lens of small D value greater then that for large D since the projector focal length f_p is small for smaller D value .

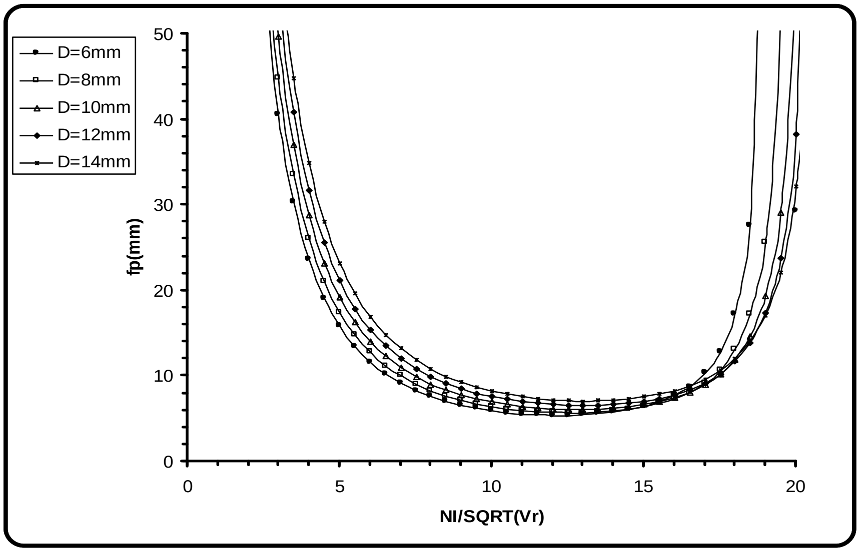

Figure (9): The projector focal length for different values of the D at S= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

3 - The distortion coefficient

The spiral distortion coefficient and its corresponding the spiral quality factor versus the excitation parameter are plotted in figures (10) and (11) respectively . The radial distortion coefficient and its corresponding the radial quality factor versus the excitation parameter are plotted in figures (12) and (13) respectively .Where figure (10) shows the decreasing of the axial bore diameter D affected the spiral distortion coefficient D_s . for all values of D = 6 mm to 14 mm.Should be noted that ,the spiral distortion coefficient Ds improves as the axial bore diameter D increases. Also for all values of the axial bore diameter D , the values of the quality factor Q_s are chose to unity as shown in figure (11) which is the accepted value.

The radial distortion coefficient and the radial quality factor are plotted in figures (12) and (13) respectively for different values of the axial bore diameter D .

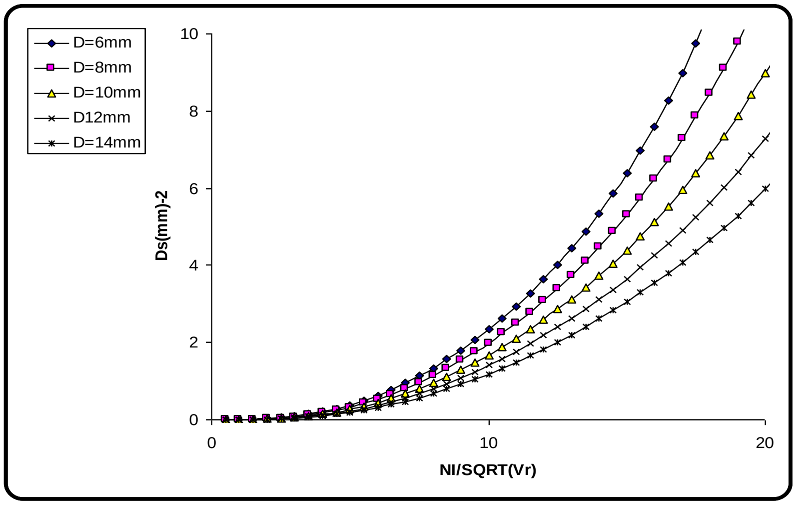

Figure (10): The spiral distortion coefficient Ds for different values of the D at S= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

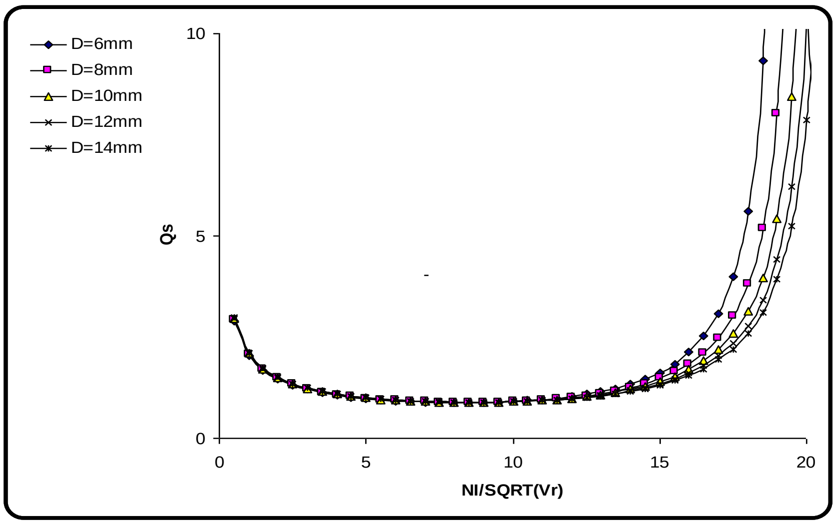

Figure (11): The spiral quality factor Qs for different values of the D at S= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

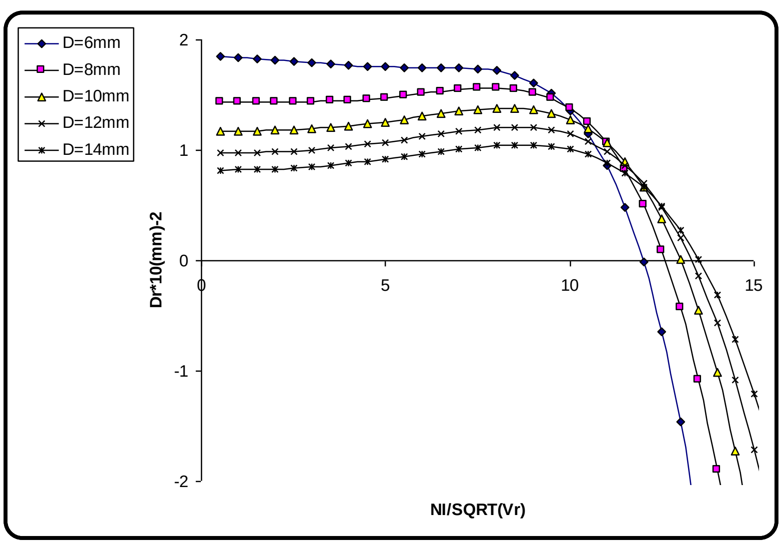

Figure (1 ... the D at S=

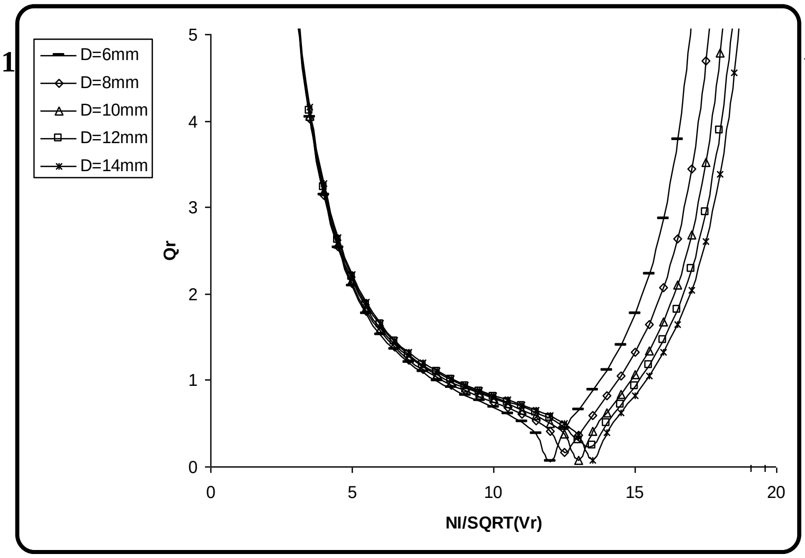

Figure (13): The radial quality factor Qr for different values of the D at S= 10 mm , NI=500 A.t , for the tapered cylindrical pole piece

Table (1) shows the effect of air-gap width (S) on maximum flux density distribution value (Bmax) and projective focal properties for test lens at excitation parameter $NI/V_r^{\frac{1}{2}}$ = 20 A.t. . It is noted that when the air-gap width increases the maximum flux density value Bmax decreases while projective focal length increases , also for chosen S values the quality factor Q_s and Q_r remain in the accepted values range from the electron optics point of view.

table (2) shows the effect of the axial bore diameter D on maximum flux density distribution value (Bmax) and projective focal properties for test lens at excitation parameter $NI/V_r^{\frac{1}{2}}$ = 20 A.t. . It is noted that when the axial bore diameter increases the maximum flux density value Bmax decreases while projective focal length increases , also for chosen S values the quality factor Q_s and Q_r remain in the accepted values range from the electron optics point of view.

Tables (3) , (4) shown the several parameters for different values of the (s) at D= 10(mm) , NI=500(A.t) and several parameters for different values of the (D) at S = 10(mm) , NI=500(A.t) respectively, for the conical pole piece

Table (1): Several parameters for different values of the (s) at D= 10(mm) , NI=500(A.t), for the tapered cylindrical pole piece

S(MM)	$B_m(T)$ $(NI = 500A.t)$	$(f_p)_{min}$ mm	$NI/V_r^{\frac{1}{2}}$ at $(f_p)_{min}$	$NI/V_r^{\frac{1}{2}}$ at $D_r = 0$	$(Q_r)_{min}$	$(Q_s)_{min}$
6	0.066404	4.92927	12.75	12.9	0.10	0.88
8	0.060225	5.55454	13	13.1	0.11	0.88
10	0.051923	6.10	١٣.٥	١٣.٦٢	0.12	0.88
12	0.03883	6.11933	13.8	13.3	0.25	0.89
14	0.033326	7.75270	13.9	14	0.30	0.89

Table (2): Several parameters for different values of the (D) at S= 10(mm) , NI=500(A.t), for the tapered cylindrical pole piece

D(MM)	$B_m(T)$ $(NI = 500A.t)$	$(f_p)_{min}$ mm	$NI/V_r^{\frac{1}{2}}$ at $(f_p)_{min}$	$NI/V_r^{\frac{1}{2}}$ at $D_r = 0$	$(Q_r)_{min}$	$(Q_s)_{min}$ -
6	0.061644	5.40621	12	11.5	0.06	0.88
8	0.058230	5.68928	12.5	12.5	0.07	0.88
10	0.0544٠٢	6.08551	13	13	0.17	0.88
12	0.0٥٠518	6.55025	13	13.25	0.24	0.88
14	0.046801	7.07805	13.5	1٣.6	0.37	0.89

Table (٣): Several parameters for different values of the (s) at D= 10(mm) , NI=500(A.t), for the conical pole piece

S(MM)	$B_m(T)$ $(NI = 500A.t)$	$(f_p)_{min}$ *mm*	$NI/V_r^{\frac{1}{2}}$ *at* $(f_p)_{min}$	$NI/V_r^{\frac{1}{2}}$ *at* $D_r = 0$	$(Q_r)_{min}$	$(Q_s)_{min}$
6	0.067390	4.74927	12.5	12.4	0.07	0.88
8	0.060808	5.37454	12.5	12.6	0.08	0.88
10	0.0544٠٢	6.08551	13	13.1	0.16	0.88
12	0.048645	6.85933	13	13.3	0.20	0.88
14	0.043651	7.70270	13.5	14	0.27	0.89

Table (٤): Several parameters for different values of the (D) at S= 10(mm) , NI=500(A.t) for the conical pole piece

D(MM)	$B_m(T)$ $(NI = 500A.t)$	$(f_p)_{min}$ *mm*	$NI/V_r^{\frac{1}{2}}$ *at* $(f_p)_{min}$	$NI/V_r^{\frac{1}{2}}$ *at* $D_r = 0$	$(Q_r)_{min}$	$(Q_s)_{min}$
6	0.058885	5.51621	12.6	11.5	0.08	0.88
8	0.055608	5.78928	13.1	12.5	0.09	0.88
10	0.051923	6.10	١٣.٥	١٣.٦٢	0.19	0.88
12	0.048168	6.65025	13.4	13.8	0.26	0.89
14	0.044550	7.47805	13.9	14.1	0.39	0.89

Table (٤): Several parameters for different values of the (D) at S= 10(mm) , NI=500(A.t), for the conical pole piece

4- Conclusions

According to the results of this work it can be said that the tapered cylindrical polepiece can be used to be a polepiece of a projector magnetic lense since their properties are better than those for conical polepiece . Also one can conclude that the manufactured of the tapered cylindrical polepiece is easier from that of conical polepiece.

5- References:

****Munro, E. (1975)“ A set of Computer Programs for Calculating the Properties of Electron Lenses”. University of Cambridge, Department of Engineering Report CUED/B-Elect TR45**
****Marai F.Z. (1977),"Electron-Optical Properties of Single-Pole Magnetic Electron Lenses", Ph.D Thesis , Aston Birmingham , England ,U.K .**
**** Al-Nakeshli, I. S. (1986). “Computer Aided-Design of Saturated Magnetic Lenses for Electron Microscopes”. Ph.D. Thesis, University of Aston , Birmingham , England , U.K.**
****Szilagyi M.(1988). "Electron and lon optics "(New York and London: Plenum Press), pp 130-137 .**
****Lencova, B. (1999) "Accurate computation of magnetic lenses with FOFEM " . Nucl . instr.Meth. In Phys . Res. A427 , 329-337**
****Al-obaidi ,H.N. and Drigan,S,J(2001)., “Projective properties of imaging magnetic fields deduced by special function,,., 5th Con. Col. Edu., Al-Mustansiriyah University. pp. 313-325.**
****Al-Batat .A.H. (2001). "A theoretical and computational investigation on magnetic lenses synthesis" Ph.D. Thesis Al-Mutansiriyah university**
**** Al-Saady A.K. Al-obaidi ,H.N. Al-`Shafi’i.T.M (2004) " Investigation magnetic leakage for a symmetrical objective magnetic lenses. J.col. Al-Mustansiriyah,15.4 Baghdad .Iraq (in Arabic)**
****Al-Bahrani. M. R.(2004). ”Computer programs for investigating the properties of Magnetic Electron Lenses” M.Sc. thesis. University of Al-Mustansiriyah, Baghdad .Iraq (in Arabic)**
**** Chalab M . R.(2009) "Effect of pole piece shape on properties of the symmetrical objective magnetic lenses" J. University of Thi-Qar .4.60-78**