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Investigate Effect of Some Geometrical Parameters on Focusing Power and Magnification of Magnetic Lenses

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ABSTRACT

The current investigation concerned with effects of geometrical parameters like bore diameter (D), airgap width (S), and the distance between the center of lens and screen (ℓ) on the focusing power (β_{max}) and magnification (M) of double polepiece projector magnetic lenses by using square top or rectangular field distribution model.

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INTRODUCTION

In 1924, Louis de Broglie first theorized that the electron had wave-like characteristics. Application of the idea of particle – wave dualism for any kind of matter. Hans Busch, in 1926, discovered that magnetic fields could act as lenses by causing electron beams to converge to a focus (electron lens). In 1931, Knoll (inventor of SEM, 1935) and Ruska invented electron microscope and demonstrated electron images.

The definition of magnetic lens based according to the law of magnetism. Thus, when the current passes through windings of coil, leads to produces a magnetic field which exerts a force on a moving charge, such as electron, proton, and ion. Therefore, this field named electron optics or generally called charged particle optics. This means, however, deflecting, forming and focusing flows of charge particles and producing images by means of electron and ions beams.

The current investigation concerned with effects of geometrical parameters on focusing power and magnification of double polepiece projector magnetic lenses by using square top or rectangular field distribution model as shown in figure 1.

The rectangular field model is almost true of the lens in which the airgap width (S) very large compared with the bore diameter (D). This model is a simple mathematical model. It is a traditional model leads to relationships represent the real properties of the magnetic double polepiece lenses in well acceptance (Fert and Durandeau, 1967).

The function f(z) for a rectangular field model of proposed lens is represented in the following form:

$$f(z) = f(z)_{max} \qquad \text{when } -z_{L'} \le z \le z_{L'} \qquad (1)$$

or ;

$$B(z) = B_{max} \qquad \text{when } -z_{L'} \le z \le z_{L'} \qquad (2)$$

At points when $|z| > z_{L'}$ the function B(z) = 0, where $z_{L'}$ equal to L'/2 , L' is the effective length, B(z) or B_z is the axial magnetic flux density, and B_{max} is the maximum flux density.

2. Theory:

The properties of the final projector lens in an electron microscope column are very important. Usually the accelerated electron beam enters the final projector lens parallel to the optical axis.

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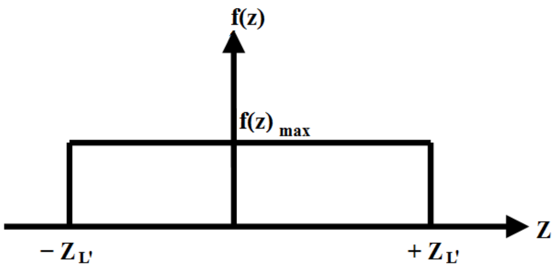

Fig. 1: The square top or rectangular field distribution model.

The difficulty of measuring the distribution of the axial magnetic field in order to accurately determine the properties of any lens, researchers hypothesized equivalent coil method (Fert and Durandeau, 1967), where it compensates for axial magnetic field between the lens poles of the bore diameter D, and airgap width S with approximate axial magnetic field of the straight coil has d length, diameter (2/3 D), and the same value of the excitation parameter NI (A.turns) as shown in figure 2.

The benefit of this hypothesis that the distribution of the axial magnetic flux density for long and slight coil be known as the alternative field would be a rectangle its area B_{max} L equivalent to the area of real field $\int_{-\infty}^{+\infty} B_z dz$, which has the same maximum value of the axial magnetic flux density B_{max} and width amount of L.

$$LB_{max} = \int_{-\infty}^{+\infty} B_z dz \quad \text{or} \; ; \quad L = \frac{1}{B_{max}} \int_{-\infty}^{+\infty} B_z dz \tag{3}$$

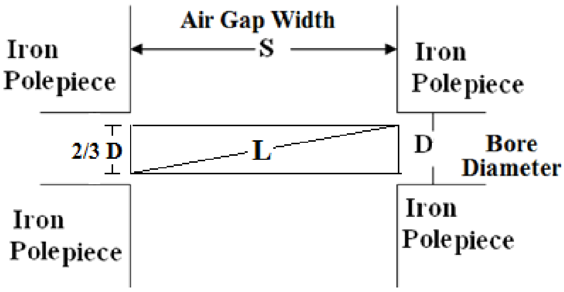

Fig. 2: The equivalent coil.

As the L represents the geometrical constant which is related with a half width W (where W = 2 a , and a is the half of half width) of the field distribution of real- axial magnetic flux density, with the relation (Hawkes, 1970);

$$W = 2a = 0.97\,L \tag{4}$$

And the relationship of the geometrical constant L with airgap width S and bore diameter D is given by the following form;

$$L = (S^2 + 0.45\,D^2)^{1/2} \tag{5}$$

It is worth mentioning that the geometrical constant L has to do with the minimum projector focal length $(F_p)_{min}$ for all symmetric double polepiece lenses as the relation (Dugas *et al*., 1961):

$$(F_p)_{min} = 0.5\,(S^2 + 0.45\,D^2)^{1/2} = 0.5\,L \tag{6}$$

The most important electron optical properties of the final projector lens in an electron microscope are its shorter focal lengths. The final projector lens is usually operated in the region of the minimum projector focal length for obtained a maximum image of the magnification (Al-Abdullah, 2006).

If the bore diameters for both lens poles are equal (D_1=D_2=D), then the magnetic field of this lens to be symmetric and the lens named symmetric as shown in figure 3.a. While when the bore diameters for both lens poles are unequal ($D_1 \neq D_2$), then became asymmetric and the lens called asymmetric lens, as shown in figure 3.b.

The symmetric lenses have a symmetric magnetic field shape and trapped in the airgap, where the maximum value of the magnetic flux density (B_{max}) lie in the middle of the airgap between the poles. The optical properties of asymmetric lens are differ from the symmetric lens due to differ the distributions of the magnetic fields, where the magnetic field loses its symmetry when it is not equally the bore diameter of its poles (one of the reasons).

The maximum value of magnetic flux density (B_{max}) of a rectangular field model represented by the equation (Dugas *et al*., 1961);

$$B_{max} = \mu_0\, NI / L \tag{7}$$

where μ_0 the magnetic permeability in space and equal to $4\pi \times 10^{-7}$ H/m, and NI is the ampere-turns which is generate the magnetic field.

The previous equations (include D) also applicable on the asymmetric double polepiece magnetic lenses so as in the symmetric double polepiece lens, when substitute the mean diameter D_m for both bores in lens polepieces $D_m = (D_1 + D_2) / 2$ instead of bore diameter D.

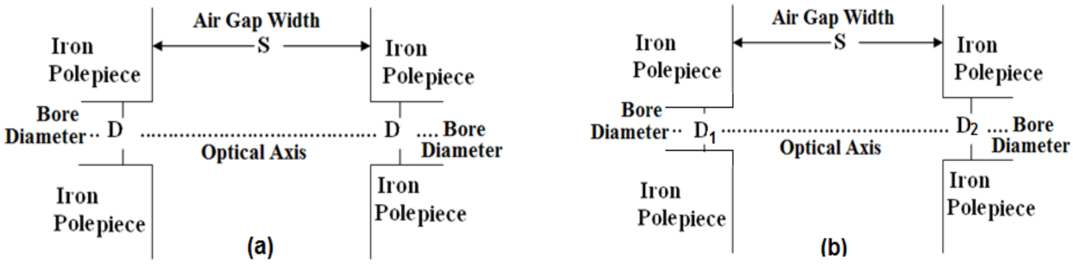

Fig. 3: The (a) symmetric, and (b) asymmetric double polepiece magnetic lens.

The magnification depending on angular size of the object and image. In any optical system the ratio between the transverse dimension of the final image and the corresponding dimension of the original object is called the magnification (Al–Zubaidy, 2007). That's mean linear magnification M, relates the size of the image to the size of the object, or the linear magnification is given simply by the ratio of the final r_2 to the initial beam diameter (angular size) r_1 in the radial axis ($M = r_2 / r_1 = r_{image} / r_{object}$) (Sise *et al*., 2007, and Sise *et al*., 2008).

The magnification is increased as smaller areas on the specimen are scanned. It is easy to increase the magnification until empty magnification is reached. Empty magnification is when enlarging an image will no longer add any new information. Therefore, magnification is related to resolution because resolution must be improved as magnification increases (Dunlap and Adaskaveg, 1997).

The magnification of proposed lens model can evaluate from the equation (Juma, 1975);

$$M = [\ell - (F_p)_{min}] / (F_p)_{min} \quad (8)$$

where ℓ is the distance between the lens and screen.

The focusing power β in general is the reciprocal of focal length F, i.e. $\beta = 1/F$ (Egerton, 2005), and in current study can take the form;

$$\beta_{max} = 1/(F_p)_{min} \quad (9)$$

Electron wavelength depends on the momentum or kinetic energy of each particle, so if the electrons have a spread in kinetic energy, one might expect a variation in focusing power of a magnetic lens. As in the case of spherical aberration, chromatic defects cannot be eliminated through lens design but can be minimized by making the lens as strong as possible; i.e. large focusing power and small focal length (Abd-Alsied, 2010).

The focusing power of electrostatic lenses independent of the mass of the charged particles and depends only on their energy; they are therefore to be preferred over magnetic lenses when heavy particles of moderate energy must be focused (Hussein *et al*., 2011).

RESULTS AND DISCUSSION

The current study investigate two cases;

3.1 The effects of airgap width:

The effects of varying values of airgap width S = 2, 4, 6, 8, and 10 mm on the focusing power and magnification depending on a numerous values of distance between the lens and screen ℓ = 30, 45, 60, 75, and 90 mm. In addition to take D = 2 mm and NI=1000 A.turns as constants.

The results depending on computations achieved from above equations (presence in theory part), are arranged in table 1.

The maximum flux density B_{max}, minimum projector focal length $(F_p)_{min}$, geometrical constant L, and half width of magnetic field W are plotted as a function of airgap width S, as shown in figure 4. From this figure the one can note the linear increasing in $(F_p)_{min}$, W, and L while there is an exponent decreasing in B_{max} with increasing S.

Figure 5 shows the exponent decreasing for focusing power with increasing S.

Plotting the lens magnification M as a function of S for various values of ℓ shown in figure 6, leads to conclusion there is an exponent decreasing with increasing S and take the same behavior for all magnification curves where obtain high value of M in high ℓ and low S as shown in figure 7.

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Table 1: The resultant effects of varying airgap width on the focusing power and lens magnification.

S (mm)	L (mm)	B_{max} x 10^{-4} (T)	W (mm)	$(F_p)_{min}$ (m)		β_{max} (m^{-1})
2	2.40823	5.2179	2.33598	0.0120411		83.04889
4	4.219	2.97852	4.09243	0.021095		47.4046
6	6.14817	2.04392	5.96372	0.0307408		32.53005
8	8.11172	1.54916	7.86836	0.0405586		24.65568
10	10.0896	1.24547	9.78691	0.050448		19.82239
S (mm)	$(F_p)_{min}$ (mm)	ℓ = 30 mm	ℓ = 45 mm	ℓ = 60 mm	ℓ = 75 mm	ℓ = 90 mm
		M_{30}	M_{45}	M_{60}	M_{75}	M_{90}
2	1.20411	23.91466	36.372	48.82933	61.28666	73.744
4	2.1095	13.22138	20.33207	27.44275	34.55344	41.66413
6	3.07408	8.75901	13.63852	18.51803	23.39754	28.27705
8	4.05586	6.3967	10.09505	13.79341	17.49176	21.19011
10	5.0448	4.94671	7.92007	10.89343	13.86679	16.84015

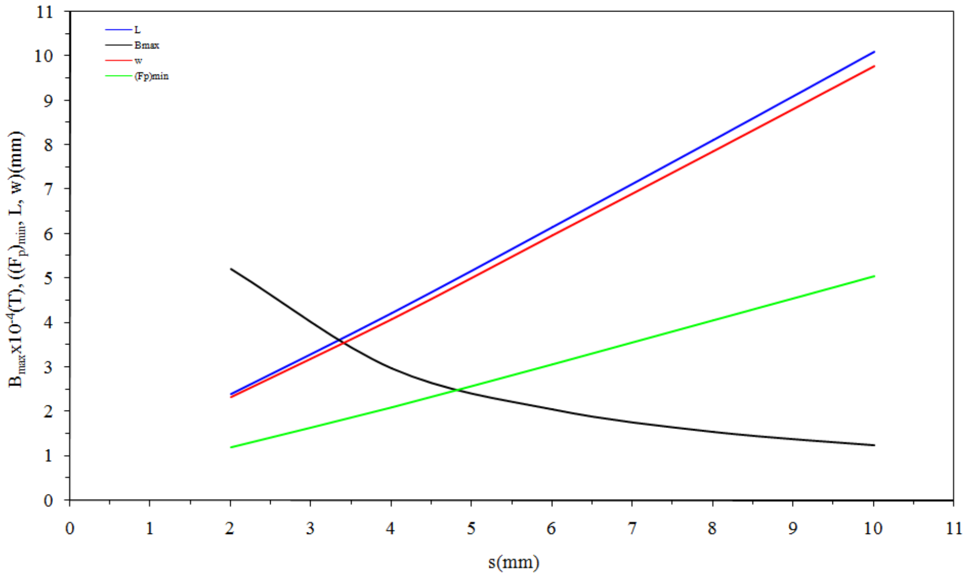

Fig. 4: The optical and geometrical parameters B_{max} , $(F_p)_{min}$, L , and W as a function of airgap width S.

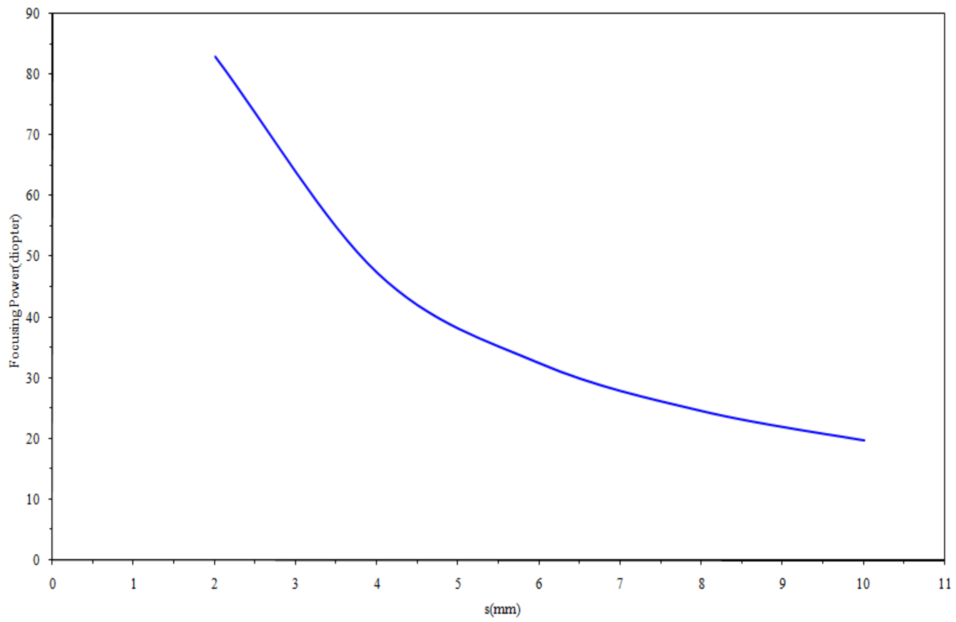

Fig. 5: The focusing power as a function of airgap width S.

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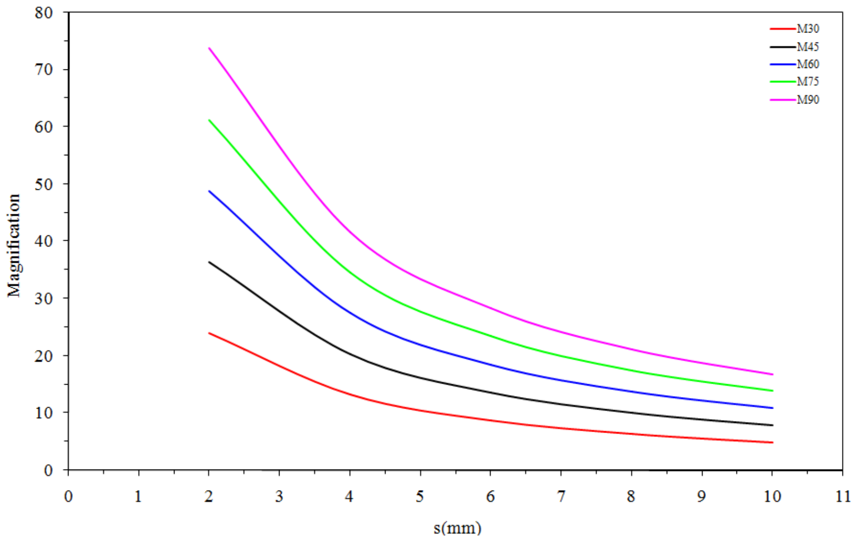

Fig. 6: The lens magnification M as a function of airgap width S for various values of ℓ.

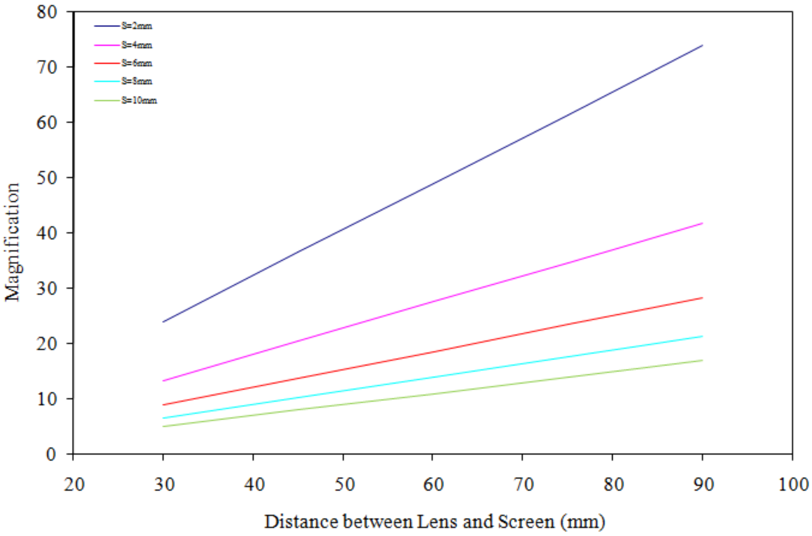

Fig. 7: The lens magnification M as a function of the distance between lens and screen ℓ for various values of airgap width S.

3.2 The effects of bore diameter:

The effects of varying values of bore diameter D = 1, 3, 5, 7, and 9 mm on the focusing power and magnification depending on a numerous values of distance between the lens and screen ℓ = 30, 45, 60, 75, and 90 mm. In addition to take S = 3 mm and NI = 1000 A.turns as constants.

The results depending on computations achieved from above equations (presence in theory part), are arranged in table 2.

Table 2: The resultant effects of varying bore diameter on the focusing power and lens magnification.

D (mm)	L (mm)	$B_{max} \times 10^{-4}$ (T)	W (mm)	$(F_p)_{min}$ (m)		β_{max} (m^{-1})
1	3.07408	4.08784	2.98186	0.0153704		65.06
3	3.61247	3.47861	3.5041	0.0180624		55.36362
5	4.5	2.79252	4.365	0.0225		44.44444
7	5.57225	2.25517	5.40508	0.0278612		35.89212
9	6.74166	1.86398	6.53941	0.0337083		29.66627
D (mm)	$(F_p)_{min}$ (mm)	ℓ = 30 mm	ℓ = 45 mm	ℓ = 60 mm	ℓ = 75 mm	ℓ = 90 mm
		M_{30}	M_{45}	M_{60}	M_{75}	M_{90}
1	1.53704	18.518	28.277	38.036	47.795	57.554
3	1.80624	15.60908	23.91363	32.21817	40.52272	48.82726
5	2.25	12.33333	19	25.66666	32.33333	39
7	2.78612	9.76763	15.15145	20.53527	25.91909	31.30291
9	3.37083	7.89988	12.34982	16.79976	21.2497	25.69965

The maximum flux density B_{max} , minimum projector focal length $(F_p)_{min}$, geometrical constant L, and half width of magnetic field W are plotted as a function of bore diameter D , as shown in figure 8. From this figure the one can note the exponent increasing in $(F_p)_{min}$, W, and L with increasing D. While there is a decreasing in B_{max} with increasing D.

Figure 9 shows the decreasing of focusing power happened with increasing the bore diameter D.

Plotting the lens magnification M as a function of D for various values of ℓ shown in figure 10, leads to conclusion there is a decreasing of M with increasing D and take the same behavior for all magnification curves where obtain high value of M in high ℓ and low D as shown in figure 11.

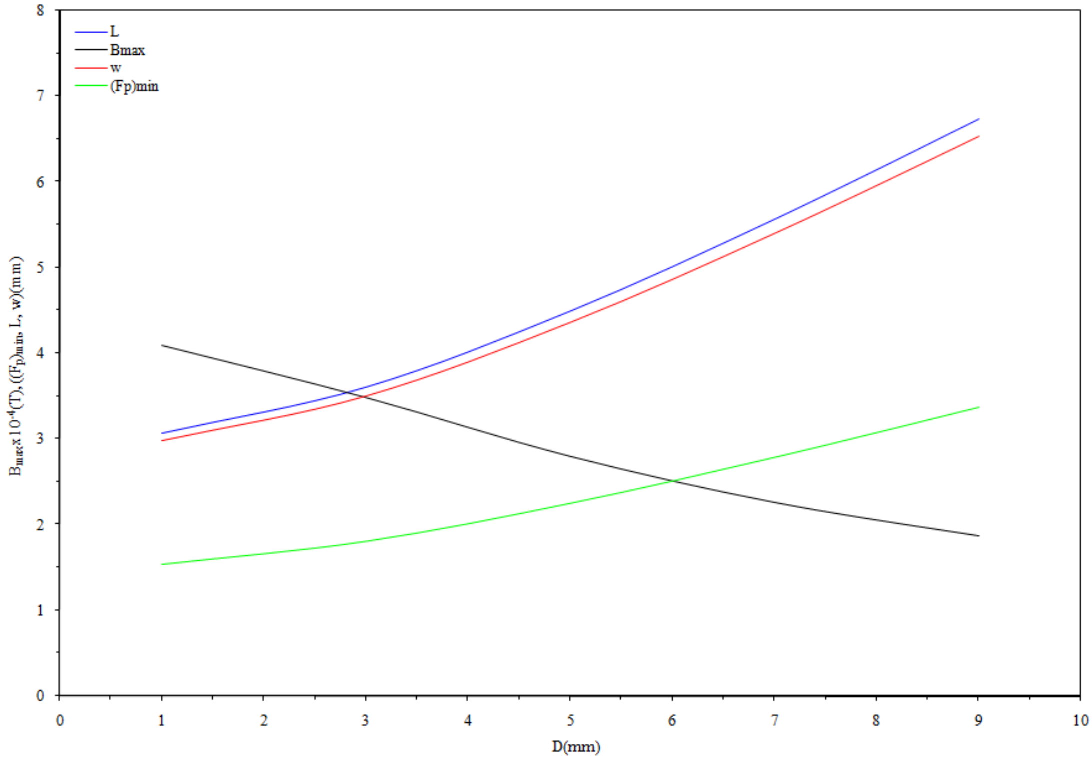

Fig. 8: The optical and geometrical parameters B_{max} , $(F_p)_{min}$, L , and W as a function of bore diameter D.

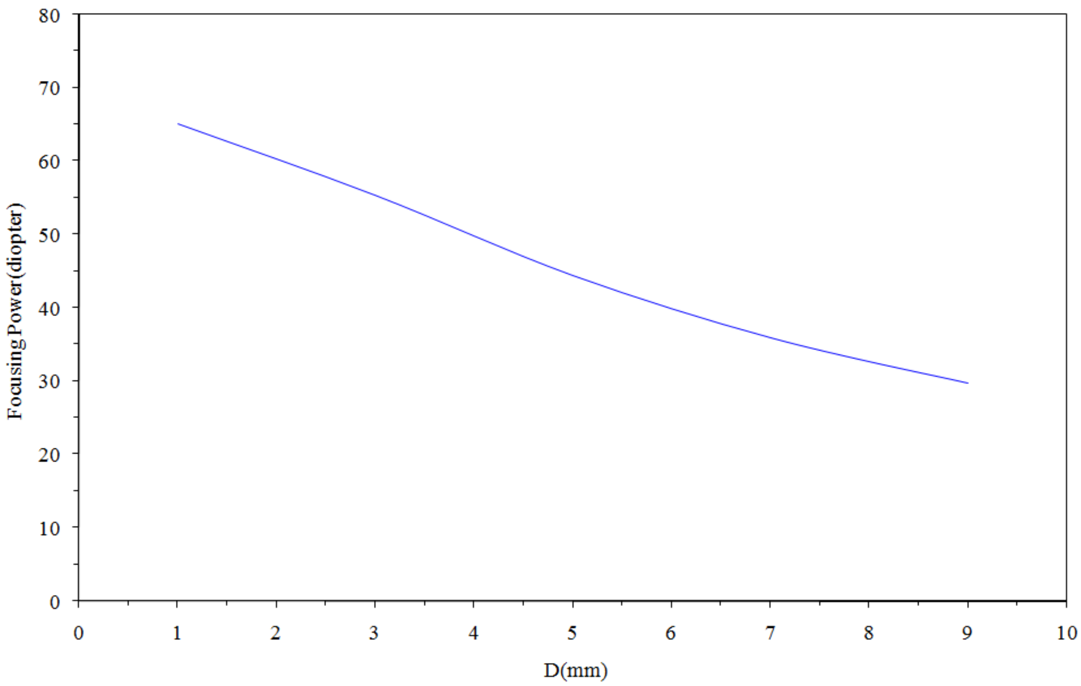

Fig. 9: The focusing power as a function of bore diameter D.

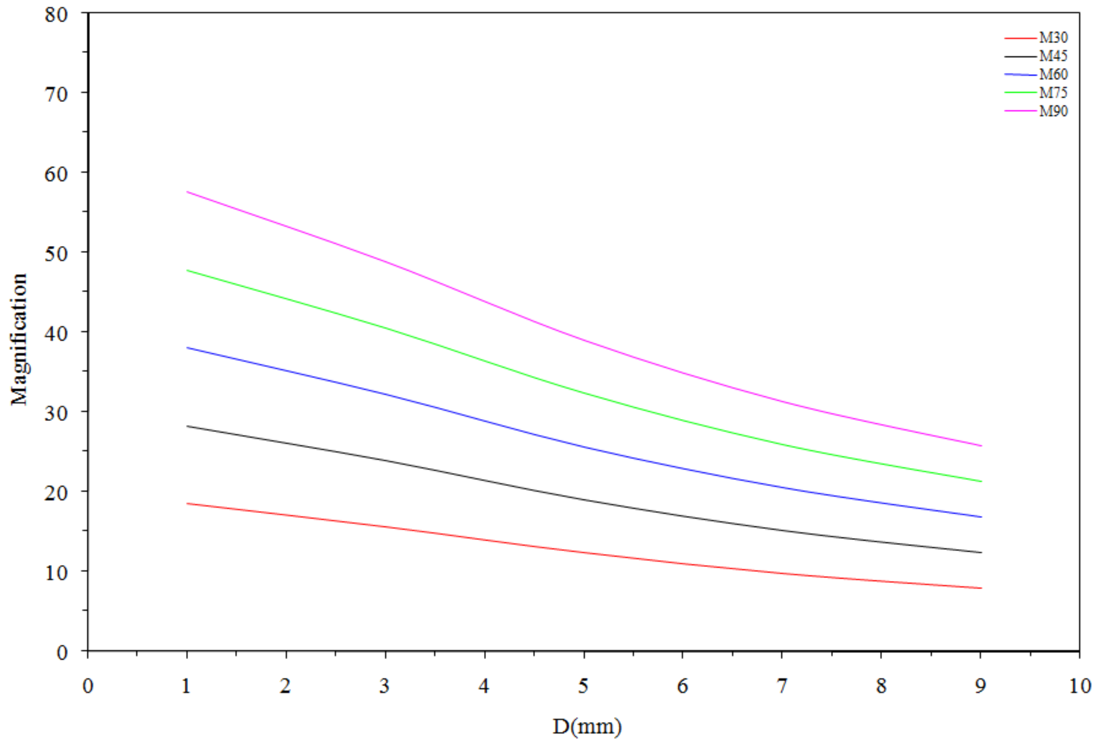

Fig. 10: The lens magnification M as a function of bore diameter D for various values of ℓ.

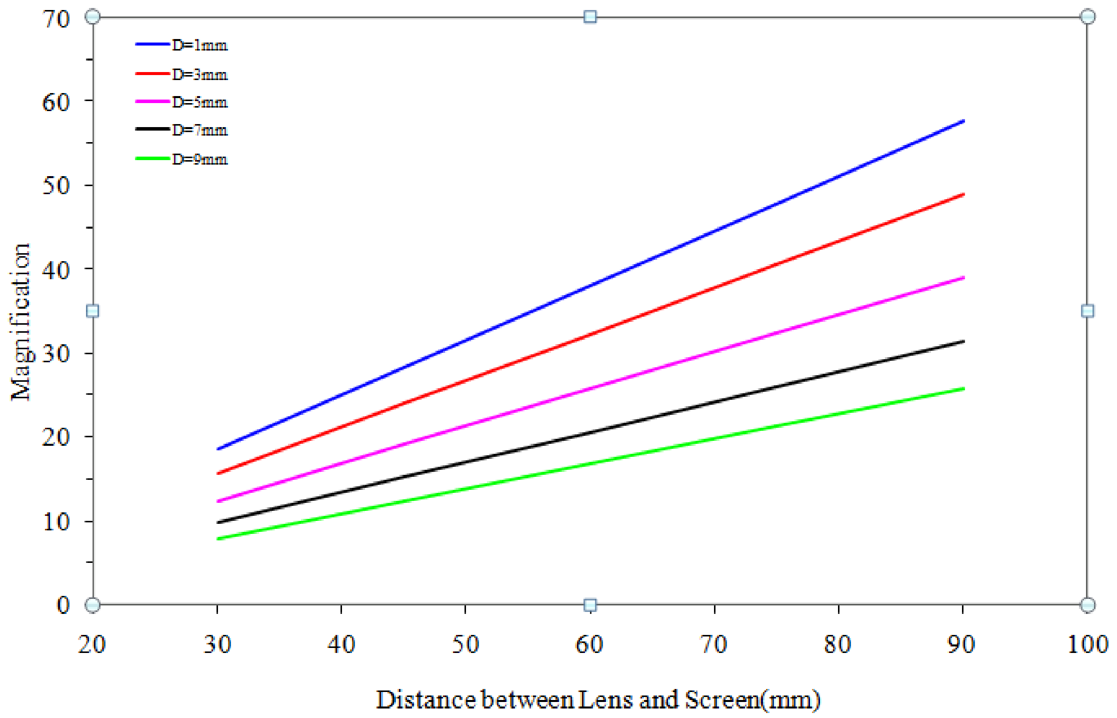

Fig. 11: The lens magnification M as a function of the distance between lens and screen ℓ for various values of bore diameter D.

Conclusion:

It should be mention that, the mathematical nature of a model used to estimate such a magnetic field plays an important role to determine its optical properties. Thus, according to the previous results, several remarks can be stated as follow**:**

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1- The rectangular field model is almost true of the lens in which the airgap width very large compared with the bore diameter.
2- This model is a simple mathematical model. It is a traditional model leads to relationships represent the real properties of the magnetic double polepiece lenses in well acceptance and notice the effects of the optical geometrical constants on the focusing power and magnifications.
3- The lens design in low airgap width with the other variables are still constants, leads to high magnification and focusing power.
4- The lens design in low bore diameter with the other variables are still constants, leads to high magnification and focusing power.
5- Decreasing the airgap width and increasing the distance between the lens and screen (with remains the bore diameter and excitation parameter are still constants), results a high lens magnification.
6- Decreasing the bore diameter and increasing the distance between the lens and screen (with remains the airgap width and excitation parameter are still constants), produces a high lens magnification.

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