Expert system of single magnetic lens using JESS in Focused Ion Beam

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ABSTRACT

This work shows expert system of symmetrical single magnetic lens used in focused ion beam optical system. Java expert system shell(JESS) programming is proposed to build the intelligent agent "MOPTION"for getting an optimum magnetic flux density , and calculate the ion optical trajectory. The combination of such rule based engine and SIMION 8.1 has configured the reconstruction process and compiled the data retrieved by the proposed expert system agent to implement the pole-pieces reconstruction for lens design. The pole pieces reconstruction has been resulted in 3D graph , and under the infinite magnification conditions of the optical path, aberration (spherical / chromatic and total) disks diameters have been obtained and got the values (0.03,0.13 and 0.133) micron (μm) respectively.

Keywords

Artificial Intelligence, Expert Systems, Magnetic Lens, Focused Ion Beam

1. INTRODUCTION

A magnetic lens is a device for the focusing or deflection of moving charged particles, such as electrons or ions, by use of the magnetic Lorentz force. In electron/ion optics a projector lenses, are often used the symmetrical design, which it has the air gap at the centre of the lens. Here, owing to the mirror symmetry of the magnetic field about the mid-plane of the lens, only one half of the lens need be considered [**1**]. In majority of symmetrical magnetic lenses, the axial field **B(z)** is bell-shaped in distribution. Grivet and Lenz are considered model takes the form **[2**] ;

$$\mathrm{B(z)} = \mathrm{B}_0 \mathrm{sech}({}^{z}/_{b}) \quad .... (1)$$

where ,$b = 0.7593\ a$; a **-** is the half width of the "bell" at one half of its maximum height.

Munro has introduced design and optimization of magnetic lenses and deflection systems for electron beams, his approach was based on the physical superimposed bothmagnetic lens and deflection fields. Which is produced a total aberration disk of 0.45μm before dynamic corrections and 0.15μm after dynamic corrections [**3**].

Also**Szilagyi**, and **Ahmad et al** have introduced the dynamic programming approach, that gets a computer aided design of an electrostatic FIB system consisting of three electrostatic lenses approximated by the Spline lens model[**4,5**]. **Steve C. Johnston et al** are presented and described a novel method of determining potentially successful starting designs by utilizing an expert systems algorithm which operates on a database of previously well-designed optical systems. The database is composed of systems created by a `not-so-local' optimization algorithm, and a collection of previously well-designed systems[**6**]. More recently **Ali** has introduced an expert system to design two electrostatic lenses column by mixing dynamic programming and AI techniques [**7**].Regina Holčáková and Martin Marek have shown the simulation of magnetic field distribution of some types of magnetic lenses in software Ansys with the employment of results of magnetic measurements [**8**]**.**

In this paper the programming method is developed and applied to a single symmetrical magnetic lens with non permeability by building agent called "Magnetic Optimization for Ions" **-** MOPTION of the rule-based system by using Java Expert System Shell (JESS 7).

The typical recursive formulation and optimization procedure is adopted in the present programming procedure has the following formula [**9**]:

$$\mathrm{Fn}\ (\mathrm{n}, \mathrm{s}, \mathrm{x}) = \mathrm{g}\ |\mathrm{R}\ (\mathrm{n}, \mathrm{s}, \mathrm{x}), \mathrm{F} * \mathrm{n} - 1(\mathrm{s}')| \ldots\ldots\ldots\ldots\ldots (2)$$

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. Therefore, the Rete algorithm [**10**] has build on imposing the optical properties (the relative spherical and chromatic aberration coefficients) of the magnetic lens into the recursion formula , equation (2). Those properties are characterized by a dimensionless parameter $(\mathbf{k}^2\mathbf{d}^2)$, where $\mathbf{k}^2$ is an expression represented in the paraxial ray equation of the optical ion trajectory , equation (3), and $\mathbf{d}^2$ is the square of the field half-width, in which is determined by the shape of the pole pieces and by the degree of saturation [**11**].

$$\mathrm{r}''(\mathrm{z}) + \mathrm{k2}\,\mathrm{r}(\mathrm{z}) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where ; r(z), r''(z) is the transformation of the ray coordinates by an ion optical system in z- axis and its second derivative , respectively. And $k^2 = [q\ B_z^2 / 8\ m\ V]$, where B_z - is the axial component of the magnetic flux density , q- is the electric charge ,V-is the accelerating voltage and m is the mass of ions accelerated through a magnetic field. The axial flux density distribution was optimized as Grivet-Lenz model for magnetic lenses, which it can be used for the description of unsaturated lenses[**12**].

2. Intelligent Agent (MOPTION) and Algorithm

Taking into account the above considerations, the proposed implementation consists of embedding an instance of the Jess engine inside a recursion formula , equation(1). Since the agent to be able to continuously reason, a cyclic code have to implement action will consist of running the Jess rule based engine. However, we will be careful not to block other agent's behaviors for a considerable amount of time, and 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 present expert system agent automatically performs the magnetic field calculations as in figure(1) ,and depending to the stored data knowledgebase for both two factors:

- The facts of the function to be optimize (magnetic flux density, ion beam trajectories).
- The rules of Linear Recursive Queries in Deductive Databases procedure solutions [**13**],
- which obey the constraints (permeability = 0 and symmetrical dimensions).

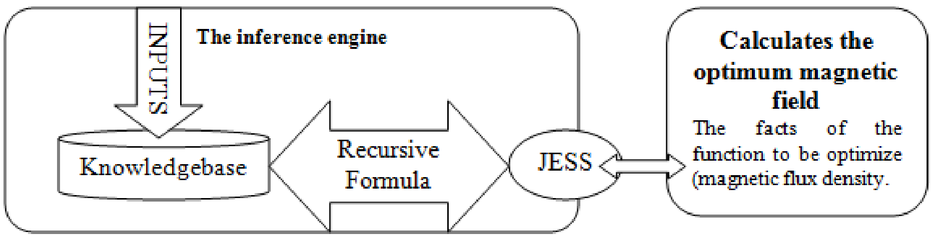


Figure1 shows the magnetic optimization for ions (MOPTION) agent scheme and its functionalities.

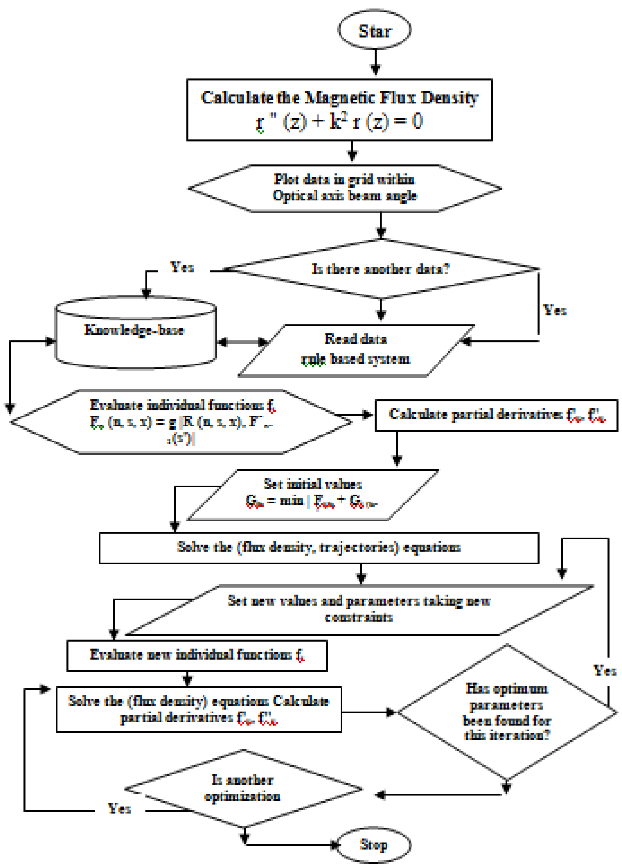


Figure 2 Shows the algorithm of the present work for optimum the magnetic lens

3. Magnetic Lens Design

Let **B(z)** be the axial flux-density distribution for the lens thatdesigned using the JESS algorithm shown in Figure (1) & (2). It has a value shown in the equation(4);

$\mathrm{B(z)} = \mathrm{B_{max}}(z) * \mathrm{sech}(\frac{z}{2})$ ....(4)

Since Grivet-Lenz model has been proposed in this work, which is given the magnetic flux density as[**14**]:

$\mathrm{B(z)} = \mathrm{B_{max}}(z)/\cosh(\frac{z}{a})$ .... (5)

where; $\mathrm{B(z)}_{max}$ is the maximum flux density in the optical path (z), and (a) is a constant. Observing that equation (4) and (5) have the same mathematical expression if the constant a=2. Figure (3) are shown the optimum flux density distribution with its first derivative and its optimum formula respectively. The maximum value for the axial flux density distribution$\mathbf{B_{max}}$ was taken equal to (**6.0**) mTesla in the programming calculations.

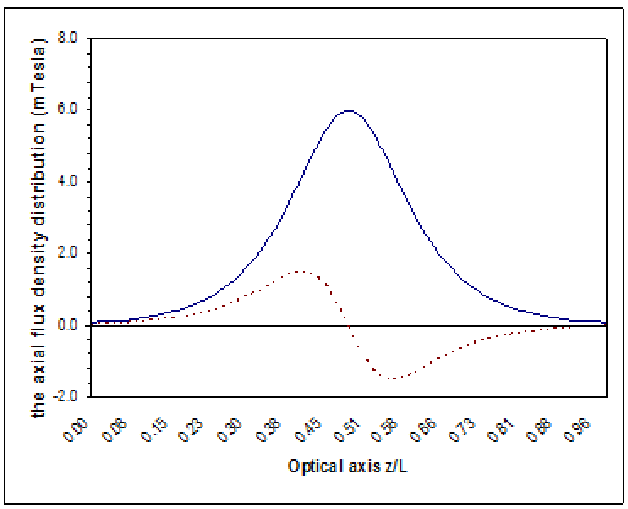


Figure 3 shows the optimum axial magnetic flux density distribution B(z) with its first derivative for the given magnetic lens obtained by Jess

4. Discussions and Implementation

The expert system was resulted two main goals after finding the optimum magnetic lens. These endeavors are summarized this approach in many applications, and proceeds to obtain more.

4. A- Trajectories Assigning

The ion beam trajectories were obtained in Focused Ion Beam system under infinite magnification condition[**15**]. Figure (4) shows the trajectory along the relative optical axis for the optimized magnetic field is obtained values the relative spherical and chromatic aberration coefficients **Cs/f_o** and **Cc/f_o**respectively [**2**], as described in Table (1). Also figure (5) is shown a function of the dimensionless parameter **k^2d^2** related to the half-width **d** for the optimized magnetic field vs. relative aberration coefficients.

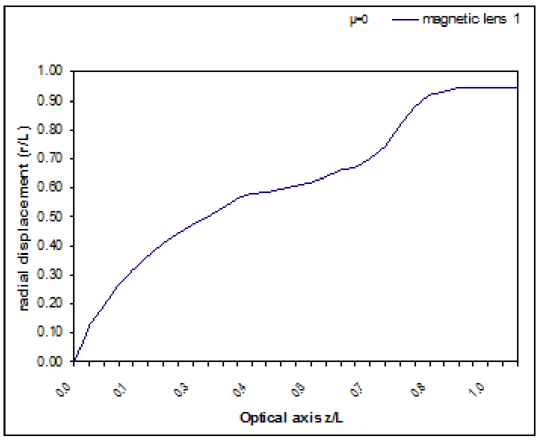


Figure 4shows the ion beam trajectories of magnetic lens under infinite magnification condition (for a constant length L=20 mm)

Cs / f_o	Cc / f_o	k^2d^2	Cs / f_o	Cc / f_o	k^2d^2
1.00	1.00	0.00	0.22	0.52	19.00
0.82	0.71	1.00	0.22	0.52	20.00
0.69	0.67	2.00	0.22	0.52	21.00
0.60	0.62	3.00	0.22	0.52	22.00
0.52	0.60	4.00	0.22	0.52	23.00
0.44	0.58	5.00	0.22	0.52	24.00
0.38	0.57	6.00	0.22	0.52	25.00
0.33	0.55	7.00	0.22	0.52	26.00
0.28	0.55	8.00	0.22	0.52	27.00
0.24	0.54	9.00	0.22	0.52	28.00
0.22	0.53	10.00	0.22	0.52	29.00
0.22	0.52	11.00	0.22	0.52	30.00
0.22	0.52	12.00	0.22	0.52	19.00
0.22	0.52	13.00	0.22	0.52	20.00
0.22	0.52	14.00	0.22	0.52	21.00
0.22	0.52	15.00	0.22	0.52	22.00
0.22	0.52	16.00	0.22	0.52	23.00
0.22	0.52	17.00	0.22	0.52	24.00
0.22	0.52	18.00	0.22	0.52	25.00

Table (1) the relative spherical and chromatic aberration coefficients of the optimized magnetic lens and the dimensionless parameter **k^2d^2**

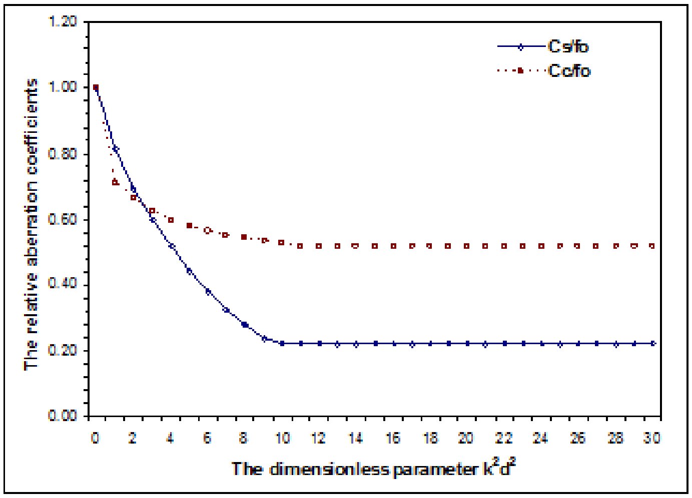


Figure 5 shows the relative spherical and chromatic aberration coefficients of the optimized magnetic lens related to the dimensionless parameter $\mathbf{k^2d^2}$

4. B- Pole Pieces Reconstruction

The present approach of a single lens design for the optimum magnetic lens, has built the pole pieces reconstruction , which taken the same procedure by using JESS and **SIMION Simulator 8.1**. The following figures (6) and (7) are shown the profiles of the pole pieces of the optimized magnetic field with **μ (permeability) = 0 and NI = 96**ampere-turns in two and three dimensions respectively

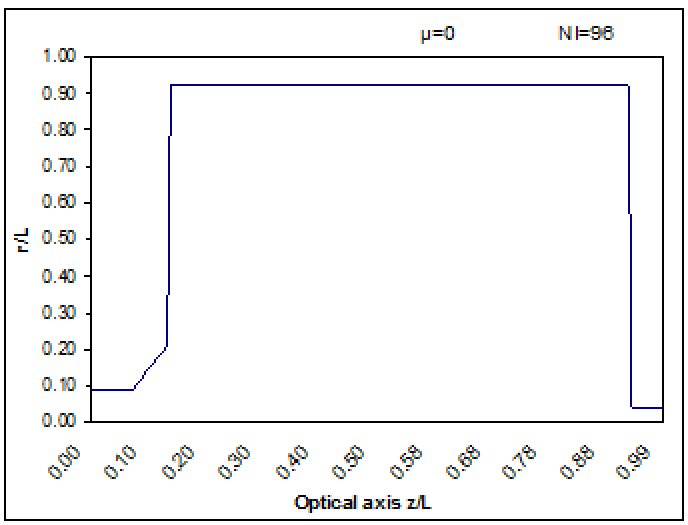
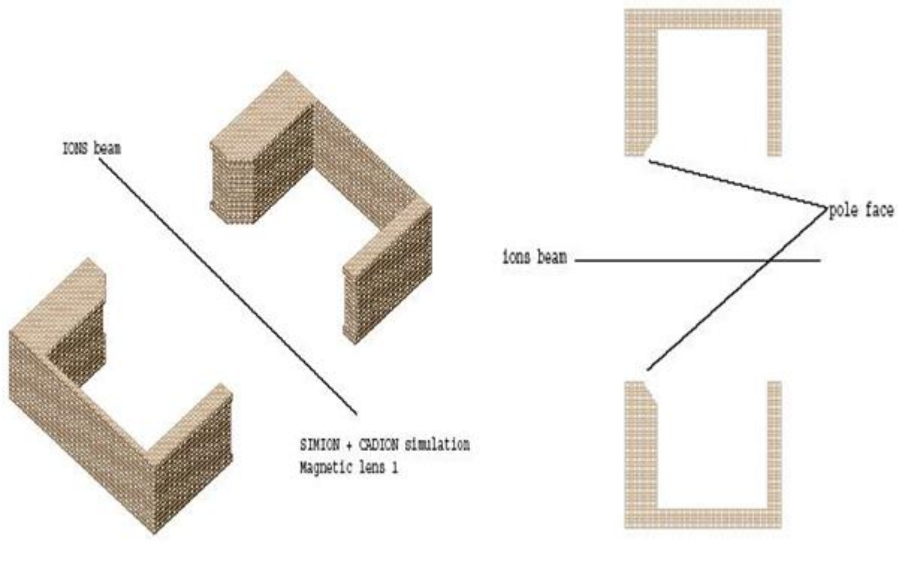


Figure 6. Shows the two dimension profile of a pole piece for a present magnetic lens



(a) (b)

Figure 7(a) three dimensions graph of the pole piece of a magnetic lens (**μ**=0). (b) The optimized pole piece profile of magnetic lens obtained by SIMION 8.1

To make comparison of the present optimum magnetic lens i.e. magnetic lens (1),with a standard Glaser's model [**2**] "magnetic lens (2)" as described in figure (8), that shows the axial magnetic flux density distribution B(z) with its first derivative for both lenses.

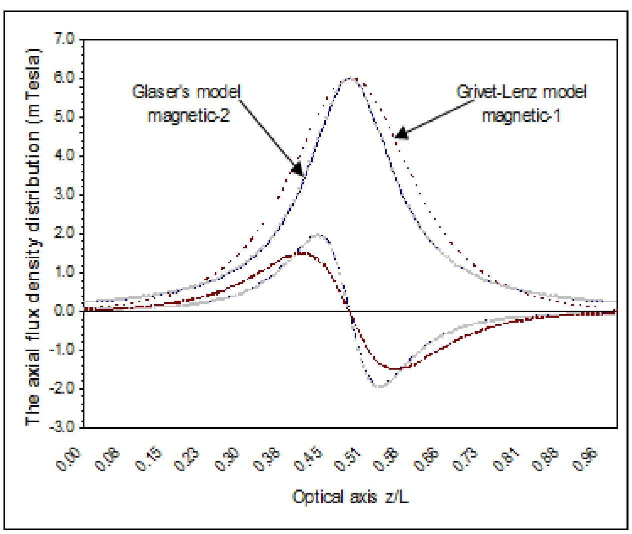


Figure 7 Shows magnetic flux density distributions B(z) with its first derivatives for both magnetic lens (1) & (2).

5. Conclusion

The present computer aided design expert system used JESS represented by Rete Algorithm has clearly shown that proposed agent is fitted optimized results of a single symmetric magnetic lens. Besides, **SIMION** 8.1 is used for building the pole pieces reconstruction and resulted 3D graphs to give the most common standards of both magnetic flux density distribution of ion beam energy spread like in electron beam energy spread [**16**]. Which is shown the distance in the air gap of the lens and its dimensions. As well as the aberration discs diameters ($\mathbf{d_s}$ –spherical aberration disc diameter, $\mathbf{d_c}$ – chromatic aberration disc diameter and $\mathbf{d_t}$– total aberration disc diameter) are shown values in micro scale (μm) under the infinite magnification condition (0.03,0.13 and 0.133) respectively. For the future work, an optimization method will be recommend to get a formula depending on the magnetic permeability **μ** in ferromagnetic materials as a function of the optical axis.

6. Acknowledgement

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7. References

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