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Measurement Of The Optimal Dimensions Of A Conduction Magneto-Hydrodynamic Pump Using The Tabu Search Optimization Technique

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The focus of this article is the optimal design of a conduction magneto-hydrodynamic pump using the tabu search method. Tabu Search is a meta-heuristic that directs a local heuristic search procedure to investigate the solution space beyond local optimality. One of the primary components of tabu search is the use of adaptable memory, which offers a more flexible search. The optimization process considers mass minimization with geometric and electromagnetic constraints, presenting the results obtained.

***Keywords**: Magneto hydrodynamics, Conduction pump; Tabu search, Fitness function, Constraints, Optimization.*

1. Introduction

The study of the interaction between magnetic fields and moving, conducting fluids is known as magneto hydrodynamics, or MHD. In 1833, W. Richie made the first observation of the MHD phenomena. The electromagnetic device pumps liquid metal with eddy currents. These induced currents and their associated magnetic fields generate the Lorentz force, and allow the pumping of liquid metal **[1]-[2]**. Magneto hydrodynamics is widely applied in various domains, such as metallurgical industry, to transport the liquid metals in fusion and the marine propulsion **[3]-[4]**. The advantage of these pumps, which ensure the energy transformation, is the absence of moving parts.

The interaction of moving conducting fluids with electric and magnetic fields allows for a rich variety of phenomena associated with electro-fluid-mechanical energy conversion **[5]**.

Numerous areas and sectors of human endeavor frequently include optimization challenges, wherein we must identify ideal solutions to certain issues while adhering to certain constraints.

Optimization focuses on the creation of efficient and powerful computer infrastructures, which will be used to accelerate meta-heuristic procedures by greatly enhancing their performance. As a result, several heuristic algorithms have been created to locate near-optimal solutions more quickly.

Heuristic algorithms can produce workable solutions promptly. The ant colony algorithm, genetic algorithms, simulated annealing, and tabu search are examples of these heuristics **[6]**.

In this paper, the design by optimization of the MHD.
pump by using tabu search technique is studied. Tabu search is developed in Matlab incorporates penalties. In addition, the magneto hydrodynamic problem is studied using the finite volume method.

2. Presentation of the Pump

The schematic of the MHD pump is shown in (fig.1). The different parts which constitute the magneto hydrodynamic conduction pump are:
The magnetic circuit: it is intended to create the magnetic field. Two coils: where an excitation current is injected.
The channel in which the electrically conductive fluid flows; It is assumed that the fluid is incompressible and laminar and the material properties such as kinematics viscosity and density are constant. The two electrodes in contact with the conductive fluid: they are used to inject current I inside the channel. They are made with a material that is a good conductor of electricity. The power supply generally with high current and low voltage.

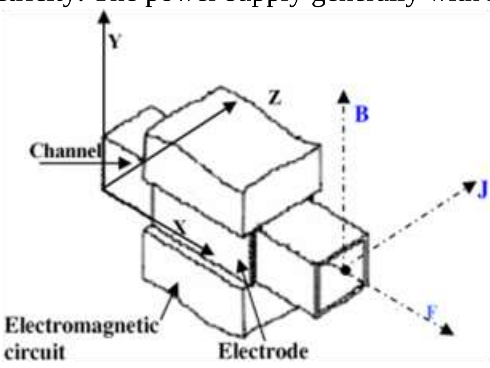

Fig. 1. Scheme of a conduction MHD pump [2]

The principle of the MHD pump is similar to that of the

DC motor. When power on the inductor it generates a magnetic induction B. The interaction between magnetic induction and the current J injected by the electrodes gives rise to a Laplace force J∧B ensuring the flows of the fluid **[7]- [8]- [9].**

The properties of the mercury fluid are given in table 1.

Table 1: Fluid properties

Parameter	Mercury solution
Density ρ	13.6×103 kg/m^3
Electrical conductivity σ	1.06×106 S/m
Relative permeability μ_r	1.55
Electric current density J ex	5×10 6 A/m^2

3. Electromagnetic Problem

The axisymmetric problem describing electromagnetic devices is obtained from the Maxwell's equations in terms of the magnetic vector potential $\vec{A}$

$$\overrightarrow{rot}(\frac{1}{\mu}\overrightarrow{rot}\ \vec{A}) = \overrightarrow{J_{ex}} + \overrightarrow{J_a} + \sigma(v.\frac{\partial\vec{A}}{\partial x}) \tag{1}$$

The magnetic induction and the electromagnetic force are given by:

$$\vec{B} = \overrightarrow{rot}\vec{A} \tag{2}$$

$$\vec{F} = \vec{J} \wedge \vec{B} \tag{3}$$

Following the two-dimensional (2D) developments in cartesian coordinates, where the current density and the magnetic vector potential are perpendicular to the longitudinal section of the MHD pump, the equation becomes:

$$-\frac{1}{\mu}(\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2}) = \overrightarrow{J_{ex}} + \overrightarrow{J_a} + \sigma(v_x.\frac{\partial\vec{A}}{\partial x}) \tag{4}$$

4 Hydrodynamic Problems

The MHD flow of an incompressible, viscous and electrically conducting fluid in a transient state condition is governed by the Navier-Stokes equations [5]

$$\frac{\partial V}{\partial t} + (\vec{V}.\vec{\nabla})\vec{V} = -\frac{1}{\rho}\,\vec{grad}P + \upsilon\Delta\vec{V} + \frac{\vec{F}}{\rho} \tag{5}$$

$$div\vec{V} = 0 \tag{6}$$

Equation (5) determines the fluid dynamics portion of the problem by illustrating the conservation of energy of the fluid in motion, where P is the pressure, ρ is density, and ϑ represents fluid kinematic viscosity. Equation (6) reveals the conservation of mass

5. Numerical Method

The determination of electromagnetic fields and velocity involves various methods, with the choice depending on the specific problem.

In this study, the finite volume method is selected, dividing the field into elements with four nodes each. (Figure.2),**[10].**

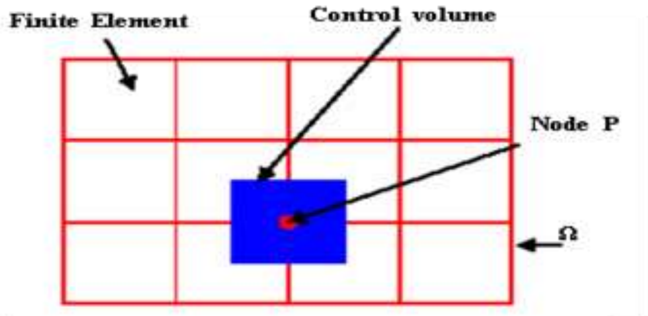

Fig. 2. Grid of the domain.

The method consists of discretizing differential equations by integration on finite volumes surrounding the nodes of the grid. In this method, each principal node P is surrounded by four nodes N, S, E and W located respectively at North, South, Est and West (figure.3).

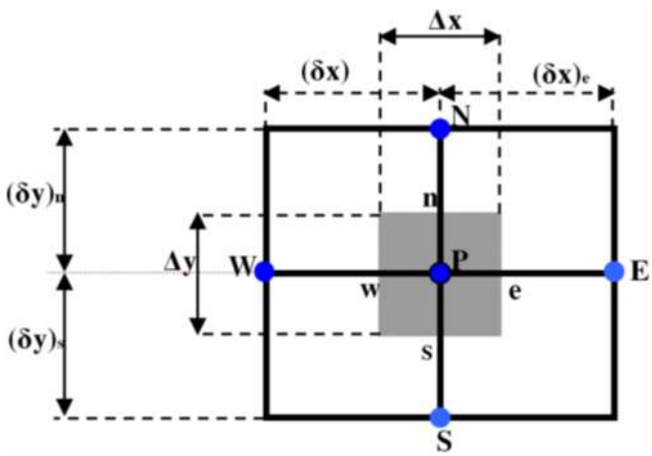

Fig. 3. Discretization in finite volume method.

The method consists of discretizing differential equations, there is one control volume surrounding each node (Fig. 3) and the differential Eq. (1) and Eq. (5) is integrated over each control volume using the finite volume approach.

We integrate the electromagnetic equation in the finite volume method delimited by the surfaces E, W, N and S, **[11]**. Finally, we obtain the algebraic equation which is written as:

$$\int_w^e\int_s^n\left[\frac{1}{\mu}\left(\frac{\partial^2 A}{\partial x^2}+\frac{\partial^2 A}{\partial y^2}\right)\right]dxdy=\int_w^e\int_s^n\left(\overrightarrow{J_{ex}}+\overrightarrow{J_a}+\sigma v_x.\frac{\partial\vec{A}}{\partial x}\right)dxdy \qquad (7)$$

After integration, the final algebraic equation will be:

$$a_pA_p=a_eA_e+a_wA_w+a_nA_n+a_sA_s+d_p \qquad (8)$$

$$a_p=\frac{\Delta y}{\mu_e(\delta x)_e},\quad a_w=\frac{\Delta y}{\mu_w(\delta x)_w},\quad a_n=\frac{\Delta x}{\mu_n(\delta y)_n},\quad a_s=\frac{\Delta x}{\mu_s(\delta y)_s} \qquad (9)$$

The resolution of the electromagnetic, equations make it possible to determine the magnetic potential vector$\vec{A}$, magnetic induction$\vec{B}$, the electric density $\vec{J}$ and the electromagnetic force $\vec{F}$, in the conduction pump. The velocity in the MHD pump's channel can be obtained according to the solution of the hydrodynamic equations.

6. Optimization procedure

The adopted procedure is schematized in figure 4. It uses the magnetic model defining the device to be conceived. An optimization method with constraints is used to reach the optimal solution (minimizing the mass of the pump).

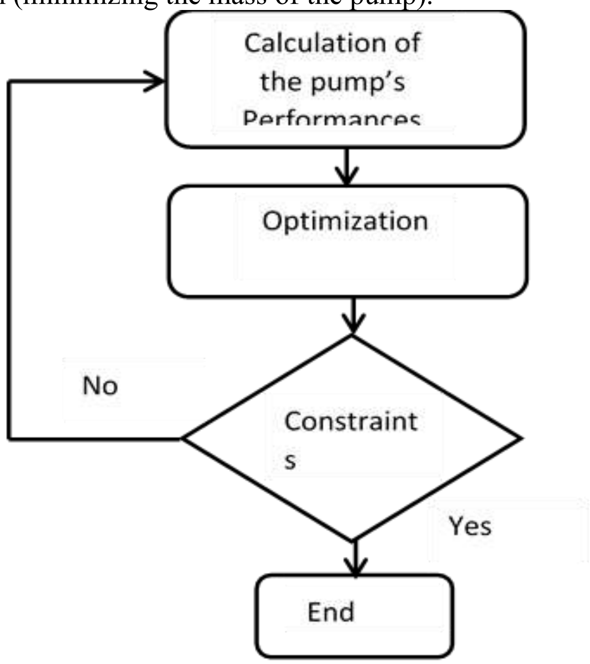

Fig. 4. Optimization procedure for the design of the conduction MHD pump

7. Mathematical formulation of the optimization problem

The objective function that has to be optimized must be defined in order to establish the optimization issues. In this case, the weight of a conduction MHD pump has been considered. The accounting of the constraints in a method of optimization stochastic is often obtained by using a function of penalty associated with the objective function.

The resolution of the design problem will be identical to that of the optimization problem described in (P).

To find the unknown vector X that minimizes the objective function mass (X):

$$(P)\begin{cases} \text{Min mass}(X) \\ B(X) \leq 1.8 \text{ Tesla} \\ J(X) \leq 5\times 10^6 \text{ A/m}^2 \\ X_{min} \leq X \leq X_{max} \\ X = (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8) \end{cases} \quad (8)$$

Where:

x_1: Channel’s width (m)
x_2: Channel’s length (m)
x_3: Inductor’s length (m)
x_4: Inductor’s width (m)
x_5: Coil’s length (m)
x_6: Coil’s width (m)
x_7: Electrode’s length (m)
x_8: Electrode’s width (m)

The optimization problem with constraints, system (8) is transformed into a problem without constraints using the external penalties method **[12].**

The optimization problem (8) becomes:

$$\text{Minmass (X)} = f(x) + r^k \left[\max^2(0, \frac{B}{1.8} - 1) + \max^2(\frac{J}{5\times10^6} - 1)\right] \quad (9)$$

Where:
f(x): The mass of the pump without constraints;
r=1, and k=0. 1.

8. Tabu Search Method

Glover developed tabu search (TS), which has been successfully used to a variety of combinatorial optimization issues. To cover a broad variety of options, this method begins by determining the most promising places based on the size of the neighborhood. When the most promising areas are identified, the algorithm intensifies the search inside the promising area of the solution space in order to identify the best solution. It has been noted that compared to many other techniques, tabu search has a higher likelihood of locating the global minimum **[12]**. One benefit of this strategy over others is its ability to solve the problem of local optimal by employing tabu lists (memory principle). A tabu list is built to forbid the selection of already visited solutions and their neighborhoods.

This technique is an adaptive memory approach:

- Short-term memory diversification;
- Long-term memory intensification.

This approach often has a faster execution time.

9. Basic Tabu Search Algorithm

Tabu search is a local search technique that needs a beginning solution and a neighborhood structure. The process starts with a first solution, which is kept as the best and current seed solution. The neighbors of the current seed are then generated via a neighborhood structure. These are proposed solutions. They are evaluated for an objective function, and a candidate that is not a tabu or meets the aspiration condition is chosen as a new seed solution. This solution is moved and added to tabu list in order to create memory. The new solution is compared with the current solution. If better, it is stored as new best solution. Repeated iterations until satisfied. **[12]-[13]-[14].**

Figure 5 illustrates the flowchart of the tabu search approach.

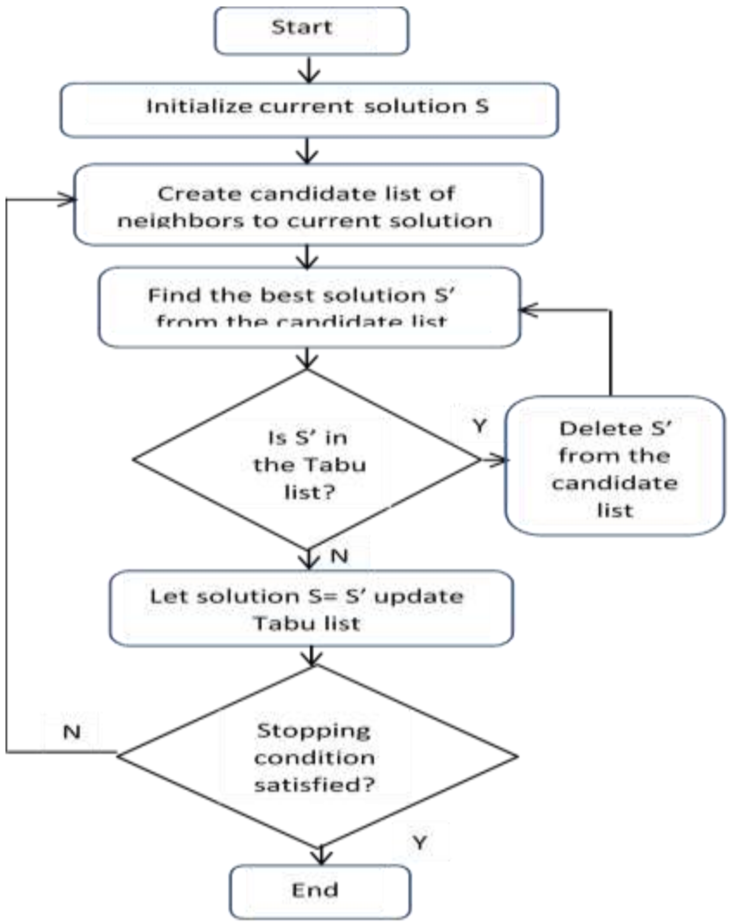

Fig. 5. Flowchart of Tabu search algorithm **[13]**

9. Application and Results

The results of optimization by the tabu search method are presented and summarized in table 2.

We see that the tabu search method always proves its capabilities and reliability for exploring the research domain and gives the best optimum.

Table 2 Results

Parameters	Dimension without optimization	Dimension with optimization
Channel’s width (m)	0.2	0.2040
Channel’s length (m)	0.2	0.2042
Inductor’s length (m)	0.07	0.0653
Inductor’s width (m)	0.3	0.2941
Coil’s length (m)	0.0250	0.0240
Coil’s width (m)	0.15	0.1341
Electrode’s length (m)	0.08	0.0311
Electrode’s width (m)	0.1	0.0936
Iron mass (Kg)	4.1212	3.7500
Coil’s masse (Kg)	1.6725	1.4610
Electrode’s masse (Kg)	0.1040	0.0380
Mercury’s masse (Kg)	3.2496	3.2473
Pump’s masse (Kg)	9.1474	8.4963

Using the obtained optimal dimensions vector, we present the 2D numerical modeling of the magneto- hydrodynamic phenomena using the finite volume method (FVM).

The figures (6) , (7) and (8) represent respectively the conduction MHD pump configuration , the equipotential lines and the distribution of the magnetic vector potential in the MHD pump.

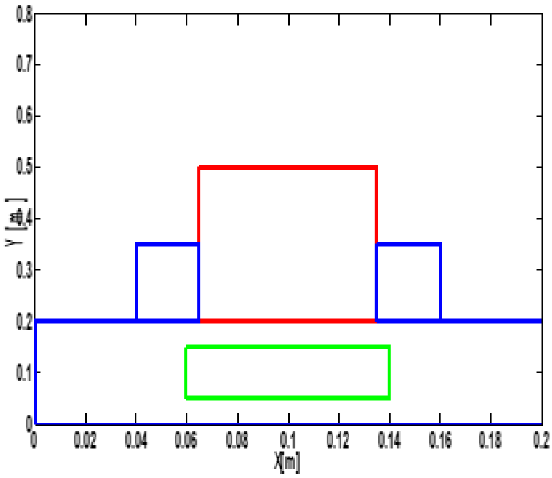

Fig. 6. The conduction MHD pump configuration

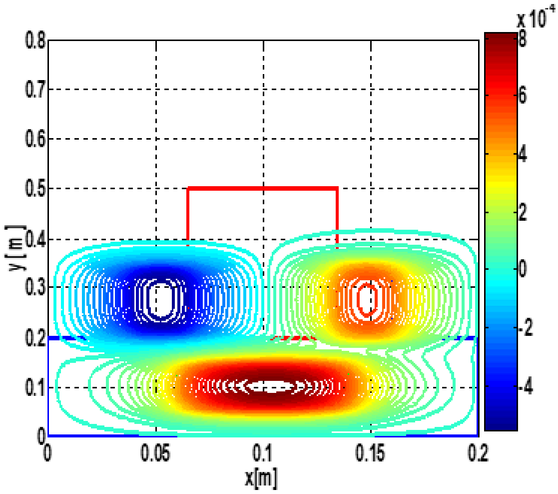

Fig. 7. Equipotential lines in conduction MHD pump

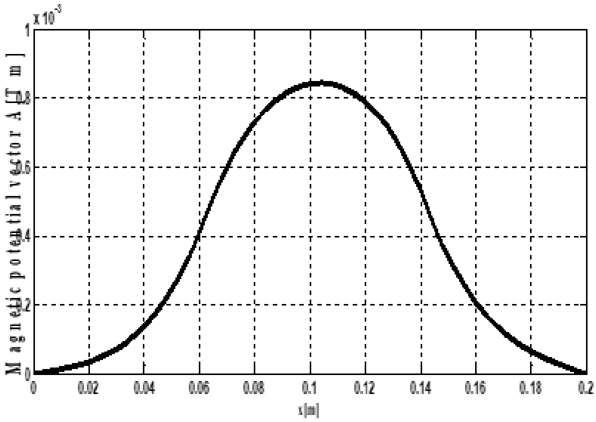

Fig. 8. Magnetic potential vector in the pump

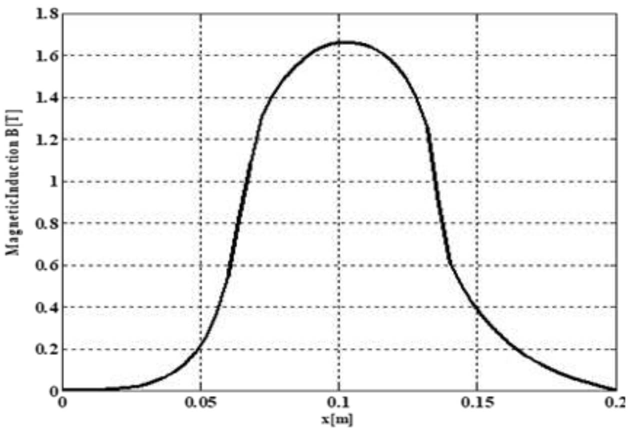

Fig. 9. Magnetic induction in the MHD pump

The magnetic induction in the channel's is shown in figure 9. Clearly, the magnetic induction reaches The greatest value is at the channel's medium and inductor.

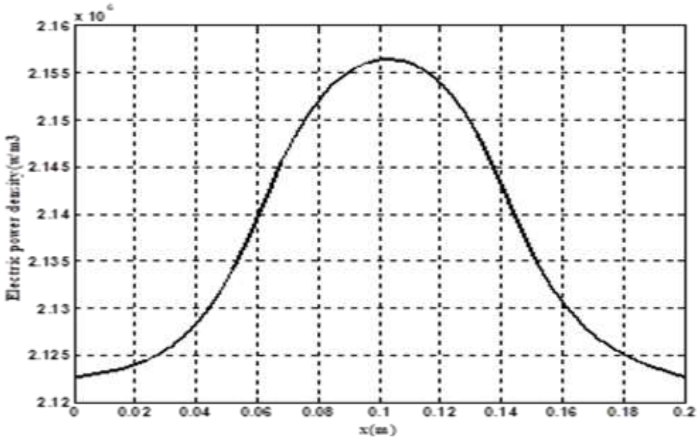

Fig. 10. The electric power density in the channel

The figure (10) shows the electric power density in the channel. The maximum induced power reaches $2.157 \times 10^6 W / m^3$. The obtained pace and the eddy current density are directly correlated.
The electromagnetic force in the channel is shown in figure (11). It is seen that the MHD pump's channel medium has the highest value.

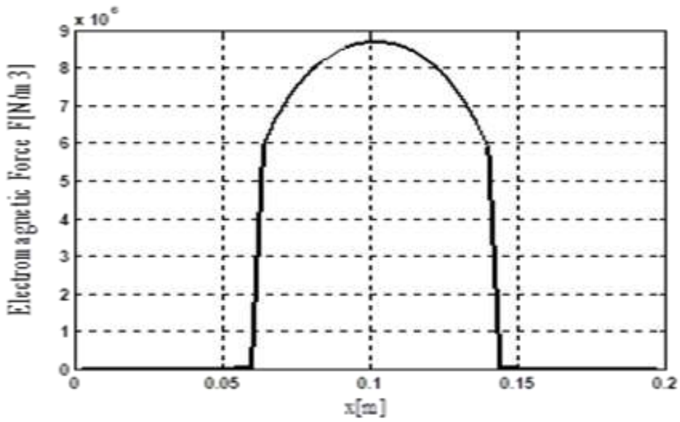

Fig. 11. Electromagnetic force in The MHD pump

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 in the channel of the MHD pump.

Figure (12) presents the variation of the velocity in the pump channel. We note that the velocity of the fluid passes through a transitional period and hen stabilizes as in all the electrical machines. The velocity increases as we advance in the channel.

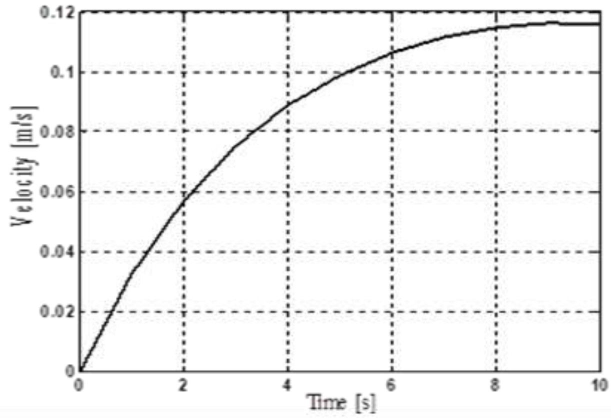

Fig. 12. Velocity in the channel of the MHD pump

Tabu search is a powerful algorithmic approach that has been applied with great success to many difficult combinatorial problems. A particularly feature of tabu search is that it can quite easily handle the constraints that are typically found in many applications.

11. Conclusion

The optimal design problems can be solved by many techniques like Genetic algorithm, Simulated annealing, Tabu Search, Ant Colony Optimization.

In this paper, tabu search is applied to optimal design problems to obtain the best weight of the conduction pump with satisfied constraints.

The pump's optimal dimensions were determined and utilized in a numerical approach to determine several parameters, including the distribution of the magnetic vector potential, the magnetic flux density, the electromagnetic force and velocity in the channel of the MHD pump are given. The approach seems to be a promising one because of its generality in nature and its effectiveness in finding very good solutions to difficult problems.

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