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Electrognetic Study of a Conduction Magetohydrodynamic (MHD) Pump

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Abstract: In this study we have studied the electromagnetic phenomena in a MHD pump for the determination of the principal parameters such as the distribution of the magnetic potential vector, magnetic induction and the electromagnetic force by the finite volume method and analyses the influence of the width of the channel on the performances of this pump.

Key words: Finite volume method, magnetohydrodynamic, conduction pump, channel

INTRODUCTION

Magnetohydrodynamic (MHD) is a scientific discipline which describes the behavior of a conducting fluid (Liquid or ionized gas called plasma) in the presence of electromagnetic fields, (Boucher, 1992; Leboucher *et al.*, 1992).

The MHD conversion is one of the applications of this discipline, it relates to the mechanical energy transformation of the movement of a fluid into electric power.

The MHD principle has been widely used in metallurgical process, such as electromagnetic casting, to control the flow of molten metals for enhancing the casting qualities.

The MHD pumps have several advantages, namely, simple fabrication process, continuous flow forces and bi-directional pumping capability (Convertert, 1995; Chang, 2004; Boissonneau, 1997).

The schematic of the MHD pump is shown in Fig.1. The basic principle is to apply an electric current across a channel filled with electrically conducting liquids and a dc magnetic field orthogonal to the currents via permanent magnets, (Boucher, 1992; Wang *et al.*, 2004; Convertert, 1995).

The aim of this study is to study the electromagnetic problem in a MHD pump for the formulated problem is solved computationally by using a finite volume method. Also, the variation of the width channel is taken account to show his effect on the pumping forces.

Governing equation: The equations which describe the pumping process in the channel are the Maxwell's equations and the equations of the medium such as:

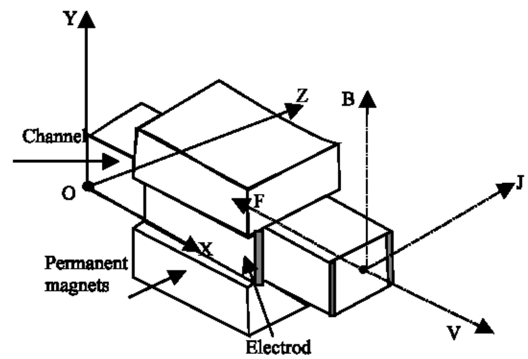

Fig. 1: Schematic of DC MHD pump

$$\vec{Rot}\vec{H} = \vec{J} \quad (1)$$

$$\vec{Rot}\vec{E} = -\partial\vec{B}/\partial t \quad (2)$$

$$Div\vec{B} = 0 \quad (3)$$

$$Div\vec{D} = \rho \quad (4)$$

$$\vec{B} = \mu\,\vec{H}, \quad \vec{D} = e\vec{E} \quad (5)$$

And in addition the law of Ohm generalized is:

$$\vec{J} = \sigma\left(\vec{E} + \vec{V} \wedge \vec{B}\right) + \vec{J}_{ex} \quad (6)$$

The electromagnetic force is given by:

$$\vec{F} = (\vec{J}_{ind} + \vec{J}_a) \wedge \vec{B} \quad (7)$$

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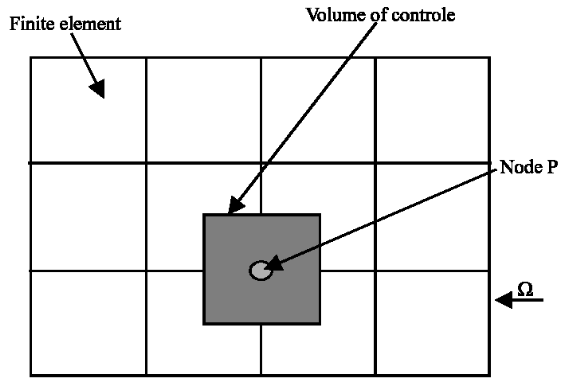

Fig. 2: Gride of the domain

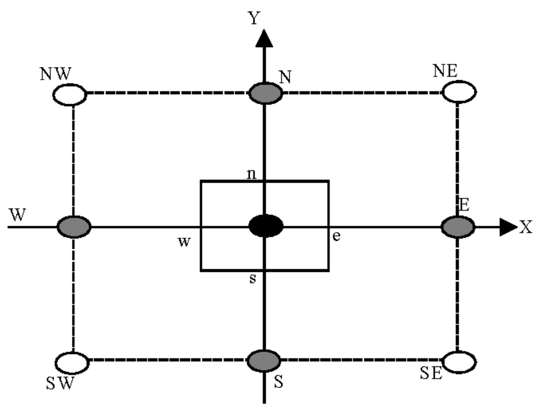

Fig. 3: Description of finite volume

The preceding equation can be combined in order to obtain the following equation:

$$\vec{R}ot(\frac{1}{\mu}\vec{R}ot\vec{A}) = \vec{J}_{ex} + \vec{J}_a + \sigma(V.\frac{\partial\vec{A}}{\partial x}) \qquad (8)$$

With;

$$\vec{R}ot\vec{A} = \vec{B}$$

is the potential magnetic vector

After development in cartesian coordinates, in the two-dimensional we have:

$$\frac{1}{\mu}(\frac{\partial^2 A}{\partial x^2}+\frac{\partial^2 A}{\partial y^2}) = J_{ex}+J_a+s\left(V\frac{\partial A}{\partial x}\right) \qquad (9)$$

To solve this system and to ensure the unicity of,we generally adds the condition of Gauge of Coulomb. This assumption is naturally checked in the two-dimensional configuration (2d).

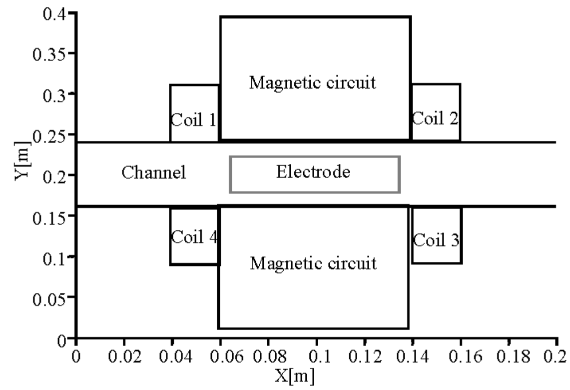

Fig. 4: A conduction MHD pump configuration

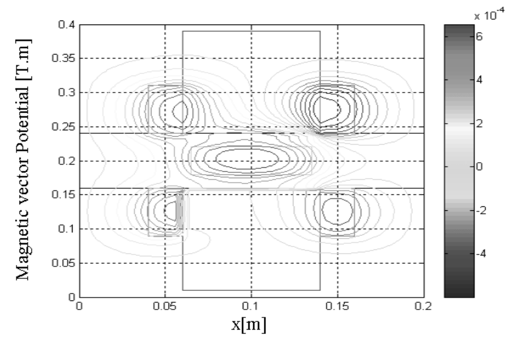

Fig. 5: Magnetic vector potential in Dc pump MHD

NUMERICAL METHODS

There are several methods for the determination of the electromagnetic fields; the choice of the method depends on the type of problem to solve.

In our research, we thus choose the finite volume method, Its principle consists on subdividing the field of study (Ù) in a number of elements. Each element contains four nodes of the grid. A finite volume surrounds each node of the grid (Fig. 2) (Patankar, 1980).

In the two-dimensional case, finite volume is limited by the interfaces (E, W, N and S), each principal node P is surrounded by four close nodes: the east E,the west W, following X and two following Y, the north N and the south S (Fig. 3) .

By integration of the Eq. (9) on the finite volume corresponding to the node P and delimited by the borders (E, W, N, S), we obtain the relation (10):

$$\int_w^e\int_s^n\left[\frac{1}{\mu}\left(\frac{\partial^2 A}{\partial x^2}+\frac{\partial^2 A}{\partial y^2}\right)\right]dx$$
$$dy = \int_w^e\int_s^n(J_{ex}+J_a+\sigma V\frac{\partial A}{\partial x})dx\,dy \qquad (10)$$

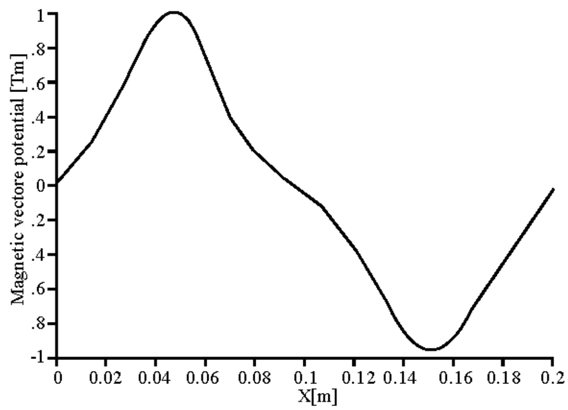

Fig. 6: Magnetic vector potential in pump

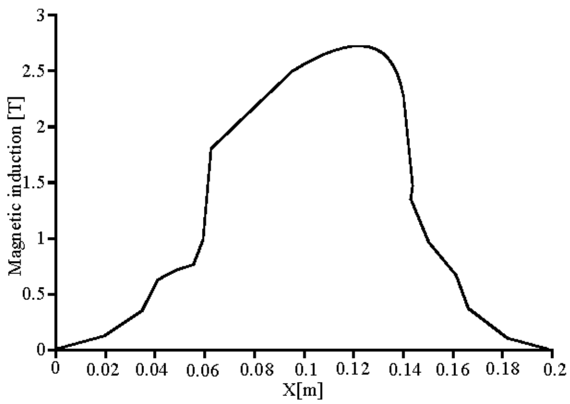

Fig. 7: Magnetic induction in channel

After integration, the final algebraic equation will be:

$$a_p A_p = a_e A_e + a_w A_w + a_n A_n + a_s A_s + d_p \qquad (11)$$

with

$$a_e = \frac{\Delta y}{\mu_e (\delta x)_e}, a_w = \frac{\Delta y}{\mu_w (\delta x)_w},$$

$$a_n = \frac{\Delta x}{\mu_n (\delta y)_n}, a_s = \frac{\Delta x}{\mu_s (\delta y)_s},$$

$$a_p = a_e + a_w + a_n + a_s \; d_P = (J_{ex} + J_a).\Delta x \Delta y$$

APPLICATION AND RESULTS

We consider the device of the following Fig. 4 which represents the transverse section of pump MHD, with the following characteristics:

- The liquid in the channel is mercury with the conductivity $\sigma_{mercure} = 1.66*10^6$ [S/m]] ;
- Current source density is Jex=$1.5*10^6$[A/m]
- Current density in the electrodes is Ja=$1.5*10^6$ [A/m].

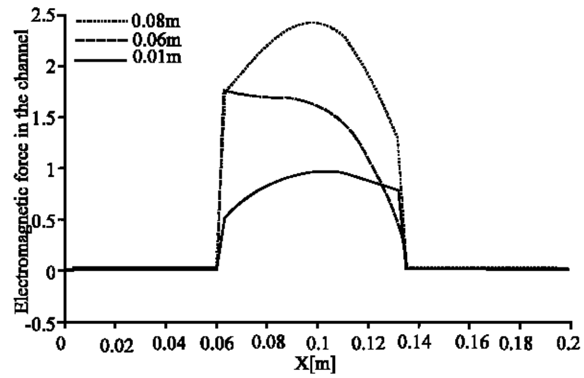

Fig. 8: Electromagnetic force in the channel

The resolution of the electromagnetic equation makes it possible to determine the magnetic potential vector.

Figure 5 and 6 represent, respectively the equipotential lines and the distribution of the magnetic vector potential vector in the MHD pump.

Figure 7 represents the magnetic induction in the channel.

It is shown that, the magnetic induction reaches its maximum value at the inductor and in the medium of the channel.

THE EFFECT OF THE CANAL WIDETH PUMP PERFORMANCES

The improvement of this study lies in the optimization of the width of the channel to maximize the electromagnetic forces. An analysis is made for three different widths of the channel:

L1 =0.08m; L2 =0.06m ; L3 = 0.1 m.

This Fig. 8 represent the electromagnetic forces for different channel width, it is note that the increasing and diminishing more than 0.08m of the width of the channel, allows the decreasing of the electromagnetic forces. These results show the need for optimization this length which is in our case of 0.08m.

CONCLUSION

In this study, we have studied the electromagnetic phenomena in 2d of pump MHD with conduction by taking account of the movement of the fluid. Various characteristics such as the distribution of the magnetic potential vector, magnetic induction and the electromagnetic force which allows the propulsion of the fluid are given. The numerical results show that the performances of the MHD pomp depend on the optimised width of the channel.

NOMENCLATURE

$\vec{H}$:Magnetic field ,[A/m.]
$\vec{E}$: Electric field,[V/m].
$\vec{B}$: Magnetic induction ,[T].
$\vec{D}$: Electric Induction, [c/m].
σ: Electric conductivity, [S/m].
ε: Electric permittivity, [F/m].
μ: Magnétic Permeability, [H/m].
V: Velocity of the fluid, [m/s].
$\vec{J}$: Current density , current source density, current density injected by electrodes ,[A/m^2].

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