Power System Technology
Volume 49, No. 3, 2025
ISSN: 1000-3673

Effect of Channel Width on the Operational Performance of a Conduction MHD Pump

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Abstract

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, 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. In this paper 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

1. Introduction

Electromagnetic converters can be associated with magnetohydrodynamics (MHD), which studies the movement of conductive fluids subjected to electromagnetic forces. In MHD, the interaction between magnetic fields and the induced electric currents in the fluid generates Lorentz forces, enabling the conversion of electromagnetic energy into mechanical or thermal energy.

Magnetohydrodynamics (MHD) is the study of conductive fluid motion under the influence of electromagnetic forces. This field combines principles of fluid dynamics and electromagnetism, focusing on the mutual interactions between fluid flow and magnetic fields. Since MHD requires electrically conductive but non-magnetic fluids, its applications are primarily limited to liquid metals, ionized gases (plasmas), and electrolytes.

Over the years, MHD has been integrated into various technological advancements, including electromagnetic propulsion and biological studies. Its applications extend to astronomy, geophysics, and engineering, particularly in liquid metal cooling for nuclear reactors, electromagnetic metal casting, MHD power generation, and propulsion [1,2].

MHD-based liquid metal pumping utilizes an electromagnetic device that induces eddy currents within the metal. These currents interact with the magnetic field, generating Lorentz forces that drive the fluid motion [3-7]. MHD technology plays a crucial role in metallurgy, where it facilitates liquid metal transport in fusion processes and marine propulsion [1-3]. A key advantage of MHD pumps is their lack of moving parts, which enhances reliability and reduces mechanical wear.

The interaction between conductive fluids, electric fields, and magnetic fields enables a range of electro-fluid-mechanical energy conversion phenomena [3,4]. Figure 1 illustrates the fundamental principle of an MHD pump, where an electric current is applied across a channel filled with a conducting fluid, while a DC magnetic field, generated by permanent magnets, is applied orthogonally to the current.

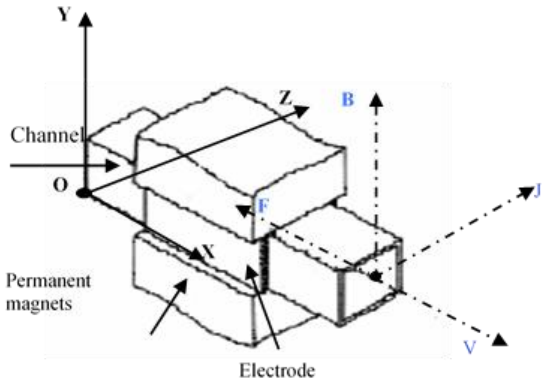

Fig1. Schematic of DC MHD pump,[3].

2. 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:

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

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

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

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

$$\left.\begin{array}{l}\vec{B} = \mu\ \vec{H}\\ \vec{D} = \varepsilon\ \vec{E}\end{array}\right. \qquad (5)$$

And in addition, the law of Ohm generalized is:

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

The electromagnetic force is given by:

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

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

$$\vec{\mathrm{Rot}}(\frac{1}{\mu}\vec{\mathrm{Rot}}\vec{A}) = \vec{J}_{ex} + \vec{J}_a + \sigma(\vec{V}\wedge\vec{B}). \qquad (8)$$

With $\vec{\mathrm{Rot}}\ \vec{A} = \vec{B}$;

$\vec{A}$ is the potential magnetic vector

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

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

To solve this system and to ensure the unicity of $\vec{A}$,we generally adds the condition of Gauge of Coulomb: $\mathrm{Div}\vec{A} = 0$. This assumption is naturally checked in the two-dimensional configuration (2d).

3. Numerical Method

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 work, we thus choose the finite volume method, Its principle consists on subdividing the field of study (Ω) in a number of elements. Each element contains four nodes of the grid. A finite volume surrounds each node of the grid (Fig.2), [9,10].

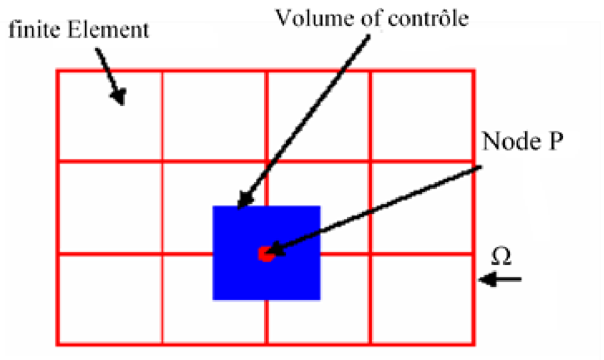

Fig 2 Grid of the domain.

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).

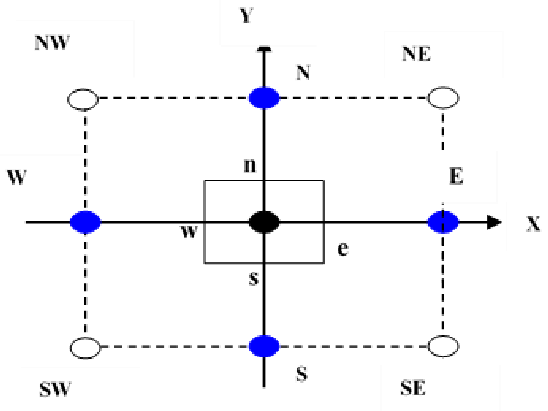

Fig 3. Description of finite volume

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

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

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

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

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

4. Application And Results

We consider the following figure which represents the transverse section of pump MHD and the equipotential lines, 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=$1.8*10^6$ [A/m²]
- Current density in the electrodes is Ja=$1.5*10^6$ [A/m²].

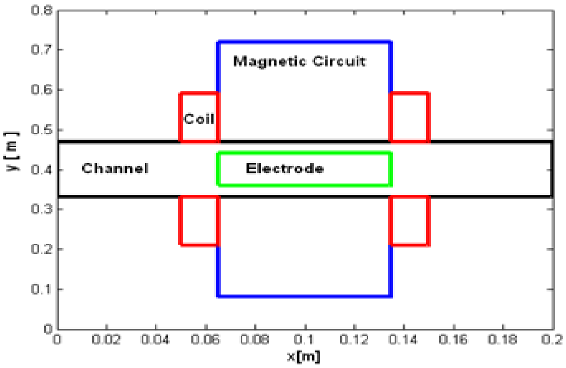

Fig 4. A conduction MHD pump configuration

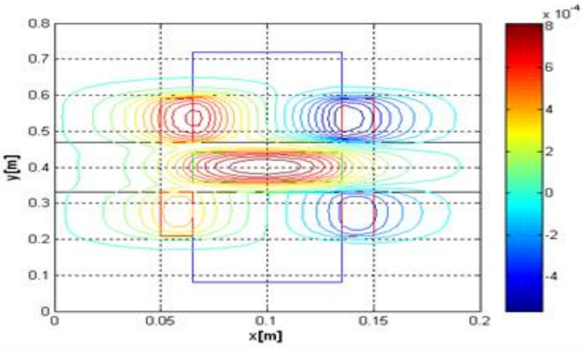

Fig.5 Equipotential lines in DC pump MHD

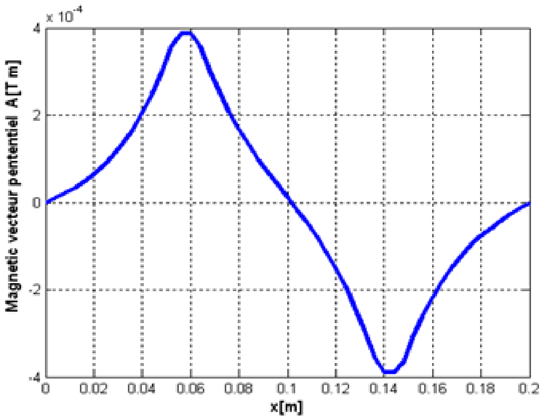

Fig 6. Magnetic vector potential in pomp

The figure (6) represents the distribution of the magnetic vector potential in the MHD pump.

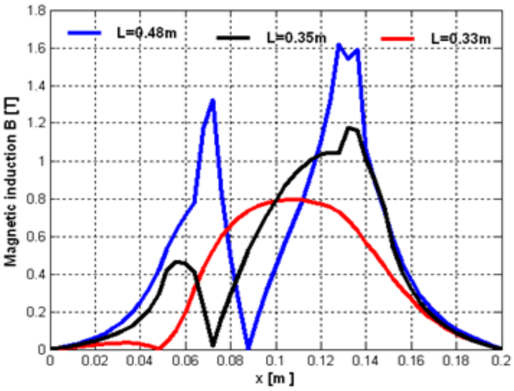

Fig.7 Magnetic induction in the pump

The figure (7) represents the magnetic induction in different area of the pump.

5. 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 =0.14m; L2 =0.1m ; L3 = 0.14 m.

This figure represent the electromagnetic forces for different channel width, it is note that the increasing and diminishing more than 0.14m 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 0.14m.

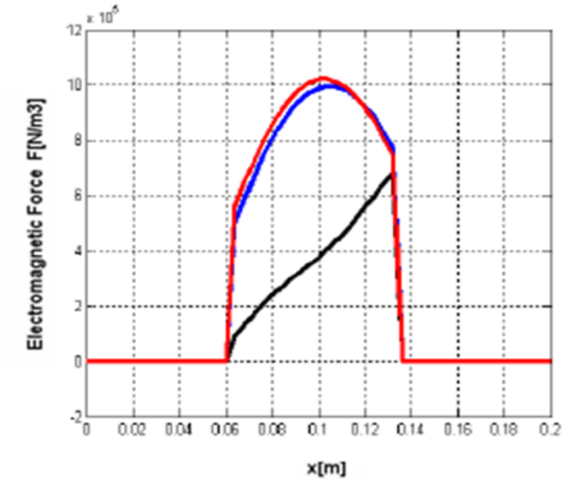

Fig.8 Electromanetic Force in the pump

6. Conclusion

In this article, 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].

$\vec{J}$, $\vec{J}ex$, $\vec{J}_a$: Current density , current source density, current density injected by electrodes ,[A/m²].

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