Expert System Design of beam spot size measurements in FIB system

Dr.Fadhil A.Ali
Basra University- College of Engineering – Computer Engineering Department, fadhilcad@gmail.com

***ABSTRACT* - This is a design of an expert system in the focused ion beam optical system by using fuzzy logic technique to build an intelligent agent. Present software has been designed as an interpretation expert system, written in Visual C# for optimizing the calculation of three electrostatic lenses column. By using such rule based engine, the axial potential distributions for electrostatic fields undergo the constraints have been used to find spot size focusing for ions in the image plane which have values are very useful for getting and designing FIB model, over ranges of ion beam angles (5, 10,30,50,75 and 100) mrad.**

I. INTRODUCTION

The ion-beam lithography system is widely used for the pattern definition. As will be shown in the present work, a simulation has used to design optical system with relatively large overall dimensions of the order of a few millimeters. It is aimed for finding the potential distribution that minimizes the aberration integral, at the same time satisfying the differential equation of the paraxial rays, and also the constraints imposed by practical requirements **[1]**.

Present procedure of our work, has database that established to provide storage and retrieval of calculated optical properties (i.e. spherical and chromatic aberration coefficients) according to fuzzy logic procedure made the agent of an expert system, which has been built according to rule-based system. It maintains a collection of knowledge nuggets called facts, knowledge base which has our relational database. By using Java Expert System Shell programming language embedded as class modules in Visual C#, present work expert system has been created the user interface **[2, 3]**.

A rule based expert system written is a data-driven program where the facts are the data stored in our knowledge base that stimulate execution via the inference engine. This engine decides which rules should be executed and when. Therefore, the field calculation and ray tracing, depending to the stored data base as in the following two factors:

1. The facts of the function to be calculated.
2. The rule of dynamic programming procedure solutions, which obey the constraints.

The subroutines comprise of our full package has described as a class module program written in visual C#, where designed as software as follows:

a- A subroutine of a fourth order **Runge –Kutta** method, which is used for computing trajectories when the initial conditions are given. The full details and outputs are given in a tabulated form inside the PC stored as one database.

b- A subroutine to calculate all set of stored data, which it can be given with many results. This is an optimized field distribution, and it has an ability to select the best formulae fitted to present procedure logically. The programming language is visual c#" as it to make the user interface. This subroutine is a rule based expert engine and SQL server connecting for the present expert system.

c- A subroutine for computing spherical and chromatic aberration coefficients, this is done by using **Simpson's rule** integration method.

d- A subroutine to calculate and plot all outputs into other GUIs, aberration spot size diagrams were plotted and analyzed in this investigation.

The spherical and chromatic aberration coefficients have been calculated, which gives the main indications for designing of each model. Different cases of electrostatic lenses have investigated in this work. Many factors and variables have to be calculated to make sure any of results among the others were corrected. Those factors have used optimizing process supported by artificial intelligence technique. So that, considerable amount of errors have obtained were neglected in the accumulation of data. Obviously, most of the formulae were optimized such subroutines. To make fitted comparisons, well known and more updating, **SIMION** software primarily used to calculate electric fields and the trajectories of charged particles. Symbolic computing has become a promising aid in different kinds of decision making and building expert systems **[4]**.

Present software has adopted this technique to maintain such smart database (i.e. expert system); the system contains database tables impeded inside the subroutines. Focused ion beam setup design needs to create by using full computational package to be smart for getting the configurations and parameter calculations likewise. Figure (1) is shown the schematic data flowing diagram steps of this investigation.

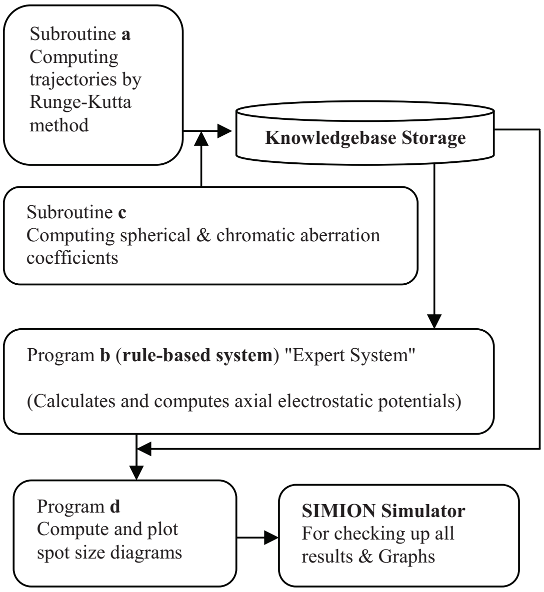


Figure 1. Represents the schematic data flowing diagram of the present software

Expert systems that have built in knowledge in the form of symbolically represented facts and rules. **Steve et al** described a novel method of determining potentially successful starting designs by utilizing expert systems algorithm which operates on a database of previously well-designed optical systems **[5]**.Also, **Xiaogang Chen et al** developed a small expert system used in lens design **[6]**.

According to **Szilagyi**, who introduced the dynamic programming approach**[7]**, and more recently to **Ahmad et al**, which have introduced a computer aided design of an electrostatic FIB system consisting of three electrostatic lenses approximated by the spline lens model**[8]**. Our rule-based has been used in the procedure is the typical dynamic programming recursive formulation as **[9]**:

$$F_n (n, s, x) = g \,|R (n, s, x), F^*_{n-1}(s')| \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where n is an integer denoting the stage of the problem, s is an integer denoting the state of the system at n, s' is an integer denoting the state of the system at stage n-1 resulting from the decision x, x is the decision being evaluated at stage n , R(n,s,x) is the immediate return associated with making decision x at stage n when the state of the system is s , $F^*_{n-1}(s')$ is the return associated with an optimal sequence of the decision at stage n-1 when the state is s' and g is the minimal function.

II. Three-lens system column FIB (Focused Ion Beam) setup

Demagnification of the beam size in the image plane is one of the most requirements of focused ion beam, which should be associated with low aberrations. The ion beam system consisting of three lenses with a beam crossover is taken the following setup.The axial potential distribution is determined with their first and second derivatives of a given two-lens system for ion collimated beam, which is forming three lenses with a beam crossover as follows:

1. Unipotential lens (1) **[einzel]** lens is operated under infinite magnification condition – immersion lens is operated under zero magnification condition- Diaphragm lens is operated under finite magnification condition.
2. Diaphragm lens is operated under infinite magnification condition – immersion lens is operated under zero magnification condition- Diaphragm lens is operated under finite magnification condition.

Likewise, the two-lens system selectivity the third lens or the right hand side of the given columns is operated under finite magnification condition, which they are shown in figures (2) and (3), respectively.

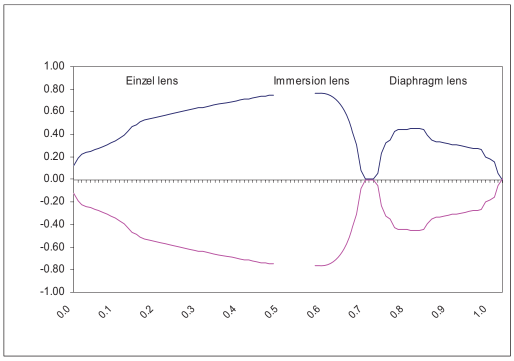


Figure 2. The ion beam trajectory for a three-lens system (1)

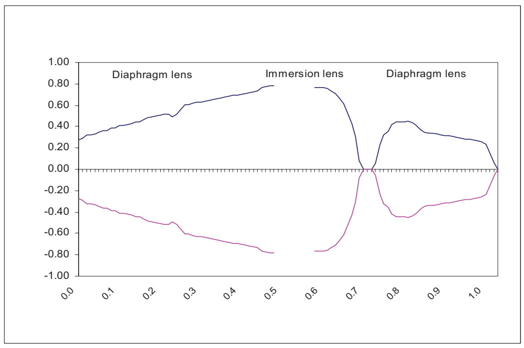


Figure 3. The ion beam trajectory for a three-lens system (2)

The relative optical properties of the given three - lens systems are listed in tables (1), (2) and (3), which they were used to calculate the spherical, chromatic and total aberration discs ($\mathbf{d_{si}}$, $\mathbf{d_{ci}}$ and $\mathbf{d_{ti}}$). The relative aberration coefficients are taken in terms of the image-side focal length of the second lens, by which it's the overall image-side focal length of the system.

Table (1) the relative optical properties for a three-lens system (1)

DEMAGNIFICATON CONDITION FOR THREE LENSES SYSTEM - 1				
relative optical properties	**einzel lens**	**immersion lens**	**diaphragm lens**	**The system**
magnification	**infinite**	**zero**	**-0.999**	**-0.403**
U_i/U_o	1.545	2.70	1.545	---
f_i/L	infinite	1.082	0.244	0.244
f_o/L	1.48	infinite	0.244	0.50
C_{si}/f_i	---	6.22	5.67	---
C_{so}/f_o	1.50	---	---	5.04
C_{ci}/f_i	---	0.541	0.63	---
C_{co}/f_o	0.70	---	---	4.32
d_{si}(µm)	---	0.08	1.80	8.788
d_{so}(µm)	0.19	---	---	---
d_{ci}(µm)	---	1.14	8.910	9.393
d_{co}(µm)	0.18	---	---	---
d_{ti}(µm)	---	1.142	8.912	9.396
d_{to}(µm)	0.26	---	---	---

Table (2) the relative optical properties for a three-lens system (2)

DEMAGNIFICATON CONDITION FOR THREE LENSES SYSTEM - 2				
relative optical properties	**diaphragm lens**	**immersion lens**	**diaphragm lens**	**The system**
magnification	**infinite**	**zero**	**-0.999**	**-0.400**
U_i/U_o	0.846	2.70	0.846	---
f_i/L	infinite	1.082	0.244	0.244
f_o/L	0.618	infinite	0.244	0.51
C_{si}/f_i	---	6.22	5.67	---
C_{so}/f_o	3.40	---	---	4.927
C_{ci}/f_i	---	0.541	0.63	---
C_{co}/f_o	2.24	---	---	1.036
d_{si}(µm)	---	0.08	1.80	2.247
d_{so}(µm)	0.43	---	---	---
d_{ci}(µm)	---	1.14	8.910	1.774
d_{co}(µm)	0.56	---	---	---
d_{ti}(µm)	---	1.142	8.912	1.78
d_{to}(µm)	0.70	---	---	---

Table (3). The optimized axial potential distributions with their dynamic parameters of the given electrostatic lenses.

Lens Type	**Optimized Axial Potential Distribution Formula**	**Dynamic Parameters**			
		a	**b**	**c**	**d**
unipotential lens (1)	a*tanh (b*z^c) +d	80	0.04	2	12
unipotential lens (2)	a*exp (-b*z^c)/cosh(z-d)	0.9	3	5	0
immersion lens	a*tanh(b*z^c)+d	0.5	1.5	1	0
diaphragm lens	a*tanh (b*z^c) +d	0.9	0.008	2	0.01

III. Spot diagrams and spot size measurements

A spot diagram is a collection of ray data resulting from tracing a large number of rays from a single object point through several aperture coordinates. The aperture coordinates are normally set up to form a square grid in the entrance pupil. Spot diagrams can be processed in a variety of ways to provide either geometrical or diffraction analyses of optical images **[10]**. Calculating the spot size is thus a matter of considerable importance in present optical design software.

The spot size to be defined by an integral equation that represents the limit that would be obtained if the number of rays traced approached infinity. Then, if the object point is located at a distance ***h*** from the axis, and the pupil intersection point is described using polar coordinates, one has the following expression for the mean square spot size as follows **[11]**:

$$\sigma^2(\mathrm{h}) = \int_0^1 \int_0^{2\pi} [y(r,\theta,h) - \bar{y}(\mathrm{h})]^2 \, r d\theta \; dr \quad \ldots(2)$$

Where $\boldsymbol{\sigma}^2(h)$ is the rms (i.e. root mean square) spot size and ***h*** is the distance from the axis of an object point. Figure (4) is shown the essential quantities included in spot size determination.

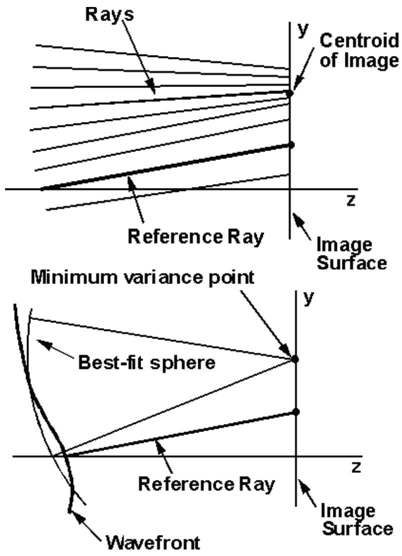


Figure 4. Shows the principal spot diagram parameters

Having computed the aberration coefficients, it is useful to be able to plot the shape of the aberrated beam at various locations in the image plane, in the form of spot diagrams. Those diagrams are very simple to generate, it could be take a bundle of rays uniformly distributed in the aperture plane. The spot size depends on the aberration coefficients of the lens which in turn, depending on the magnification, the potential at the target, and the half acceptance angle α subtended by the cone of particles at the spot. Then probe disc radius r_{ii} can be added in quadrature as **[9]**:

$$r^2_{ii} = r^2_{gi} + (r_{si}/4)^2 + (r_{ci})^2 + (r_{ai})^2 \quad \ldots\ldots\ldots.. (3)$$

where the radii of the Gaussian image (r_{gi}), (r_{si} and r_{ci}) are the spherical and chromatic aberration discs radii and (r_{ai}) is the Airy disk, respectively. The formulae of each component in equation (3) are described as follows:

- $r_{gi}=(I/b_i)^{1/2} / (\pi\ \alpha)$ ………..… (4)
- $r_{si}=M\ C_{so} \tan^3(\alpha)$ ……………..(5)
- $r_{ci}=M\ C_{co} \tan(\alpha)\ \Delta U_o / \{2\ [U(z_o)-U_o]\}$ … (6)
- $r_{ai}=0.6\ \lambda_i / \sin(\alpha)$ …………… (7)

where the I is the total current of the Gaussian beam and b_i is the value of the brightness at the image, M is the magnification and (C_{so} and C_{co}) are the object-side spherical and chromatic aberration coefficients, respectively. Also, ΔU_o is the total energy spread of the beam and λ_i is the wavelength at the image plane and α is the half acceptance angle of the ion beam.

Since the ion source was not included in the present investigation aims, present software has been neglected [r_{gi}] and [r_{ai}]. Therefore, it uses enhanced spot diagrams that contain angles and path lengths in addition to the intersection coordinates of rays with the image surface. This enables the subroutines to carry out focus-shifting operations without tracing additional rays. Spot diagrams in this code are stored in memory (i.e. jess rule-base [the knowledge base] of our expert system), making computations of image evaluations that may use them very fast. The diameter of the beam transmitted through the system in computing a spot diagram is normally determined by the entrance beam radii.

Therefore, the probe radius to determine the spot size (i.e. equation (3)) has been rewritten as follows:

$$r^2_{ii} = (r_{si}/4)^2 + (r_{ci})^2 \quad \ldots\ldots\ldots (8)$$

By using equation (8), the present software calculates the spot size. Figure (5) shows the spot size calculations for a range of beam angles [5, 10,30,50,75, and 100] **mrad** of the given ion beam three-lens systems.

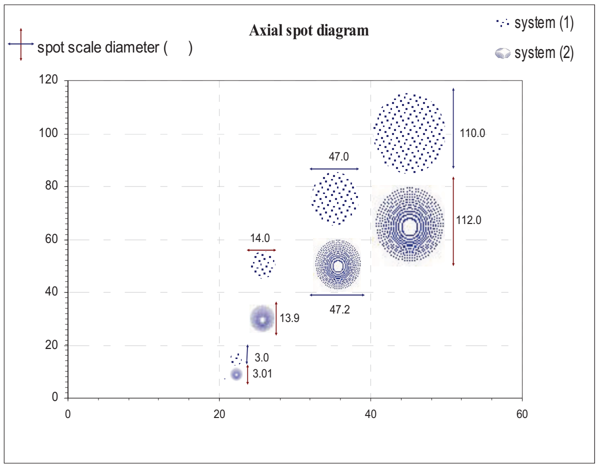
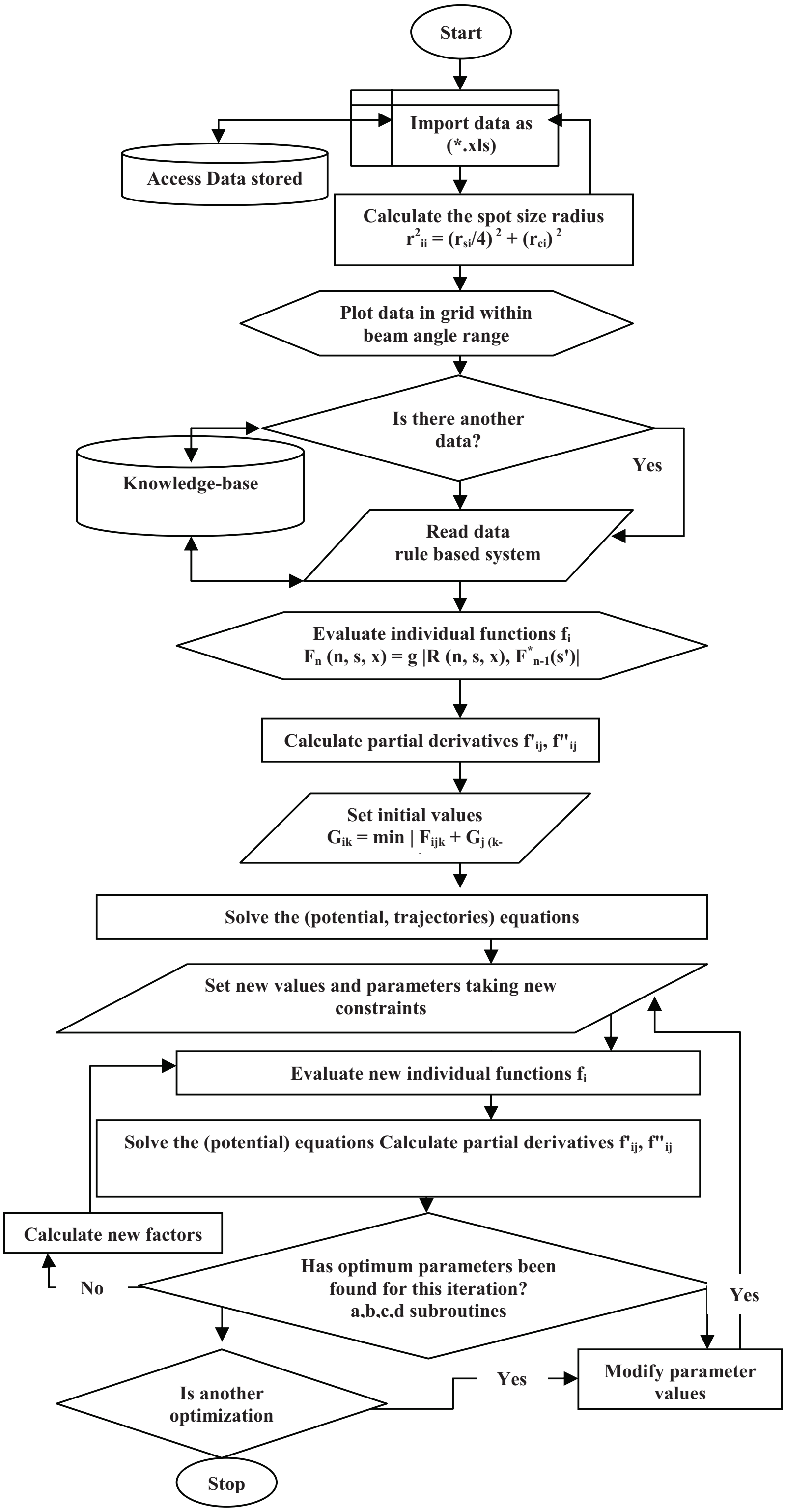


Figure (5) the axial spot size measurements versus the beam angle for three-lens systems (1& 2).

Also, it has shown at beam angle 100 mrad the spot size is (110 nm) and (112 nm), while at the beam angle of high resolved system are taken the values (3.0 nm) and (3.01 nm), respectively. This might be a good indication to get the optimum reduction for the aberrations inside the given systems.

IV. Expert system flowchart

The present software is the main significant "expert system"; the steps are configured as included in the following flowchart:



V. Conclusion

The present investigation has clearly measurements of spot size focusing for ions in the image plane have values are very useful for getting FIB designing. Over different ranges of ion beam angles (5, 10,30,50,75 and 100) **mrad**, the results were summarized as follows:

- System (1)-[3.0, 14.0, 47.0 and 110.0] **nm**.
- System (2)-[3.01, 13.9, 47.2 and 112.0] **nm**.

VI. Acknowledgement

I would like to thank College of Engineering-University of Basra. Also, many thanks to SIMION researchers group at SIMION Company (www.simion.com) for delivering a test compiler of SIMION package, helping us for checking our results.

VII. References

[1] Tsumagari T.,Kimata Y., Ohiwa H., and Noda T. , An optimum design of focused ion beam system with a beam crossover ,Jpn.Appl.Phys., vol. 27,p.L1567-L1578,1988

[2] Li-Yen Shue, Ching-Wen Chen, Weissor Shiue , The development of an ontology-based expert system for corporate financial rating, Expert Systems with Applications, Vol. 36 , Issue 2 , p. 2130-2142 , 2009

[3] Tam S. M., Kwong C. K., and Ip W. H, A hybrid artificial intelligence system for optical lens design, International Journal of Computer Applications in Technology, Vol. 13, Issue 3-5, p.229-236, 2000

[4] Friedman E. J., (Jess) the Rule Engine for the Java Platform, Computing Systems Sandia National Laboratories Livermore Version **6.1,4,** CA USA, 2003

[5] Steve C. J., Alan W. G., David Y. Wang, and Dilworth D. C., Combination of global-optimization and expert-systems techniques in optical design, Proc. SPIE Vol. 1780, p. 192-196, 1993

[6] Xiaogang C., Zhijiang W., Da-Jian L., and Guoliang Sun, Small expert system used in lens design, Proc. SPIE Vol. 1780,p.197-201, 1993

[7] Szilagyi M., Electron optical synthesis and optimization, Proc. IEEE, vol.73, p.412-418, 1985

[8] Ahmad, A.K., Sabah M.J. and Ahmed A.Al-Tabbakh, Computer aided design of an electrostatic FIB system, Indian J.Phys. 76B, p.711-714, 2002

[9] Szilagyi M.,Electron and Ion Optics, Plenum Press, New York, 1988

[10] Forbes G.W., Computing spot size, J.Opt.Soc.Am. A5, 1943-1956, 1988

[11] Sinclair D.C. and McLaughlin P.O.,Systems with vignette pupils,Proc SPIE 55,1049,1989