# Optimization of an MHD Pump by Tabu Search Method


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## Abstract

This paper is devoted to a global optimization method for an optimal design of MHD pump. This method based on the tabu search algorithm does not depend on initial guesses and gives preference to global optima. It is showed that using appropriate parameters in the tabu search algorithm, the computing time for solution of an optimal point is reduced considerably.

The optimization procedure uses an objective function which can be the minimum of the mass. The constraints are both of geometrical and electromagnetic type. The obtained results are reported.


## 1. Introduction

Two main types of electromagnetic pump for liquid metals can be distinguished: conduction pumps, AC or DC, in which a magnetic field is established across a tube containing liquid metal, and current is fed to the liquid through electrodes connected to the tube walls; and induction pumps, in which a magnetic field induces the required current, as in the induction motor. The induction pump takes three main forms: annular linear (Alip), flat linear (Flip), and spiral (Sip). These are probably the most useful types of electromagnetic pumps for liquid metal. And each one is examined and compared in an attempt to predict their relative performance and their main design features [1].

Magnetohydrodynamics (MHD) is the study of the interaction between magnetic fields and moving, conducting fluids. The MHD phenomenon was first observed by W. Richie in 1833. The first experiments about magnetic field effects on electrochemical systems date back more than a century ago and have been credited to M. Faraday. However, the development of MHD as an independent scientific discipline started at the first half of the 20th century when astrophysicists realized how ubiquitous magnetic fields and plasmas are throughout the universe. In 1940, H. Alfvén formulated the main principles of MHD, and in 1970 was awarded the Nobel Prize for his pioneering work in MHD. Scientists in several fields are interested in MHD, namely for plasma physics, geophysics, or liquid metal flow engineering [2].

Electromagnetic pumps have several advantages to mechanical pumps. They offer maneuverability by directional thrust along with quietness and are conceived with an aim of eliminating all moving parts, being also free from problems of wear and tiredness of use [3].

This paper suggests a tabu method, for solving the general constrained optimization problem in an MHD pump. The presented approach has the potential to find the global optimum and it does not need any additional information than the dynamic model.

This method that we have developed in matlab incorporates penalty methods. tabu search is used in optimal design of a MHD pump. This pump consists on a magnetic in the torus shape, two winds, two electrodes and a channel. It is assumed that the fluid is an incompressible, laminar and the material properties such as kinematics viscosity and density are constant.

Figure 1 and figure 2 represent respectively a schematic view and plane geometry of the MHD pump.

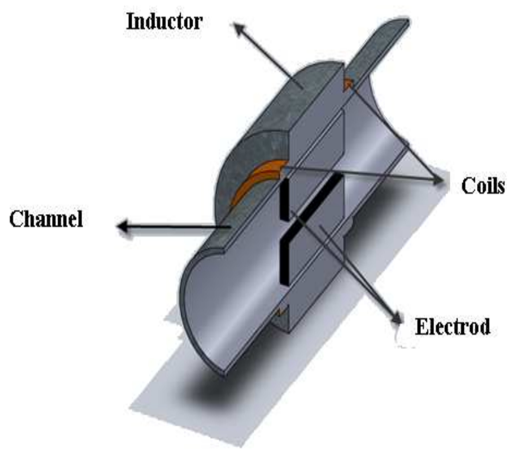


**Fig. 1.** Schematic view of the DC pump

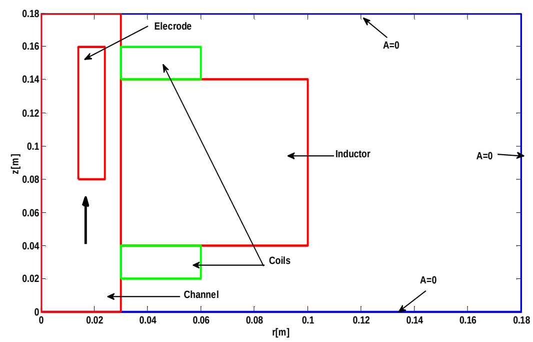


**Fig. 2.** Plane geometry of the DC pump

## 2. Optimization procedure

The adopted procedure is schematized on figure 3. 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 and satisfying the constraints of the schedule conditions). Figure 3 shows the adopted optimization procedure.

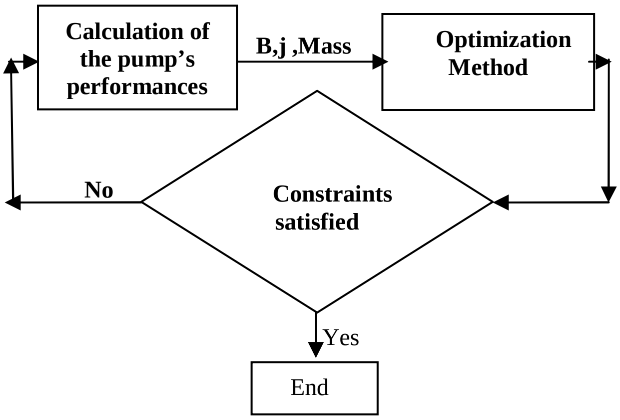


**Fig. 3.** Optimization procedure for the design of the MHD pump

## 3. Optimization problem formulation

To formulate the optimization problems, it is necessary to define the objective function to be optimized. In this case, we have considered the weight of an annular induction MHD pump. The remainder of the criteria of the schedule conditions will be used like constraints of equalities and inequalities.

In order to investigate optimal structure of a DC pump MHD, in which an electromagnetic force directly moves an electromagnetic fluid, the magneto-fluid analysis should be carried out.

The resolution of the design problem will be equivalent to the resolution of the optimization problem defined as follows:
To determine the unknown vector X: which minimizes the objective function mass (X):
Min mass (X) Subjugated with:
Constraints of inequalities:

$B(X) \leq 1.5$Tesla

$j(X) \leq 5.10^6 A/m^2$

Thrusts fixing the acceptable field:

$X_{min} \leq X \leq X_{max}$

$X=(x_1, x_2. x_3, x_4, x_5, x_6, x_7, x_8)$.

Where:

$x_1$: Electrode's width
$x_2$: Electrode's length
$x_3$: channel's radius
$x_4$: channel's length
$x_5$: inductor's radius
$x_6$: inductor's length
$x_7$: coil's radius
$x_8$: coil's length

## 4. Tabu search method

Tabu search (TS) was originally developed by Glover and successfully applied to a variety of combinatorial optimization problems. However, very few works deal with its application on the global minimization of functions depending on continuous variables. In order to cover a wide domain of possible solutions, this algorithm first performs the diversification: it locates the most promising areas by fitting size of the neighbourhood structure to the objective function and its definition domain. When the most promising areas are located, the algorithm continues the search by intensification within one promising area of the solution space to find the optimum design. It has been observed that tabu search is more likely to find the global minimum than many other methods [4].

It is an iterative metaheuristic technique used for finding, in a set $X$ of feasible solutions, the solution that minimizes an objective function f based on neighbourhood search (NS). In tabu search, each feasible solution $x$ has an associated set of neighbours, $N(x) \subset X$, called the neighbourhood of $x$. It starts with a given initial feasible solution and checks the space $X$ by moving from one solution to another one in its neighbourhood. At each iteration of the process, a subset V of $N(x)$ is generated and we move from the current solution $x$ to a best one $x_n$ in V, whether or not $f(x^*)$ is better than$f(x)$. In some optimization problems, including the problem at hand, when exploring the set V we find that there are multiple optimal solutions. Then, an important feature in these problems is to make a random choice of a best solution $x_n$ of V. However, the main short coming of this simple heuristic optimization algorithm lies in cycling. The tabu search algorithm offers another interesting possibility for overcoming the above-mentioned obstacle of the NS technique. To prevent cycling, a queue called the tabu list L of length [L] is provided. Its aim is to forbid moves between solutions that reinstate certain attributes of past solutions. After t iterations they are removed from the list and are free to be reinstated [5].

Sometimes, the tabu list may forbid certain interesting moves, such as those that lead to a better solution than the best one found so far. An aspiration criterion is introduced to cancel the tabu status of a move when this move is judged useful. Stopping rules must also be defined. In many cases (including our optimization problem), a lower bound $f^*$ for the objective function is known in advance.

As soon as this bound is reached the algorithm is interrupted. In general, however, $f^*$ is not available with sufficient accuracy, or the algorithm may not attain the lower bound in a reasonable number of iterations. Therefore, a fixed maximum number of iterations is used in practice [5].

## 5. Basic tabu search algorithm

As a first step towards the description of TS, we reformulate the classical descent method as follows [6]:

- Step 1: Choose an initial solution i in S.
  Set i* = i and k=0.
- Step 2: Set k=k+1 and generate a subset V* of solution in N (I, k) such that either one of the Tabu conditions is violated or at least one of the aspiration conditions holds.
- Step 3: Choose a best j in V* and set i=j.
- Step 4: If f(i) < f(i*) then set i* = i.
- Step 5: Update Tabu and aspiration conditions.
- Step 6: If a stopping condition is met then stop. Else go to Step 2.

## 6. Tabu search stopping conditions

Some immediate stopping conditions could be the following [6]:

1. N (i, K+1) = 0. (no feasible solution in the neighborhood of solution i)

2. K is larger than the maximum number of iterations allowed.
3. The number of iterations since the last improvement of i* is larger than a specified number.

## 7. Accounting of the constraint

As mentioned earlier, the aim of the tabu method is to move away from local optima by allowing degradation of the solution with respect to the leader's objective. This method is performed whenever no improvement of the current solution is reached through the local ascent phase. The tabu method is stopped after a maximum number $i_{max}$ of iterations without improvement [7].

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. Classically, one uses a function of external penalty [8], according to which the function to be minimized becomes equal to:

$$W(X) = f(X) + r\sum_{i=1}^{m}\left[\max\left[0, g_i(X)\right]\right]^2 \tag{1}$$

Where:

$f(x)$: Objective function without constraints;

$g_i(X)$: Constraints function;

$r$: Penalty coefficient.

## 8. Results

Table 1 shows the results obtained by tabu method

**Table 1.** Results obtained by tabu method

| Parameters | Dimensions |
|---|---|
| electrode's length (m) | 0.0094 |
| electrode's width (m) | 0.1000 |
| inductor's length (m) | 0.1000 |
| inductor's radius (m) | 0.0294 |
| coil's radius (m) | 0.0294 |
| coil's length (m) | 0.0200 |
| channel's radius (m) | 0.0294 |
| channel's length (m) | 0.1799 |
| Iron mass (Kg) | 20.9799 |
| Coil's masse (Kg) | 0.7383 |
| Electrode's masse (Kg) | 0.4242 |
| Mercury's masse (Kg) | 4.2829 |
| Pump's masse (Kg) | 26.4253 |

The optimized vector dimension is used the finite volume for the study of electromagnetic model the results obtained is presente by figures below:

The figures (4), (5), (6), (7) and (8), represent respectively, the equipotential lignes, the magnetic potential vector, the magnetic induction, the current density and the electromagnetic force in the channel in MHD pump.

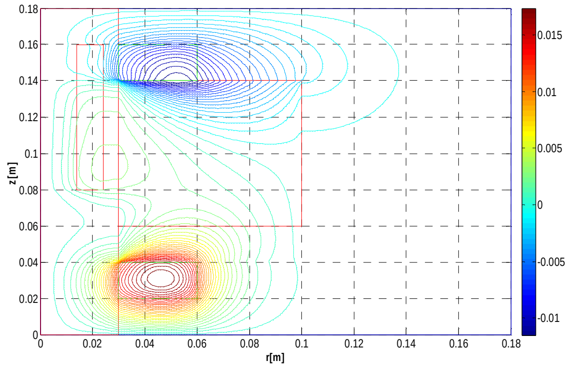


**Fig. 4.** Equipotential lignes in MHD pump

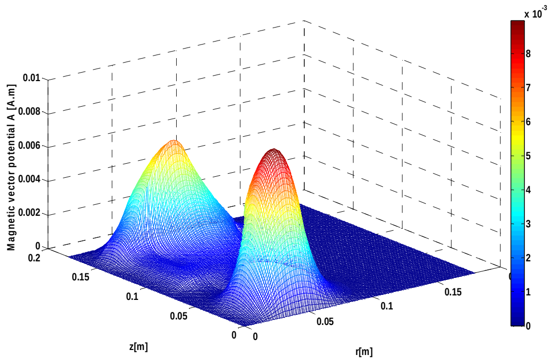


**Fig. 5.** The potential vector in the MHD pump

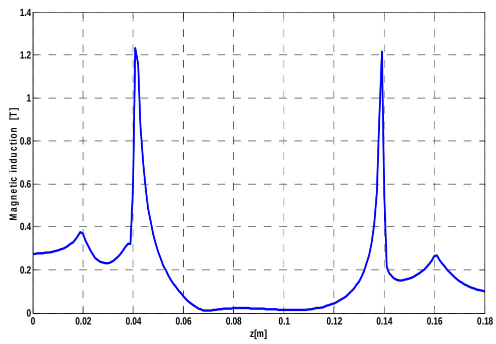


**Fig. 6.** The magnetic induction in the MHD pump

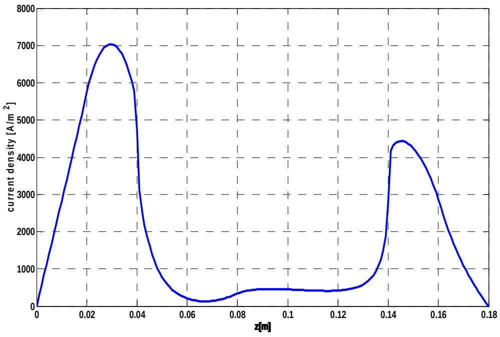


**Fig. 7.** The current density in the MHD

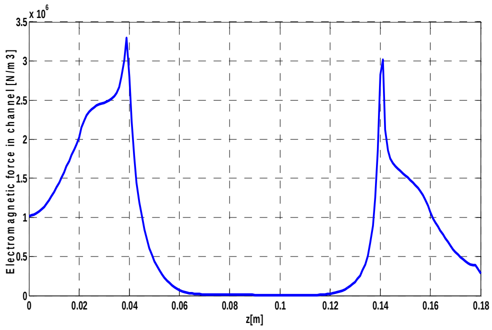


**Fig. 8.** The electromagnetic force in the MHD channel

The optimization design procedure of an MHD pump is applied successfully by the tabu search method.

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.

## 9. Conclusion

The optimization of the MHD DC pump has been done using the Tabu method with different constraints.

The obtained optimized dimensions of the pump have been used in the numerical method in order to find the different characteristics such as the magnetic induction and the electromagnetic force to move the fluid.

The tabu search is a higher level heuristic algorithm for solving optimization problems. It is an iterative improvement procedure that starts from any initial solution and attempts to determine a better solution. Although tabu search is generally a slow optimization method but this method, can cover a wide solution space and decrease the possibility of trapping in local minima. It has now become an established optimization approach that is rapidly spreading to many new fields. .

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