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MHD Flow around Circular Cylinder Under-Control through three Different magnetic Permeability Status

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Abstract*— Through the current work, the flow around an insulating cylinder of various magnetic permeability, submitted to a flow of an incompressible electrically conducting fluid has been investigated. The homogeneous fluid flow and the homogeneous applied magnetic field are aligned at infinity. When the cylinder has the similar magnetic permeability as the fluid, the applied field is not influenced by the cylinder. However, when the cylinder has a different magnetic permeability than that of the fluid, the applied field is agitated by the cylinder and then the flow structures will become different from those of the previous case. Consequently, two cases can be distinguished following the last state whereas the cylinder magnetic permeability may have less or greater value than the fluid one's. The best agreed results that have been obtained following the comparison to the literature magnetic field behaviors were selected .The event has been occurred, where the convergence and divergence of the magnetic stream lines were realized to the previous both cases of magnetic permeability situations, respectively. In fact, an important influence of magnetic field on the fluid has been occurred. Consequently, it can be concluded that the fluid has significant influences on the cylinder structure, through the impact of the fluid structure phenomenon, the shedding vortex process and its suppression. Accordingly, good results of drag aerodynamic coefficient evolution were obtained at the fixed value of the Reynolds number Re=550, for different Stuart numbers, greater than and lessen than a critical value adopting at N=0.8.

Keywords: **MHD, Permeability, Magnetic.**

I. INTRODUCTION

The generation and evolution of vortex structures in the bluff bodies wake region have a significant effect on the hydrodynamic coefficients and heat transfer phenomenon [1], [2], [3] have studied by numerical simulation and experimental way this problem. [4] Investigated analytically the influence of an alternate magnetic field on a no limited cylindrical conducting liquid. Since the decade of 2000, the interest of the scientific community for magnetic field action in liquid metals has been renovated, successful experiments. In similar, [5] conducted a comparative study; where they based on the experiment method applying the magnetic field interact with the conducting liquid metal. They found that the proper frequencies of the induced magnetic field were synchronized with the proper mode of the solid. In meanwhile [6] investigated experimentally the magnetic field perturbation amplification. The same method has been adopted in [7], where they presented an experiment study of the dynamo effect in the von-Karman sodium magnetic field, which is generated by a swirling liquid metal flow turbulent. Within this frame, the magnetic induction in a finite rotating solid cylinder has been studied by [8], whereas, the aim was to fit the impact of soft iron disks on induction fields. Throughout their analysis, two counter-rotating disks embedded in a cylindrical conductor in which was submerged in vacuum were considered, while the significant findings can be occurred by adopting the main restriction method as it was detailed in [9] and [10]. The mentioned restriction is based on the condition of that the magnetic permeability must be smooth in the conducting region. This is a major impediment since magnetic permeability heterogeneousness is suspected to play a key role in the confinement of the magnetic field in some dynamo experiments (referred particularly to the VKS2 (von Karman Sodium 2) which was a successful dynamo experiment, mentioned in [7] and thus significantly lowers the dynamo threshold, as described in [11].

The magneto-hydrodynamic problem which has been considered in the research work conducted by [12], with increasing Hartmann number, a suppress vortex shedding process has been observed due to the action of the Lorentz forces. Consequently, the flow became completely stabilized and returned back to the two dimensional shape. Accordingly, the current work was focused on the influence of an applied external magnetic field on the flow-structure around the cylinder with various magnetic permeability. In this view, the problem has been partially and analytically investigated, thus partially and numerically adopted the finite difference and finite volume methods to resolve this MHD flow problem.

Following the previous works, this contribution investigate the effect of different permeability of the solid fluid in topological flow structure and aerodynamic forces highlighted by the following main axes; the analytical study mainly aims to determine the magnetic field distribution

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according to any value of the magnetic permeability of the cylinder. The flow structure was obtained by Computational Fluid Dynamic (CFD) Fluent software. Thus, flow structure has been also developed in parallels when introducing the previous magnetic field values in the computational domain that were used for the "Fluent" calculation. We are considered for this coupling a User Define Function (UDF) developed by C++ language. The magneto-hydrodynamic flow of liquid metal over circular cylinder under magnetic fields is performed for different Stuart numbers (Interaction parameter), and considering a discontinuity of the angular component Bθ and continuity of radial the ones Br. In this stage, the validation of the found results, as shown in table N°1, have been executed, based on a different analytical and numerical values of the magnetic radial and dimensionless time, velocity, pressure, and imposed magnetic field. Three dimensionless numbers that appear in the momentum equation (15) and magnetic induction equation (16) are the classical Reynolds angular components at a fixed point of angle $\theta = \pi / 4$ on the surface. For a variety of most sensitive places of the magnetic field variation. The comparative values assembled in the (table N°1), presented below show a good agreement between the analytical and numerical results, where μsolid = 2 and μfluid = 1. The error order of the 1% occurred in this comparison can be explained by the numerical discretization applications, the essential balance of forces in the Hartmann layer is established between the electromagnetic force and the viscous force. The ratio of these forces can be expressed in terms of the Reynolds number and the interaction parameter as N.Re = Ha2. Hence, the Alfven number has been process and truncated error.

II. RESULTS AND DISCUSSION

The magnetic stream lines trajectories varied through the shape depending to the type of the various environments permeability through which the magnetic field was established. The figure 4, presents the magnetic stream lines corresponding to the neutral case (μSolid=μFluid) that are not diverted by the cylindrical body carried a same magnetic permeability of the surrounding fluid. However, in the second case μSolid=1 μFluid=10, the magnetic stream lines seems to be repulsed near the cylinder, due to the effect of weakness magnetic permeability of the cylinder relatively to the surrounded fluid permeability. this case show a similarity to the materials' behavior, known as "diamagnetic materials" which are characterized by their magnetic permeability μreduit lower or equal 1.Considering the third case, μSolid=10 μFluid=1, the trajectories of the magnetic stream lines are observed in figure 4. They appeared in the near cylinder to be absorbed and concentrated on the center line axis of the cylinder. These results averred in good agreement with the ferromagnetic materials behavior. These results are also in agreement with the Burhanu ones, shown in figure 4. They are known by the "ferromagnetic materials" behaviors which characterized by a relative magnetic permeability μreduit very greater than 1.

The agreement is excellent considering that the gradient of the solution is discontinuous at the edges of the cylinder. Where, that's can be explained by the continuity of ψ guarantees that the tangential components of the magnetic field are continuous and the continuity of ∂ψ/∂r guarantees that the normal component of the magnetic induction is continuous [9].

The main goal is to define the evolution of the von Karmann eddies street when the flow is submitted to the applied magnetic field. When the magnetic permeability of the fluid is equal to that of the cylinder, the eddy street disappears for a critical Stuart number Nc=0.27 [14] for Re=200, and for Nc=0.18 [15], when Re=100, in a previous study [16] we have found the critical value Nc=0.8 for the Reynolds number Re=550.

The figure 6, show the evolution of the wake behind the cylinder for the ratio μsolid/μfluid in the order to 1, 10, 0.1, associated to the Stuart number N equal to 0.8. It can be observed that as the magnetic permeability of the cylinder is lower than that of the fluid, the oscillations of the wake are higher than in neutral case. Otherwise they are reduced when the magnetic permeability of the cylinder is higher than that of the fluid. In the neutral case we note that the von Karman street are completely suppressed at N=1. Nevertheless, the free shear layer vortices oscillated and extended to reach a length of forty times of the cylinder diameter. Where, it is slightly reduced at N=1.6 and well redressed (without oscillations).

When the Stuart number values are varied, these behaviors can be delayed or accelerated respectively in the cases of μSolid=1 μFluid=10 and μSolid=10 μFluid=1. Where the von Karman street is completely suppressed in first case at N=1.2, and the free shear layer oscillations disappear at N=1.6 and his length reduced toward about thirty times diameter of cylinder. In the second case, the von Karman street is completely suppressed at N=0.8, the oscillation of the free shear layer disappears at N=1.

In extra dos and intrados both sides of cylinder, the free shear layer thickness increased in the case of μSolid=1 μFluid=10, relatively to the neutral case that is shown in figure 6. The inversed phenomenon can occurs in the second case of μSolid=10 μFluid=1, where the free shear layers are squeezed in both sides, and the upstream boundary layer thickness increase to appear the new wake in this side. Previously, [17] have shown that the aligned external magnetic field increases the velocity downstream of the cylinder and the contrary decreases the velocity upstream. The present results (figure 8) show a good agreement with [17], in super-alfvenic regime (α>1) and subalfvenic (α<1). We note that relatively to the case of μSolid=μFluid, a variation of magnetic permeability can accelerate or decelerate, respectively when (μSolid< μFluid)

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or (µSolid> µFluid), the velocity in upstream boundary layer as it is shown in figure 7.

The velocity curves show that the rate of transport is considerably reduced with the increase of N. It clearly indicates that the parallel magnetic field opposes the transport flow. The variation of N leads to the variation of the Lorentz force, which is produce more the resistance to the fluid flow.

The figures 8-A and 8-B show a drag coefficient evolution versus the interaction magnetic number, respectively. The first case illustrates the total computational domain under influence of applied magnetic field. Second case presents the limited one's at D=4R over cylinder under influence of applied magnetic field. In this view, [15], [18], [19] and [20], have found that Cd decreases in the case of µSolid/µFluid=1, and N<Nc, and increases as N increases (if N>Nc), (figure 8-A). For the values of Stuart number larger than the critical values Nc, the increasing of the drag is not observed (figure 8-B). This disagreement could be attributed to the size of the domain of simulation applied magnetic field which was limited to three diameters from the cylinder. However these results have to be verified taking into account the increased domain of study. The drag coefficient is reduced in the case of µSolid<µFluid, where Cd=0.18 at N=10, or see continues to decrease with increasing of N. On the other hand, Cd increased with N in the case of µSolid>µFluid relatively to the same magnetic permeability case.

Table 1: Comparison of Analytical and numerical results.

Magnetic field	Analytical Value	Numerical Value	R M S %
Br radial Component	1,178,511,302	116,698,995	0,97
Bθ angular Component	-0,471404521	0.46390989	1,59
BT Total Magnetic field	1,269,225,518	125,581,764	1,05
Φ Tangent Angle	23°,1986	23°.3208	0,52

Table 2: Hydrodynamic and magnetic boundary conditions.

Magnetic	Fluid/ solid interface (r=R+), (r=R-)		In the domain border r=D=4R	
	$B_\theta(R+,\theta)$, $B_\theta(R-,\theta)$ Relation (13)		$B_\theta(D,\theta)=B_0\cos(\theta)$	
	$B_r(R-,\theta)=B_r(R+,\theta)$ Relation (14)		$B_r(D,\theta)=B_0\sin(\theta)$	
Hydrodynamic	Inlet computational domain	Outlet computational domain	In the (Wall) cylinder area	Top and Bottom computational domain
	Velocity inlet V=U0=cst	Pressure outlet P=P0=cst	No slip condition V=0 m/s	Symmetric condition (∂u/∂y=0)

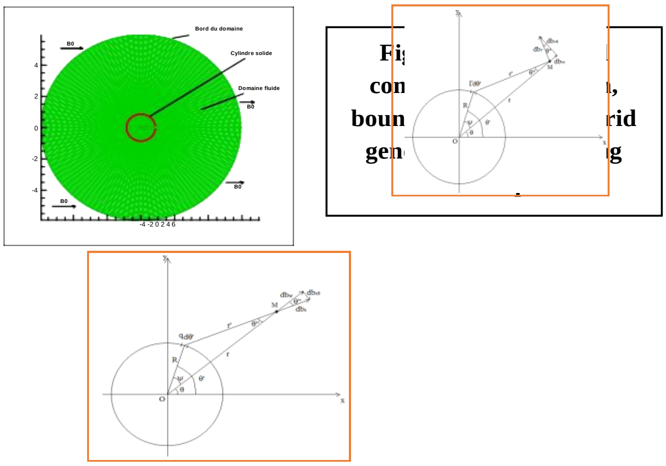

Fig.2: The radial and angular magnetic field perturbations produced by the vortex and source in the external medium.

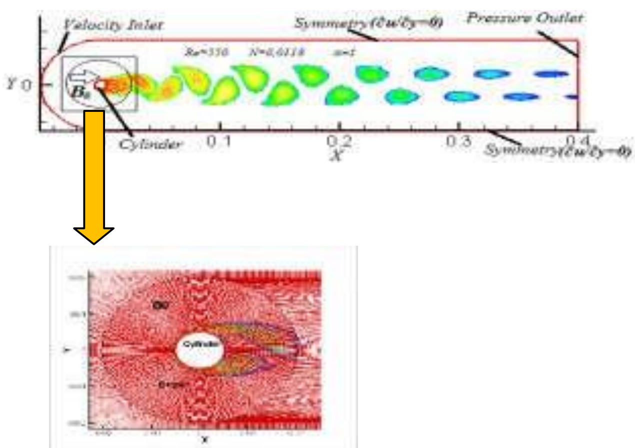

Fig.3: Magneto-hydrodynamic computational domain, boundary conditions. Grid generation and meshing technique

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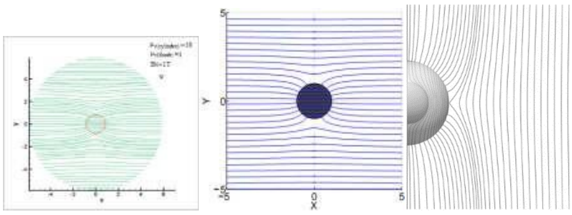

Fig. 4: Magnetic stream lines distribution according to (µsolid=10 µfluid=1) and (µsolid>µfluid [9]).

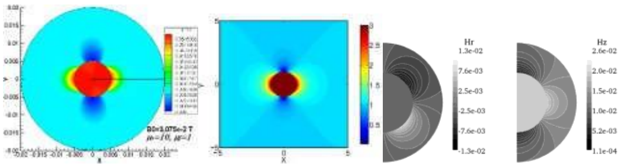

Fig.5: Magnetic field distribution according to (µsolid=10 µfluid=1) and (µsolid>µfluid [9]).

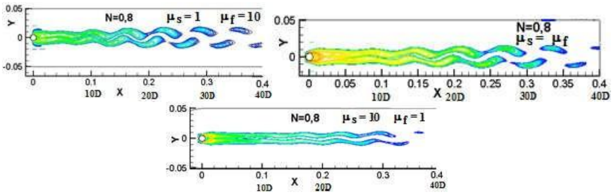

Fig. 6: Instantaneous vorticity contours at Re=550, (N=0.8) (µsolid= µfluid, µsolid=1 µfluid=10, µsolid=10 µfluid=1).

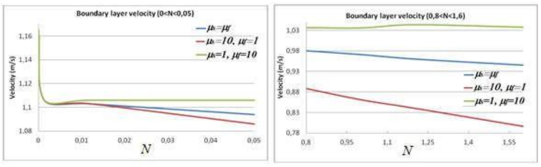

Fig.7: Upstream boundary layer velocity evolution, Re=550, N=0.8 (α>1 and α<1) For µsolid=µfluid, µsolid>µfluid, µsolid<µfluid.

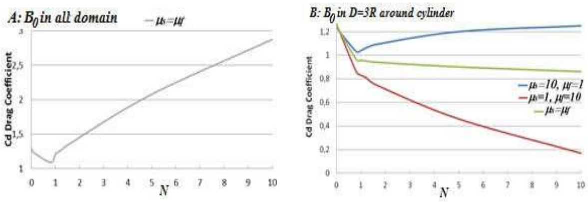

Fig. 8: Drag coefficient evolution versus N at (α>1 and α<1), for µsolid=µfluid, µsolid>µfluid, µsolid<µfluid

III.CONCLUSION

A novel magnetic analytical approached has been developed, using both analytical and numerical methods to resolve a magnetic problem, through the numerical technique based on Lagrange finite differences for solving magneto-hydrodynamics problems involving different magnetic permeability. The various magnetic permeability changes dramatically the configuration of the magnetic field distribution near the cylinder. In fact, the flow around bluff bodies at different permeability under applied external magnetic field showed as various configurations. Moreover, the possibility of suppressing the von-Karman street in the wake of cylinder near the critical value of Stuart number N=Nc has been particularly highlighted. Furthermore, it can be noted that a significant drag force reduction can occur when the suppression of the vortex shedding occurs at µSolid<µFluid case. It can be concluded that the obtained result is likely due to the boundary layer velocity behaviors, which can be increase in the cylinder boundary layer.

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