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Optimal Design of an Annular MHD Pump by Genetic Algorithm Method

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Abstract: The magnetohydrodynamic (MHD) is the study of the interaction of electrically conducting fluids and electromagnetic fields. This paper deals with the optimal design of an annular induction MHD pump using global optimization method. This paper proposes the genetic algorithm method, for the optimal design of the MHD pump. The problem of designing of the pump is formulated as an optimization problem, which assumes the minimum of mass as the objective function. The constraints are both of geometrical and electromagnetic type. The obtained results are reported and discussed.

Keywords: *Genetic Algorithm (AG); Design, Objective Function, Optimal Design, Constrained Optimization, Finite Volume Method, Optimization, MHD pump.*

1. Introduction

Magnetohydrodynamics (MHD) is the study of the motion of electrically conducting fluids in the presence of magnetic fields. Effects from such interactions can be observed in liquids and gases. A number of researches have investigated the flow of an electrically conducting fluid through channels because of its important applications in MHD generators, pumps, accelerators, flowmeters and blood flow measurements [1, 2 and 3].
The pumping of liquid metal may use an electromagnetic device, which induces eddy currents in the metal. These induced currents and their associated magnetic field generate the Lorentz force whose effect can be actually the pumping of the liquid metal. The advantage of these pumps which ensure the energy transformation is the absence of moving parts. Linear induction MHD pumps are electromagnetic devices using the principle of induction motors to move liquid metal by the action of a sliding field [3].

The optimization of the liquid metal induction pump is considered in [4, 5]. Optimal design methods have been applied successfully over the last years in electrical engineering. Most of these activities have been carried out using determinist methods [6, 7, and 8].

In the previous works [9, 10] we studied the coupling electromagnetic – hydrodynamic equations of an annular induction MHD pump using the finite volume method and the stream vorticity formulation **ξ, ψ**. The proposed pump produces an axial flow. Different characteristics of the MHD pump (current density, electromagnetic force, velocity profiles and variation of the pression) in the channel.

In this paper, the factors affecting the convergence to the optimal solution using determinist method (genetic algorithm) are considered when optimizing the design of an annular induction MHD pump. This method that we developed in MATLAB incorporates penalty methods for constraint handling which shows more reliable in the worst-case performance.

2. Mhd Pump Model

An electromagnetic pump for a liquid metal is considered. A schematic view of the pump is shown in Fig.1.
The liquid metal flows along a channel with a cylindrical geometry of annular cross section. A ferromagnetic core is placed on the inner and the outer side of the channel, [11].
The principle of the MHD pump (Fig.1) is similar to that of the asynchronous motor; the supply of the inductor creates a magnetic field ***B*** sliding with the velocity of

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synchronism, where electric currents are induced in the liquid metal by means of a magnetic field, producing an electromagnetic force **F** with the instantaneous field ensuring the flows of the fluid.

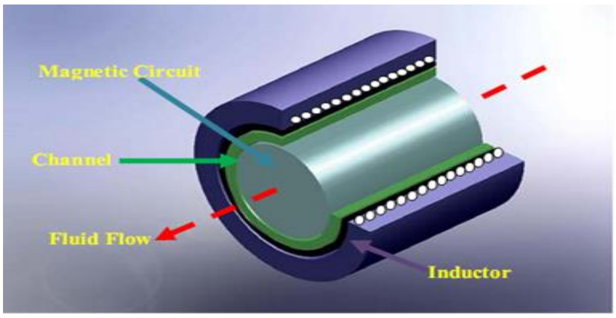

Fig. 1 Schematic view of the Annular MHD pump

3. Mathematical Formulation

The usual theoretical formulation of the magneto hydrodynamic model for electrically conducting and Newtonian incompressible fluid has been derived from Ohm's law for moving media, coupled with the Navier-Stokes equations for laminar flow with Lorentz force given by the cross product $\vec{F}=\vec{J}\times\vec{B}$. The equations used for the 2D MHD model can be summarized as follows:

a. **Electromagnetic part of the problem**

$$\overrightarrow{rot}\left(\frac{1}{\mu}\overrightarrow{rot}\vec{A}\right)=\vec{J}ex-\sigma\left(\frac{\partial\vec{A}}{\partial t}-\vec{\vartheta}\wedge\overrightarrow{rot}\vec{A}\right) \quad (1)$$

$$\vec{B}=\overrightarrow{rot}\vec{A}, \quad (2)$$

Here Maxwell-Ampère's law in equation (1) includes Ohm's law. The constants in equations (1) are the electrical conductivity σ and the permeability μ.

b. **Fluid dynamics for laminar flow**

$$\frac{\partial V}{\partial t}+\left(\vec{V}.\vec{\nabla}\right)\vec{V}=-\frac{1}{\rho}gra\vec{d}P+\upsilon\Delta\vec{V}+\frac{\vec{F}}{\rho} \quad (3)$$

$$div\vec{V}=0 \quad (4)$$

The fluid dynamics part of the problem is determined by equation (3) representing the conservation of momentum of the fluid in motion, where **P** denotes the pressure, **ρ** is the density and then is the kinematic viscosity of the fluid, where the conservation of mass is given in equation (4)

It is necessary to define the objective function and the constraint conditions in the formulation of the optimization problems. In this case, we have considered the mass of the MHD pump as the objective function to be optimized whereas geometrical, electrical and electromagnetic conditions are inequalities constraints.

The resolution of the design problem will be equivalent to the resolution of the optimization problem (P) defined as follows:

$$P\quad\begin{cases}\text{objectivefunction}=\text{Minmass}\,(X)\\ B(X)\leq 1.5\,\text{Tesla}\\ J(X)\leq 6.10^{6}\ A/m^{2} & (4)\\ X_{lower}\leq X\leq X_{uper}\qquad \text{where} & (5)\ (6)\\ X=(x_1,x_2,x_3,x_4,x_5,x_6,x_7,x_8,x_9,x_{10},x_{11})\end{cases}$$

Where:

X_3: coil width

X_4: coil length

X_5: channel length

X_6: channel width

X_7: air-gap width

X_8: inductor width

X_9: inductor length

X_{10}: medium length

X_{11}: medium width

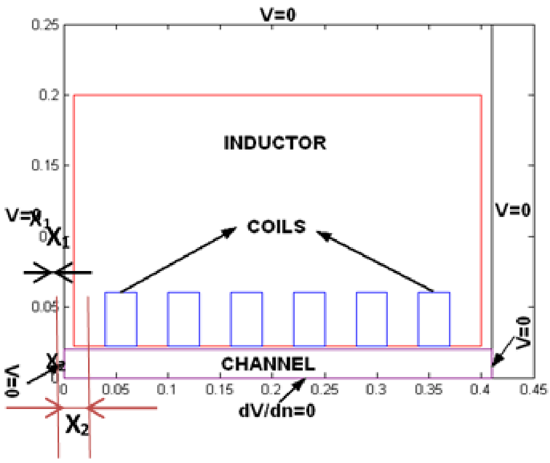

Fig.2. Geometrical model of the an annular MHD pump

Simplified schema of the MHD model, channel length L = 0.4 m, height H = 0.02 m and width of the inductor Wm = 0.2 m. Magnet length Lm = 0.4 m, width of the air-gap Wair=0.004.

In this study, where the model must represent an actual pump for mercury, working at different operating conditions, liquid mercury at 356.7°C is used as an electrically conductive fluid with density ρ = 13.6×103 kg/m3, electric conductivity σ = 1.06×106 S/m, relative permeability μr=1.55 and kinematic viscosity ν = 0.11×10-6 m2 /s.

4. Numerical Procedure

The method consists of discretising differential equations, there is one control volume surrounding each node (Fig. 3) and the differential Eq. (1) and Eq. (3) is integrated over each control volume using the finite volume approach.

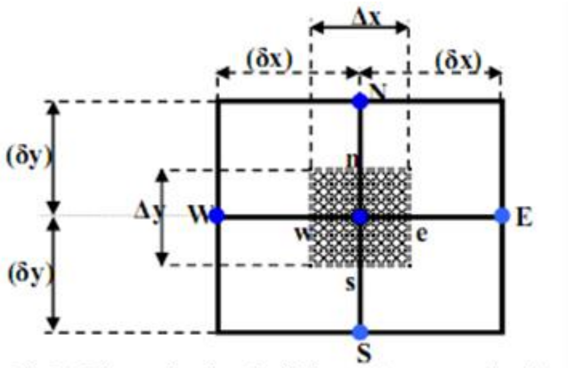

Fig.3. Discretization in finite volume method

5. Algorithm Genetic Method

Genetic algorithm (GA), as a popular optimization method being applied to many fields, is motivated by Darwin's theories of evolution and manipulated according to the rule of survival of the fittest through "genetic" operations, such as selection, crossover and mutation [12, 13,14]. Genetic algorithm is a search algorithms based on the mechanism of natural selection and natural genetics, follow principle of the survival of the fittest, and use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover. It is different from traditional algorithm, and the characteristic as follow:

- ✓ Search from a population of points, not a single point.
- ✓ Use objective function information, not require derivatives, or continuity of a function.
- ✓ Use probabilistic transition rules, not deterministic rules.
- ✓ Operate without any knowledge of the task domain and used only the fitness of evaluated individuals.
- ✓ Easy to parallelize.

As can be seen above, genetic algorithm is one of the random search methods and the initial solutions are selected at random. Theoretically it can at a certain probability convergence to the optimal solution and has strong global search capability. However, the convergence is usually very slow compared with other methods [12]. Genetic algorithm (GA) has been presented in 1962 by Holland Professor of the American University of Michigan simulated natural genetic mechanisms and biological evolution formation of a parallel random search optimization methods. "slightly better elimination, survival of the fittest "theory of biological evolution to genetic algorithms, according to the fitness function of genetic algorithms through selection, crossover and variation to screening of individuals, the good of fitness the value individuals are preserved, the bad to be eliminated, the new generation inherits the group information, but also better than the previous generation, so that repeated cycles that satisfy the convergence conditions [15].

Figure 4 shows the organigram of a Genetic algorithm (AG) method.

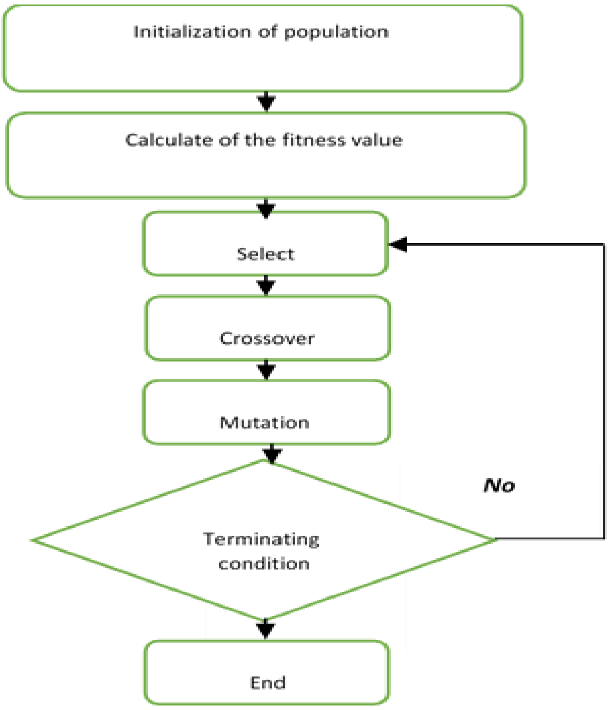

Fig.4. flow chart of genetic algorithm

Solving of the Genetic Algorithm is the minimum of fitness value function. The parameters for genetic algorithms: the largest number of iterations 51 max generation100, the initial population size 20, crossover probability 0.8, mutation probability 0.2. The solution obtained is a global optimal solution. The algorithm of GA is presented in figure 4.

6. Ag Optimization Results

Tables 3 and 4 show the results obtained by algorithm genetic.

TABLE3. Pump performances GA

Performance	AG
Best function (kg)	08.1025
Number of iterations	100

TABLE4. Pump dimensions obtained by Genetic Algorithm

Parameters	Before optimization	After optimization
X1 (m)	0.028	0.032
X2 (m)	0.056	0.062
X3 (m)	0.00	0.00
X4 (m)	0.36	0.39
X5 (m)	0.008	0.012
X6 (m)	0.36	0.36
X7 (m)	0.00	0.00
X8 (m)	0.23	0.26
X9 (m)	0.008	0.012
X10 (m)	0.18	0.22
X11 (m)	0.056	0.056
Iron mass (Kg)	2.2523	2.0621
Coil's mass (Kg)	0.1487	0.1525
Mercury's mass (kg)	6.6261	5.8354

Figure 5 show the results of the optimum design obtained by Genetic Algorithm method.

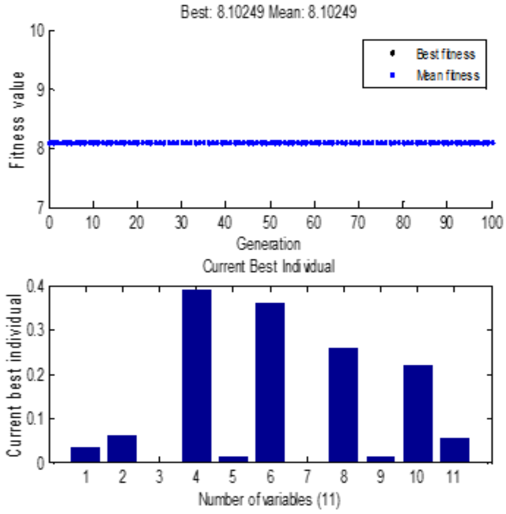

Fig.5. Genetic Algorithm Result

7. Analysis Results

The results of the genetic algorithm should be the optimal overall solution in theory, but in order to verify the feasibility of the genetic algorithm method, their results are considered as the initial point of the genetic algorithm method.

With this optimal vector dimension; we have presented the 2D numerical modeling of the electromagnetic phenomena using the finite volume method (FVM) in cylindrical coordinates.

The figures (6), (7) and (8), present respectively, the distribution of the magnetic vector potential and the magnetic induction in the channel of the MHD pump.

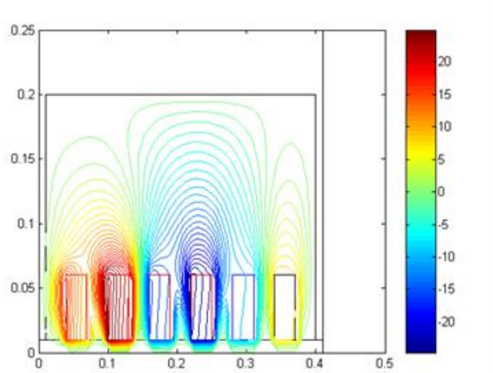

Fig.6. Equipotential lines in the MHD pump

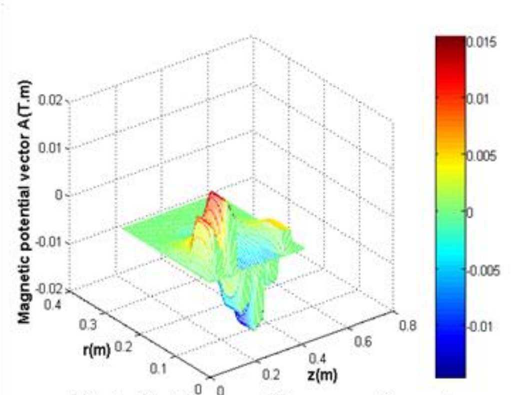

Fig.7. Distribution of the magnetic vector potential in the MHD pump

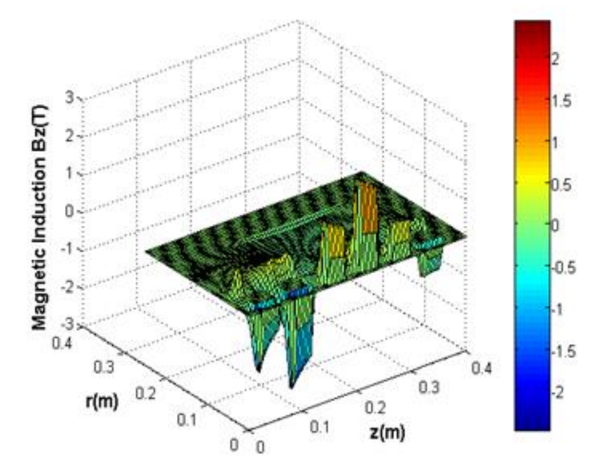

Fig.8. Distribution of the magnetic induction in the MHD pump

It is clear that the magnetic induction B reaches its limit value at the inductor and decreases as one moves away from the field.

The figures (9) and (10), present respectively, the current density and electromagnetic force with and without optimization in the channel of the MHD pump.

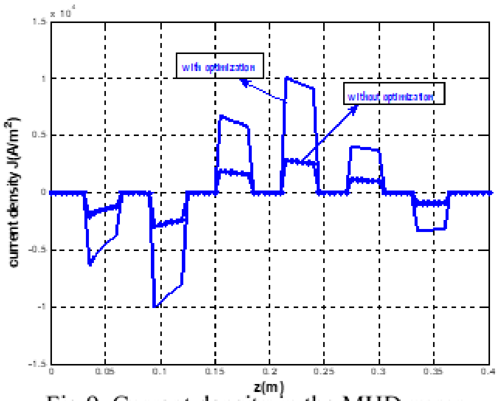

Fig.9. Current density in the MHD pump

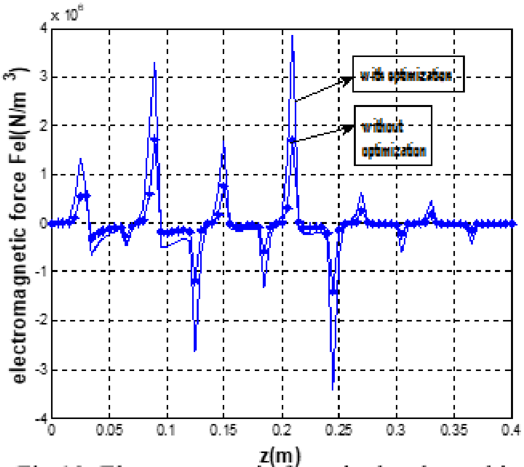

Fig.10. Electromagnetic force in the channel in the pump

The hydrodynamic model of the MHD pump is based on the Navier-Stokes equation. The solution of the flow equations allows the determination of the velocity and pressure.

Figure 11 presents the variation of the velocity with and without optimization in the channel of the MHD pump. We note that the velocity of the fluid passes through a transitional period and then stabilizes as in all the electrical machines. The velocity increases as we advance in the channel.

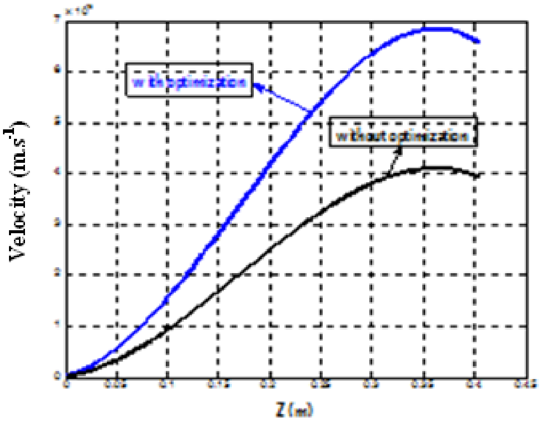

Fig.11. Velocity in the channel of the MHD pump

Figure 12 shows the pressure variations with and without optimization in the channel. It is found that the pressure increases as we advance in the channel. Moreover, the shock values become important with a shorter transient state.

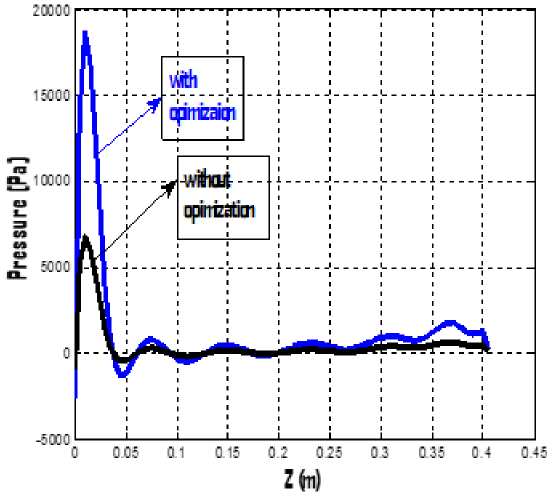

Fig.11. Pressure variations in the channel of the MHD pump

8. Conclusion

In this paper we have studied the optimal design of an annular induction MHD pump using the genetic algorithm method, for assumes the minimum of mass as the objective function.

This method has several advantages as a good quality solution where the constraints can be easily introduced.

The obtained results show that the optimized pump has a good performance. According to the obtained results, we see the strong capacity of the genetic algorithm (GA) method in obtaining the optimum of the pump mass.

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