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The Influence of the Channel Width on the Performances of Annular Induction Magnetohydrodynamic (MHD) Pump

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Abstract: This study presents numerical modeling 2D of the MHD pump in cylindrical coordinates by the finite volume method and the determination of the influence of the channel width on the different characteristics of the pump such as distributions of the electromagnetic force and the distributions of the current density.

Key words: Finite volume method, Magnetohydrodynamic (MHD), induction pump, annular channel

INTRODUCTION

Historically, it is the study of production of electricity by MHD generators which was a long time the more significant activity in this domain. From 1969, date from which this activity was deactivation and definitively stopped because hypothetical profitability in this sector and far from perishing by disinterest, the MHD on the contrary developed and diversified (Leboucher, 1992).

The interaction of moving conducting fluids with electric and magnetic fields provides for a rich variety of phenomena associated with electro-fluid-mechanical energy conversion (Borghi, 1997).

The applications of magnetohydrodynamics are very large and in very varied domains, such as metallurgical industry, the transport or the pumping of the liquid metals in fusion and the marine propulsion (Chirstofotini and Borghi, 1995).

The principal advantage of the induction electromagnetic pumps is the absence of moving part compared to the mechanical pumps and contact with the fluid which is convicted by electromagnetic forces (Boissonneau, 1997; Tillack and Morley, 1998).

The object of this research is the study of the electromagnetic phenomene in 2D by the finite volume method and analysis of the influence of the channel width on the currents density and the electromagnetic force.

DESCRIPTION OF THE MHD INDUCTION PUMP

The 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

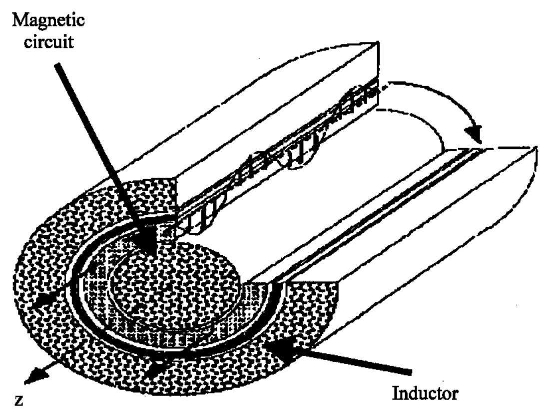

Fig. 1: Schematic of induction MHD pump (Borghi, 1997)

cylindrical geometry of annular cross sction. A ferromagnetic core is placed on the inner and the outer side of the channel (Borghi, 1997).

The principle of fonctionnement of the MHD pump (Fig. 1) is similar to that of the asynchronous motor; the alimentation of the inductor creates a magnetic field $\vec{B}$ skating with the velocity of synchronism, where electric currents are induced in the liquid metal by means of a magnetic field, producing an electromagnetic force $\vec{J} \wedge \vec{B}$ with the instantaneous field ensuring the flows of the fluid (Kadid, 2004).

ELECTROMAGNETIC MODEL

The equation describing the pumping process in the channel are the Maxwell equations (Leprovost, 2004; Abdessemed *et al.*, 1998; Farous and Renault, 1998).

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$$\begin{aligned}&\overrightarrow{\text{rot}}\vec{H} = \vec{J}\\&\overrightarrow{\text{rot}}\vec{E} = -\partial\vec{B}/\partial t\\&\text{div}\vec{B} = 0\\&\text{div}\vec{D} = \rho\end{aligned} \tag{1}$$

$$\begin{aligned}&\vec{B} = \mu\,\vec{H}\\&\vec{D} = \varepsilon\,\vec{E}\end{aligned} \tag{2}$$

Such as:

$\vec{E}$: Electric field,

$\vec{D}$: Electric flux density,

$\vec{H}$: Magnetic field,

$\vec{B}$: Magnetic induction,

$\vec{J}$: Current density,

μ: Magnetic permeability,

ε: Electric permittivity,

$\vec{\vartheta}$: Velocity.

The magnetic vector potential $\vec{A}$ is expressed by:

$$\vec{B} = \text{Rot}\vec{A} \tag{3}$$

The currents density is written in the following form:

$$\vec{J} = -\sigma(\frac{\partial\vec{A}}{\partial t} + \text{grad}U) + \vec{J}_{ex} \tag{4}$$

The equations can be combined to lead to the total equation following:

$$\overrightarrow{\text{Rot}}\left(\frac{1}{\mu}\overrightarrow{\text{Rot}\vec{A}}\right) = \vec{J}ex - \sigma\left(\frac{\partial\vec{A}}{\partial t} - \vec{\vartheta}\wedge\overrightarrow{\text{Rot}\vec{A}}\right) \tag{5}$$

The expressions of the currents density and the electromagnetic force are given by (Faroux and Renault, 1998).

$$\vec{J}ind = -\sigma\left(\frac{\partial\vec{A}}{\partial t} - \vec{\vartheta}\wedge\overrightarrow{\text{Rot}\vec{A}}\right) \tag{6}$$

$$\vec{F}_{el} = \vec{J}_{ind}\wedge\vec{B} \tag{7}$$

After developments in 2D cylindrical coordinates (r, θ, z) where the current density and the magnetic vector potential are perpendicular to the longitudinal section of MHD pump, the equation becomes:

$$\frac{\partial}{\partial z}\left(\frac{1}{r\mu}\frac{\partial A^*}{\partial z}\right) + \frac{\partial}{\partial r}\left(\frac{1}{r\mu}\frac{\partial A^*}{\partial r}\right) = -J_{ex} + \frac{\sigma}{r}\left(\frac{\partial A^*}{\partial t} + \vartheta\frac{\partial A^*}{\partial z}\right) \tag{8}$$

DISCRETISATION BY THE FINITE VOLUME METHOD (MVF)

The method consists for discretising differential equations by integration on finite volumes surrounding the nodes of the grid, (Fig. 2) (Patankar, 1980).

In this method, each principal node P (center volume of control) is surrounded by four nodes N, S, E and W which are the centers of the adjacent volumes of control located respectively at North, South, Est and West among that containing P (Fig. 3).

After integration, the final algebraic equation is written as:

$$a_P A_P^* = a_E A_E^* + a_w A_W^* + a_N A_N^* + a_S A_S^* + d_P \tag{9}$$

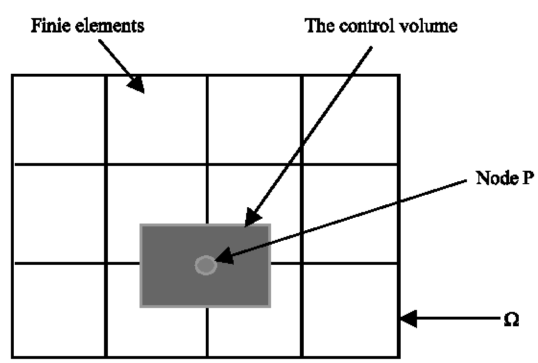

Fig. 2: Mesh domain

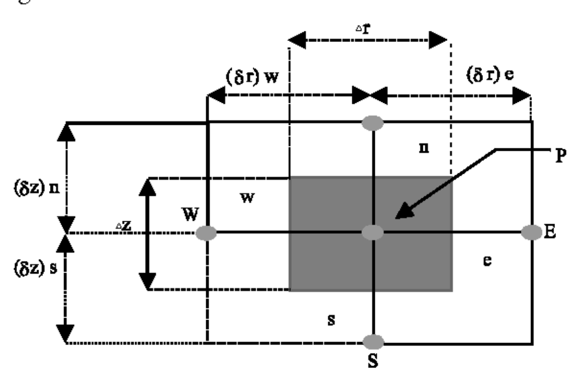

Fig. 3: Discretisation in finite volume method

such as:

$$a_E = \frac{\Delta z}{\mu_e r_e (\delta r)_e}, \; a_N = \frac{\Delta r}{\mu_n r_n (\delta z)_n},$$

$$a_w = \frac{\Delta r}{\mu_w r_w (\delta z)_w}, \; a_w = \frac{\Delta z}{\mu_w r_w (\delta r)_w},$$

$$a_P = a_E + a_W + a_N + a_S + j\omega \frac{\sigma_P}{r_P} \Delta r \Delta z,$$

$$d_P = J_{ex} \Delta r \Delta z.$$

The matrix of this system of equations is written in the form:

$$[M+jL][A] = [F] \qquad (10)$$

Where

[M+jL]: Matrix Coefficients,
[A]: Vector Potential,
[F]: Vector source.

With the Dirichlet boundary condition, the resolution is done according to an iterative process (method of Gauss Seidel).

APPLICATION

The selected application is an annular induction MHD pump with 6 slots whose dimensions and physical properties are given as follows:

Length of the inductor: 40 cm, width of the inductor: 20 cm, width of channel: 2cm, width of the air-gap: 4mm, μ_r (H/m) = 1.55 (for the channel), σ $(\Omega.m)^{-1} = 1.06.10^6$, $\vec{j}_{ex}(A/m^2) = 4.10^6$

The Fig. 4 represents the annular MHD pump in the plan (r, z) with the boundary conditions.

The magnetic reluctivity is interpolated starting from the curve B (H) which represents the characteristic of magnetisation of ferromagnetic materials (Heiny *et al*., 1970).

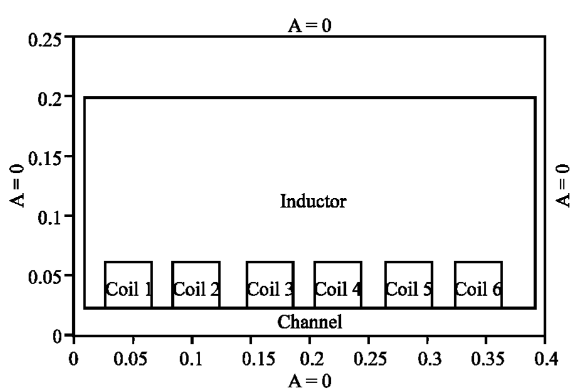

Fig. 4: Geomertrical model of the annular MHD pump

RESULTS AND DISCUSSION

Distribution of vector potential and of magnetic induction: Figure 5-7, represent, respectively, equipotential lines, the distribution of the vector potential $\vec{A}$ and the module of magnetic induction $\vec{B}$ of the MHD pump.

Variation of the current density and electromagnétic force in the channel: Figure 8 and 9 represent, respectively the variation of the current density and the electromagnétic force in the channel.

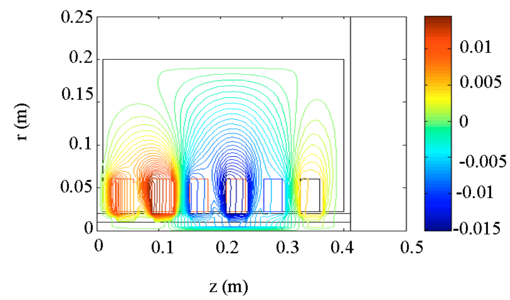

Fig. 5: Distribution of the vecto potential $\vec{A}$ in the MHD pump

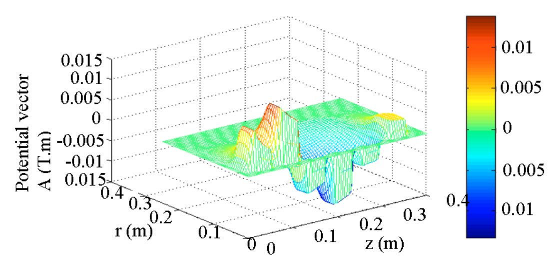

Fig. 6: Distribution of the magnetic vector potential $\vec{A}$

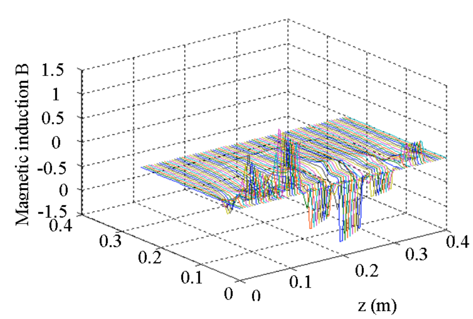

Fig. 7: Magnetic induction in the MHD pump

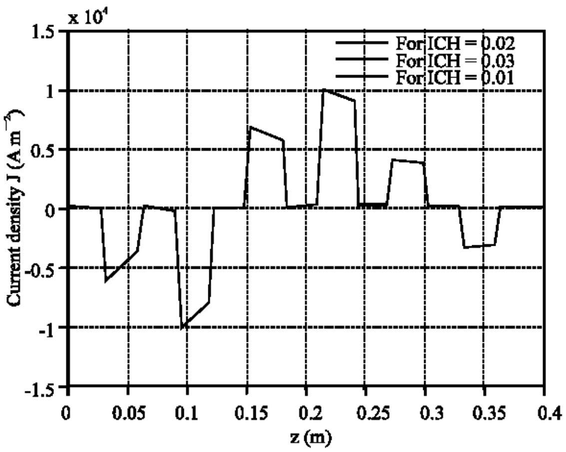

Fig. 8: Variation of the current density in the channel

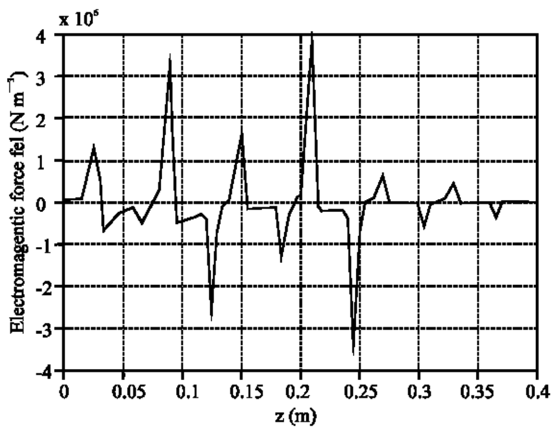

Fig. 9: Variation of the electromagentic force in the channel

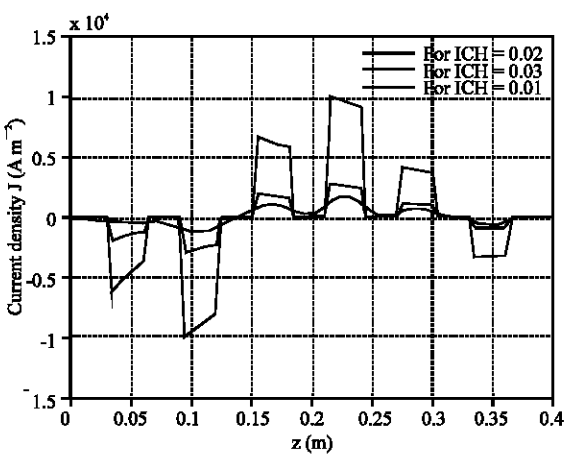

Fig. 10: Variation of the current density for different channel widths

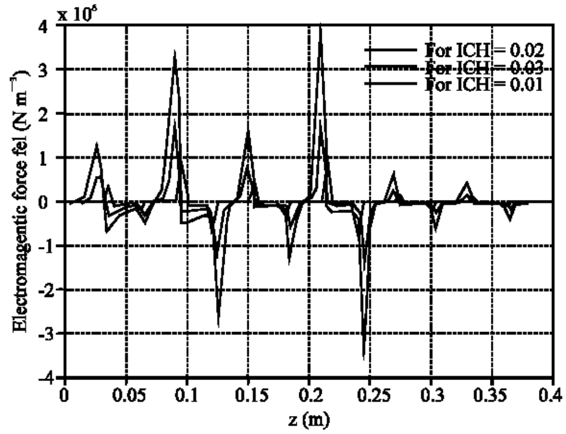

Fig. 11: Variation of the electromagnetic force for different channel widths

The influence of the width of channel on the performances of the pump: Figure 10 and 11 represent respectively the eddy current density and the electromagnetic forces for different channel widths such as: l_{CH} = 0.02m, l_{CH}= 0.01, l_{CH}= 0.03 m.

The results show that the increasing of the width allows the decreasing of the current density and the electromagnetic force; this is due to the action of the transverse forces which become more significant.

In the case of the decreasing of the channel width, the current density and the electromagnetic force decrease because of the increase in the magnetic losses.

CONCLUSION

In this study, the influences of the channel width on the different characteristics of induction MHD pump (electromagnetic force, current density) are studied.

Thus, it is noticed that an optimisation approach of the channel width allows improving the performances of the MHD pump.

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