COMPUTER-AIDED-DESIGN OF A MAGNETIC LENS USING A COMBINED DYNAMIC PROGRAMMING AND ARTIFICIAL INTELLIGENCE TECHNIQUES

AHMAD K. AHMAD
Physics Department, College of Science
Al-Nahrain University
Baghdad, Iraq.

FADHIL A. ALI
Physics Department, College of Science
Al-Nahrain University
Baghdad, Iraq.

ABSTRACT

A computer aided design (CAD) by using optimization methods for designing magnetic lens, by mixing the dynamic programming procedure and artificial intelligence technique. CADION package has been designed and written in Java expert system shell (JESS 6.1) and Visual Basic 6 (VB6) for optimizing and analyzing full calculation processes. The optimized axial magnetic flux density according to the constraints has been used in the design of pole pieces.

Keywords: *magnetic lenses, dynamic programming, artificial intelligence, aberration*

INTRODUCTION

Any axially symmetric magnetic field produced by current carrying coils with or without ferromagnetic materials or by permanent magnets is called a magnetic lens. Manufacturing of magnetic lenses is usually more complicated than that of electrostatic lenses. The action of a magnetic lens can be understood on the basis of the **Lorentz** force **[1]**. The paraxial ray equation in axially symmetric magnetic fields can be written as **[2]**:

$$r''(z) + k^2 r(z) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $\mathbf{k^2}$= [q B_z^2 / 8 m V], $\mathbf{B_z}$ - 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 charged particles accelerated through a magnetic field.

As will be shown in the present work, a simulation and optimization procedure has used to design lens with medium resolution of the order of (30 – 100) nm. It is aimed for finding the magnetic flux density 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.

Ahmad et al **[3, 4]** investigated a computer aided design of an electrostatic system by using dynamic programming and artificial intelligence techniques. In the present work, a database was established to provide storage and retrieval of calculated optical properties (i.e. spherical and chromatic aberration coefficients) and optimized magnetic flux density according to dynamic programming procedure mixed with an expert system, which has been built according to artificial intelligence technique rule-based system **[5]**. It maintains a collection of knowledge nuggets called facts. This collection is known as the knowledge base, which is our relational database. By using a Jess 6.1 (i.e. Java Expert System Shell-version 6.1) programming language and a class modules in VB 6 (i.e. visual basic studio - version 6), the present work expert system has been created and setting up the user interface.

Our rule based expert system written in Jess 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 **[6]**. Therefore, the present expert system automatically performs the field calculation and ray tracing, depending on the stored data base (i.e. jess knowledge base) and the following two factors:

1. The facts of the function to be analyzed (i.e. magnetic potential distribution).

2. The rule of dynamic programming procedure solutions, under given constraints.

The subroutines comprise of our full package (CADION) which is stand for (Computer Aided Design for ION system) has described as a class module program written in jess 6.1 and visual basic 6, where designed as one simulator as follows:

a- Accomplished program for solving the fourth order **Runge –Kutta** method, used for computing trajectories under given initial conditions. The full details and outputs are given in a tabulated form (set of data) inside the PC stored as one database.

b- Accomplished program to analyze all set of stored data, which it can be given with many results. This program is called (**CADION ANALYZER "SMART SYSTEM"**), it analyses all optimized field distributions, and it has an ability to select the best formulae fitted to the optimization procedure (i.e. dynamic programming). This analyzer is involving both techniques i.e. artificial intelligence and dynamic programming. Also it is a search engine depending on the SQL statements (i.e. SELECT statement). The programming language used is classified into two categories: [JESS – java expert system shell and Visual Basic 6 as it to make the user interface], this program is a knowledge base search engine and SQL server connector for the expert system used.

c- Accomplished program for computing spherical and chromatic aberration coefficients, using **Simpson's rule** method.

d- Accomplished program to draw (2 and 3 Dimensions) all kind of inputs as an optimized field distributions.

e- Accomplished program to fit the data according to least square fitting method.

f- Accomplished program to convert and read all outputs into another application, Visual Basic Application programs as an Excel sheets were used in this investigation **[7]**. This program has a search engine to facilitate work with multi formulae that could be stored in the **Analyzer** database.

The spherical and chromatic aberration coefficients have been calculated within the CADION simulations, which their values gives the main indications for building the pole pieces design of the model. Obviously, most of the formulae were optimized in the CADION simulator subroutines. To make fitted comparisons, a well known and more updating simulator SIMION 7.0 package has been used for importing data resulted by CADION stored database to computerized manipulation the precise results. Adding that plotting and configuring the lens pole pieces in three dimension profiles. Figures (1) and (2) are shown the schematic diagram and the data flow chart of the optimization steps of our investigation, respectively.

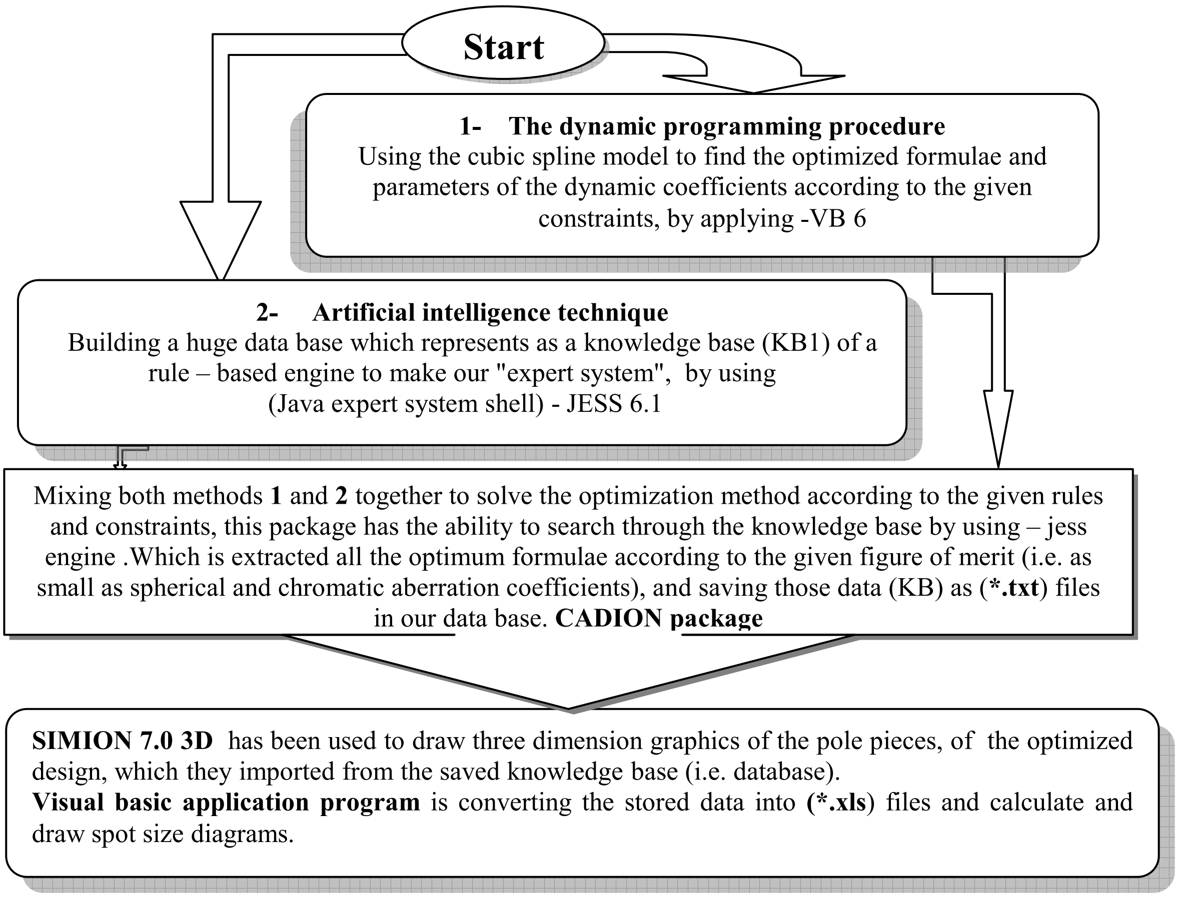

Figure 1 Shows the schematic diagram of our work

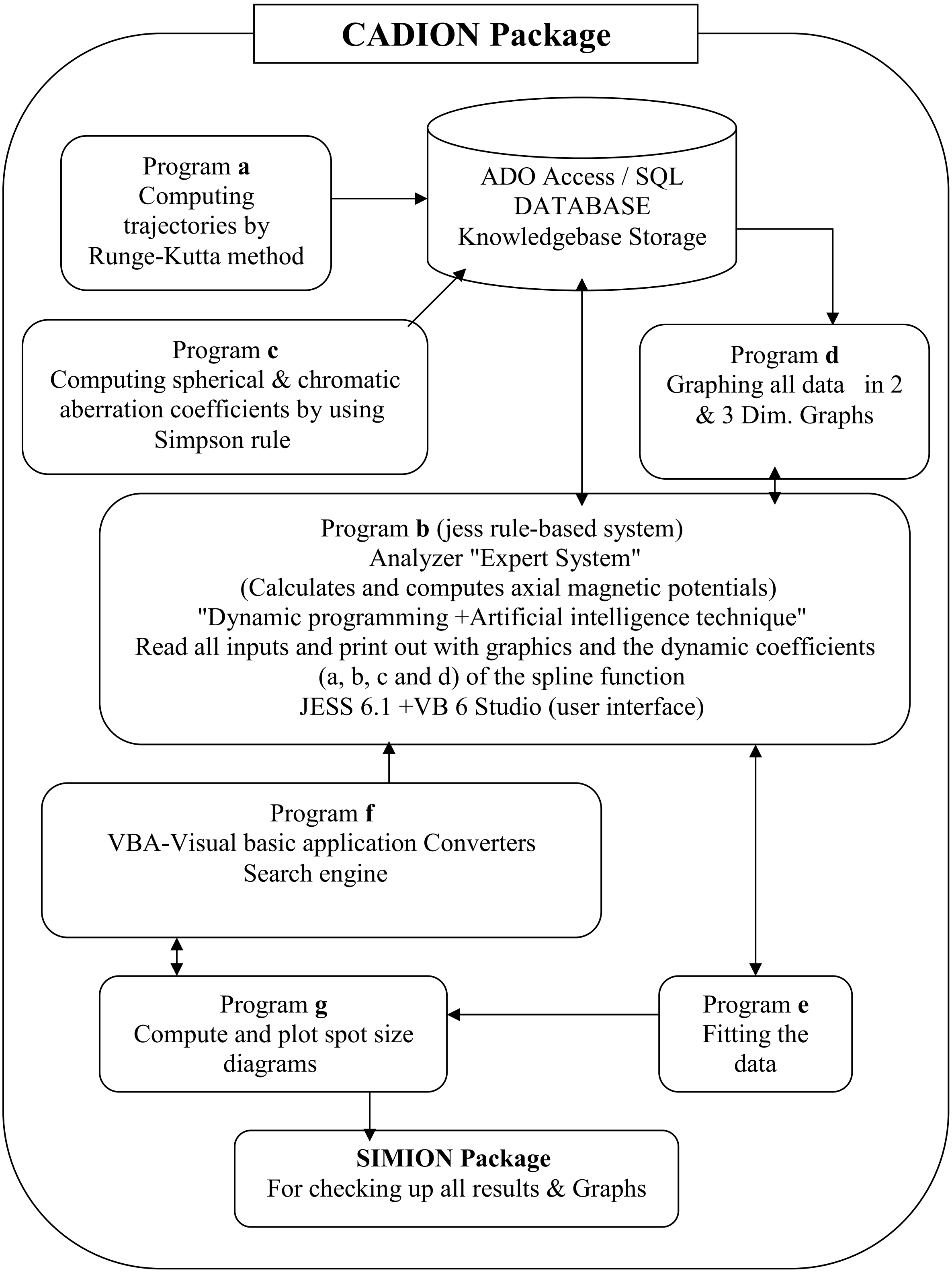

Figure 2 Represents the optimization schematic diagram of the present work software.

DESIGN OF MAGNETIC LENS

The computational grid for the dynamic programming procedure with the aid of artificial intelligence technique is shown in figure (3). It defined the domain of existence of the solution for the sought distribution function presented in this work.

The abscissa of this figure represents the axial extension of the lens along which its potential and field distribution exist. The ordinate shows the position of the nodal points where the axes of the grid intersect. These points control and fix the value of the spline function coefficients and consequently the

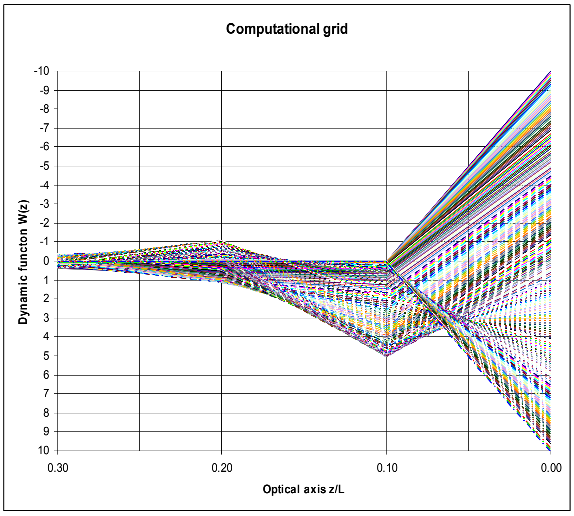

Figure 3 The computational grid of the dynamic programming procedure with the aid of artificial intelligence technique for magnetic lenses defined over twenty intervals.

The optimum magnetic flux density with its first derivative for a magnetic lens (permeability $\mu = 0$) has been determined by using the dynamic programming procedure and artificial intelligence technique are shown in figure (4). Table (1) gives the optimized formulae and their dynamic parameters. The maximum value hd been taken in our work or the axial flux density distribution B_{max} is equal to (6mT).

The optical properties (i.e. the relative spherical and chromatic aberration coefficients) are characterized by the dimensionless parameter **(k^2d^2)**, where $\mathbf{k^2}$ as in paraxial ray equation (1) and **d** is the field half-width, in which is determined by the shape of the pole pieces and by the degree of saturation. 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. The maximum value has been taken in our work for the axial flux density distribution $\mathbf{B_{max}}$ is equal to (**6.0**) mT. For future work optimization will be done to get a formula depending on the magnetic permeability **μ** in ferromagnetic materials as a function of the optical axis.

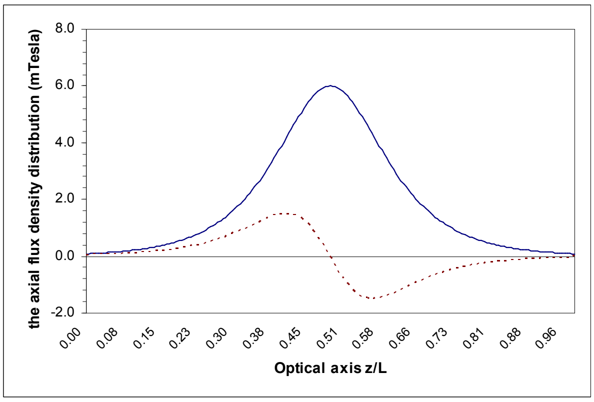

Figure 4 the optimum axial magnetic flux density distribution B(z) with its first derivative obtained by the dynamic programming procedure and artificial intelligence technique.

Table 1 the optimized magnetic lens formula with its dynamic parameters by using the dynamic programming procedure and artificial intelligence technique

Lens Type	**Optimized Flux density Distribution Formula**	**Dynamic Parameters**			
		a	**b**	**c**	**d**
Magnetic μ=0	**a*sech (z^c/ b) +d**	$\mathbf{B_{max}}$	**2.0**	**1.0**	**0**

The ion beam trajectories were obtained under infinite magnification condition. Figure (5) shows the trajectory along the relative optical axis for the optimized magnetic field obtained in table (1). Figure (6) shows the relative spherical and chromatic aberration coefficients $\mathbf{Cs/f_o}$ and $\mathbf{Cc/f_o}$ - respectively, as a function of the dimensionless parameter $\mathbf{k^2d^2}$ which related to the half-width **d** of the optimized magnetic field.

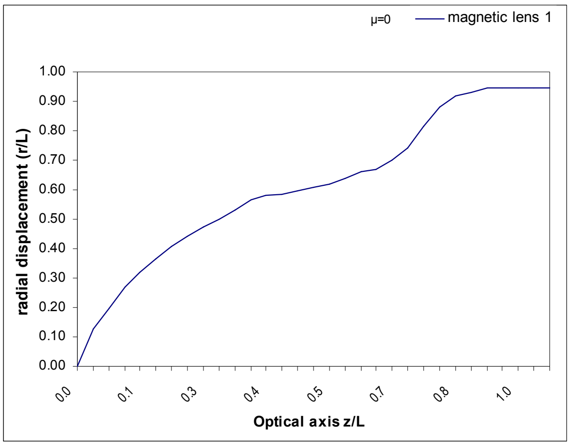

Figure 5 The ion beam trajectories of magnetic lens under infinite magnification condition (for a constant length L=20 mm)

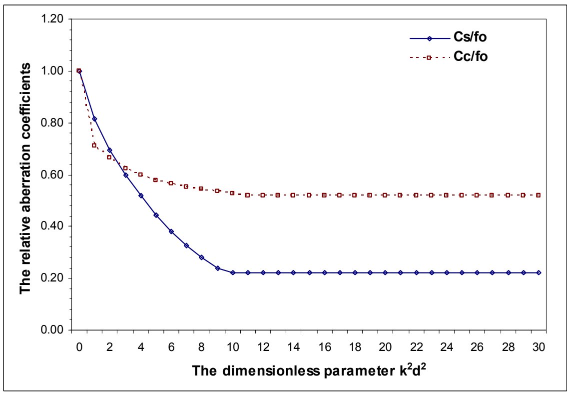

Figure 6 The relative spherical and chromatic aberration coefficients of the optimized magnetic lens related to the dimensionless parameter $\mathbf{k^2d^2}$.

To summaries the optimized results optioned in the single-lens design for aberration discs diameters d_s (spherical aberration disc diameter), d_c (chromatic aberration disc diameter) and d_t (total aberration disc diameter), table (2) gives the values in micro scale (µm). The calculations of these parameters depends on equations can be seen in reference **[8]** and choosing the minimum values of the relative spherical and chromatic aberration coefficients, $\mathbf{Cs/f_o}$ and $\mathbf{Cc/f_o}$ respectively, of the optimized lens.

Table 2 The minimum optical properties for a single magnetic lens

Lens Type	Relative aberration coefficients		Aberration discs diameter (µm)		
	Cs/f_o	Cc/f_o	d_s	d_c	d_t
Magnetic lens	0.22	0.52	0.3	0.13	0.133

Figures (7) and (8) are shows the pole pieces of the optimized lens in two and three dimensions by using SIMION 7.0 simulator.

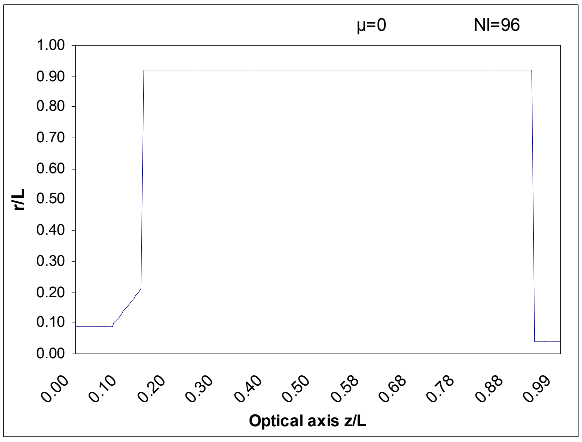

Figure 7 A two dimension profile of a pole piece for a magnetic lens with **μ=0 and NI = 96** ampere-turns.

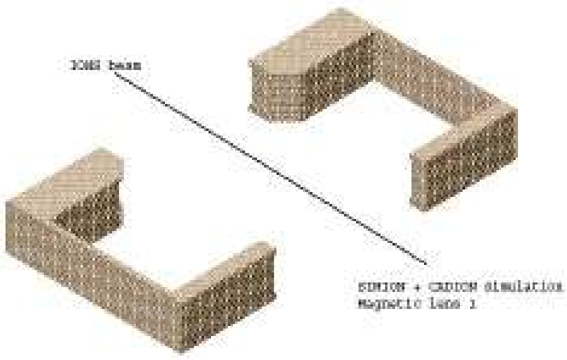

Figure 8 The optimized pole piece profile of magnetic lens obtained by SIMION 7.

CONCLUSION

The present investigation has clearly adopted a combined optimization procedures by adding the dynamic programming procedure and the artificial intelligence technique, which was mixed to find a smart simulator, packed in one program (i.e. expert system). This significant computational work was made to get and develop design of a magnetic lens can be used in nano-application technology. The minimum optical properties of relative aberration coefficients and aberration disc diameters are justified the above statement , where as the results are in the sub-micron range. Also a design of an focusing ion beam FIB optical system using this procedure is very promising.

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