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VELOCITY DISTRIBUTION CHARACTERISTICS OF SEA WATER IN CONDUCTIV MAGNETOHYDRODYNAMIC (MHD) HOMOPOLAR DUCTS

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Abstract: *Shortcomings of conventional propeller propulsion can theoretically be removed by using a modern technology - unconventional hydroelectromagnetic propeller or magnetohydrodynamic (MHD thruster), that highlights an application of great interest about physical phenomena that occur in the interaction between electromagnetic fields and electrically conductive fluids. In application to marine propulsion, investigations of a variety of physical phenomena was carried out, including the flow characteristics in a MHD duct, thrust efficiency and optimum shape of the duct.*
This paper presents related interaction phenomena between a magnetic induction, created by a d.c. electromagnet and d.c. current, perpendicular to the field, imposed by a voltage difference between two electrodes in the conductive sea water. The fluid is forced to the direction perpendicular to the plane where magnetic and electric fluxes are intersecting, this force is called the Lorentz force. Experimental and theoretical studies were carried out on small magnetohydrodynamic model (DC homopolar model) having two channels arranged in series or parallel. Each time the speed distribution was followed over the channel axis and perpendicular to channel axis.

Keywords: magnetohydrodynamic, homopolar

1. Introduction

During its existence, propeller was much improved, but it has some shortcomings derived from its principle of operation that cannot be removed.
The movement of water is subdivided into a translational movement which in response provides useful power and a rotational component. The energy associated with the rotation movement of the propeller is lost, from the point of view of the drive, and is a major cause of yield decrease.
On the surface of the blade, which rotates fast enough in the water, the pressure falls so much with formation of vapor bubbles, known as cavitation phenomenon. Vapor bubbles in contact with the metal surface of the propeller explodes, causing, over time, its destruction. Moreover, the propeller performance is reduced and they are produced a characteristic noise, detectable from a great distance. In the case of military submarines, cavitation is a problem, leading to their detection.
The link between the engine and propeller group is often a very long axle, called propeller shaft, and it is at the same time, an additional source of hull vibrations that are transmitted through the bearings, which can become a possible sources of faults and technological complications.
For applying the MHD in naval propulsion, a series of investigations have to be performed for a variety of physical phenomena, including flow characteristics through a ducts MHD, the optimal form of the duct, including the phenomena of electrolysis electrodes with non-corrosion and superconductor magnets.

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When two electrical and magnetic fluxes are applied to a conductive fluid, it is driven in the direction perpendicular to the plane in which the electric and magnetic fluxes intersect. The force by which liquid is entrained is called the Lorentz force.

The first MHD studies were conducted in the United States during the sixties. Later it was found higher need for magnetic induction (> 5 T) in large volumes (more than m^3) for MHD propulsion becomes effective. MHD propulsion offers advantages such as high efficiency and speed, improved handling, greater flexibility of the payload and not least lower noise.

Nowadays, in the world are investigated two main types of marine engines magnetohydrodynamic: conduction and induction.

In the first case, use two separate fields - an electric field created by electrodes that generate a very intense current through water and a uniform magnetic field produced by a coil. From interaction with the magnetic field current Laplace propulsive force arises. It is the naval magnetohydrodynamic conduction truster or, as it is called homopolar truster.

In the second case, the electric field induced by the magnetic field gradually and the electrodes are missing (OMPhilips imagined solution in 1962, and repeated in several other papers). It is the naval magneto hydrodynamic induction truster, which is actually a linear induction machine with the induced seawater.

The modeling of fluid flow phenomena in electric and magnetic fields electrically is a rather complex and this has been solved by many authors under various conditions. The problem is for solving the magneto hydrodynamics equations using appropriate initial conditions and boundary condition. Basic equation in terms of seawater is Navier-Stokes equation within the electromagnetic force.

Seawater can be considered incompressible and thus the continuity equation, we obtain the relation:

$$\nabla \vec{v} = 0 \tag{1}$$

The only non-zero component of velocity vector is:

$$v_y = v_y(x, y) \tag{2}$$

The liquid movement is governed by the Navier-Stokes equation, which for stationary flow (v = constant, rot v = 0) has the following form:

$$\begin{gathered}\frac{d_s \vec{v}}{dt} = \frac{\partial \vec{v}}{\partial t} + \vec{v}\,\nabla\,\vec{v} = \\ \frac{\partial \vec{v}}{\partial t} + rot\,\vec{v}\times\vec{v} + \frac{1}{2}\nabla(v)^2\end{gathered} \tag{3}$$

where substantial derivative of velocity is zero.

Taking into account (1) was obtained:

$$\eta\Delta\vec{v} + \vec{J}\times\vec{B} - \nabla p = 0 \tag{4}$$

Considering that sea water acts as ohmic, the Ohm's law can be written as $\vec{j}_c = \sigma\vec{E}$, where total field strength which consists of E_0 - produced by the existence of voltage between the electrodes and E_i - the electric field induced in electrically conductive fluid.

Through an approximation that neglects the variation of electrolyte concentration in the channel, the Ohm's law can be expressed:

$$\vec{J} = \sigma(\vec{E}_0 + \vec{v}\times\vec{B}_0) \tag{5}$$

The electric field E_0 is oriented along the Ox-axis and has a constant intensity. The field B is the resultant of he magnetic field B_0 applied externally along the Oz-axis and the magnetic field generated by the current flowing through the liquid.

$$\vec{B}(z) = B_y(z)\,\vec{j} + B_z(z)\,\vec{k} \tag{6}$$

From the magnetic circuit law, was obtained:

$$\frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z} = 0 \tag{7}$$

and that $\frac{\partial B_z}{\partial z} = 0$, so we can say that B_z = B_0, such as (5) becomes:

$$\vec{J} = \sigma(E_0 + v B_0)\,\vec{i} \tag{8}$$

By replacing current density expressed by equation (4) into equation (7) it will be obtained the following differential equation with partial derivatives:

$$\eta\nabla \vec{v} + \sigma B_0\left(E_0 - vB_0\right)\vec{j} - \sigma B_y\left(E_0 - vB_0\right)\vec{k} - \nabla p = 0 \qquad (9)$$

For along the channel flow there are condition: $\vec{v} = v\,\vec{j}$ (10)

So the question is limited to solving the three scalar equations decomposed after three axes:

$$\frac{\partial p}{\partial x} = 0\,; (11)$$

$$\eta\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) + \sigma B_0\left(E_0 - vB_0\right) - \frac{\partial p}{\partial y} = 0 \qquad (12)$$

$$\frac{\partial p}{\partial y} = -\ \sigma B_y\left(E_0 - vB_0\right) \; (13)$$

2. Experimental set-up

The experiments described in this paper were performed by the authors on small models, being more interested in physical phenomena that occur. In this respect, were performed a series of experiments with models of trusters, using the MHD double propulsion systems, from the point of view of hydrodynamic arranged in series or in parallel.

The system used for seawater propelling consists of: an inductor formed by two electromagnets, a channel with insulator walls on which were installed two opposite stainless steel electrode, from a pool containing sea water and the supply and measuring devices.

The inductor was obtained from two electromagnets configuration, made of a solid iron core and winding. The core was formed of a yoke which has been fitted two pole pieces by means of screws,. Each pole piece was equipped with one winding with 500 coils copper wire with ϕ= 2.5 mm. Such a magnet is shown in figure 1.

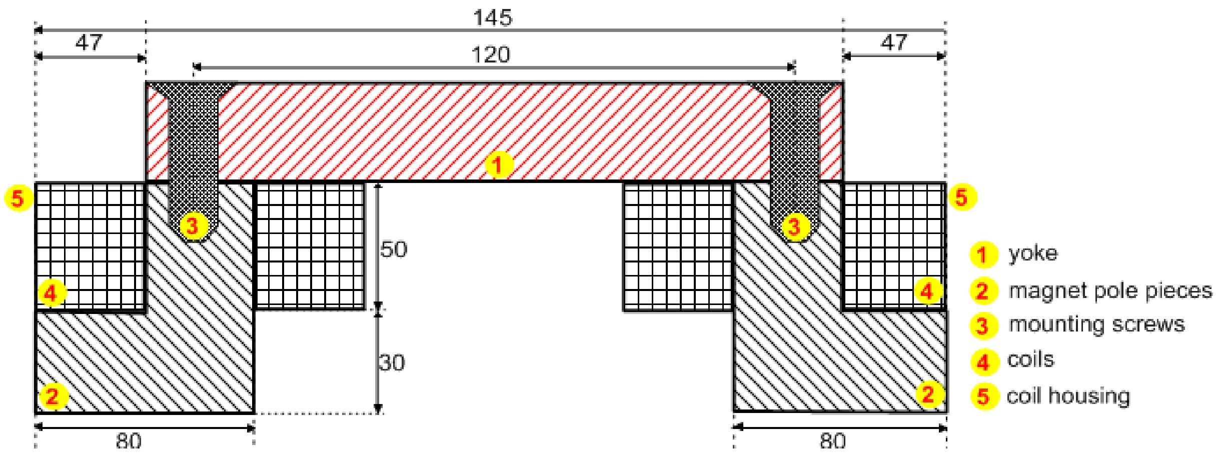

Figure 1. The inductor

The flow channel (channel MHD) was made from two pieces of wood covered with an adherent film of polyethylene. The polyethylene film is intended to provide walls insulation. The two pieces of wood were shaped in such a way to facilitate the movement of water. On the walls of the flow channel were fixed electrodes, each having length 2b = 80mm, height h = 20mm and thickness of 0.5 mm. The two parts remote at 2a = 80mm relied on the pond bottom and on the upper part is one of electromagnets supported inductor coils housing. Under each pole piece is a pair of electrodes. In figure 2 is shown a front section with electrode arrangement. They are buried in the wooden wall of the channel to not disturb the seawater flow.

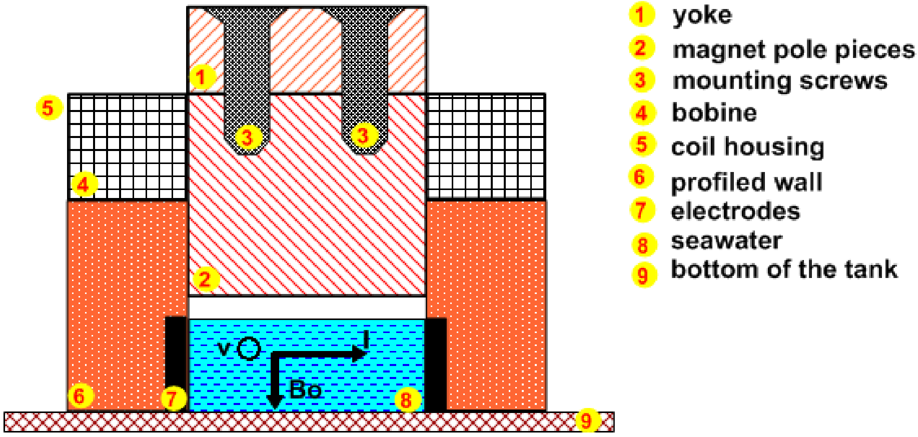

Figure 2. Front section of electrode arrangement

Tank containing sea water was made of polyvinyl chloride, having a 5 mm thickness. Its length is 1600 mm and width 650 mm. Its corners have been rounded to facilitate movement of the liquid. The second electromagnet of inductor is placed underneath the basin in the right of upper electromagnet.

The assembly shown in figure 3 consists of two MHD propulsion systems (propellant MHD) arranged in series in terms of hydrodynamic (in extension or in tandem). In this M.H.D channels, the magnetic field lines have opposite directions and therefore in order to propel water in the same direction, so the two electrodes were arranged on the same wall and were connected in opposition, in terms of power.

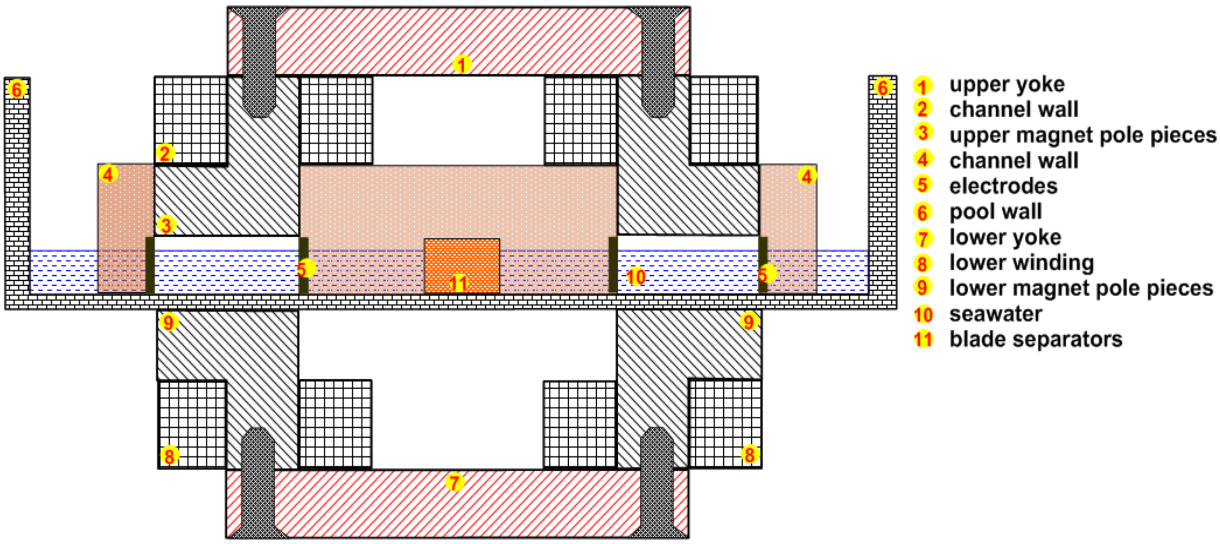

Figure 3. MHD propulsion systems

The consequence of electromagnetic energy conversion into mechanical energy in MHD channel is the flow of water with a certain speed. Size of this speed is determining for evaluation of the magnetohydrodynamic engine quality.

In order to measure the speed of seawater in the flow channel it was used the pitot probe. Pitot probe has been made using two glass tubes with an outer diameter of 3 mm and the inside diameter of 1.5 mm and a length of 50 mm. Two graphite rods were introduced through the top and form two electrodes inside the tube. The lower ends of the tubes have been inserted into a body hydrodynamic profile and form the dynamic pressure probe tube and static pressure probe. The maximum diameter of the housing was 6 mm and a length of 12 mm.

The electrical circuit. The experimental installation was supplied with DC, using separate circuits for electromagnets and power supply channel electrodes. For supplying electrodes, was used an autotransformer ATR 250-8 followed by a diode bridge rectifier consisting of four radiators. The current peaked 20 A for short periods of time (on the order of seconds). The electromagnets are connected in parallel so that the top and bottom to form polar opposites. Wiring diagram of the circuit is shown in figure 4. It is noted that the scheme allows working with one channel (noted by C1) by closing switches K1 and K2 and opening K3. Opening K4 will interrupt the flow of current through the coil excitation for the channel C2. The wiring diagram is the same as in the case of channels arranged in the extension or parallel.

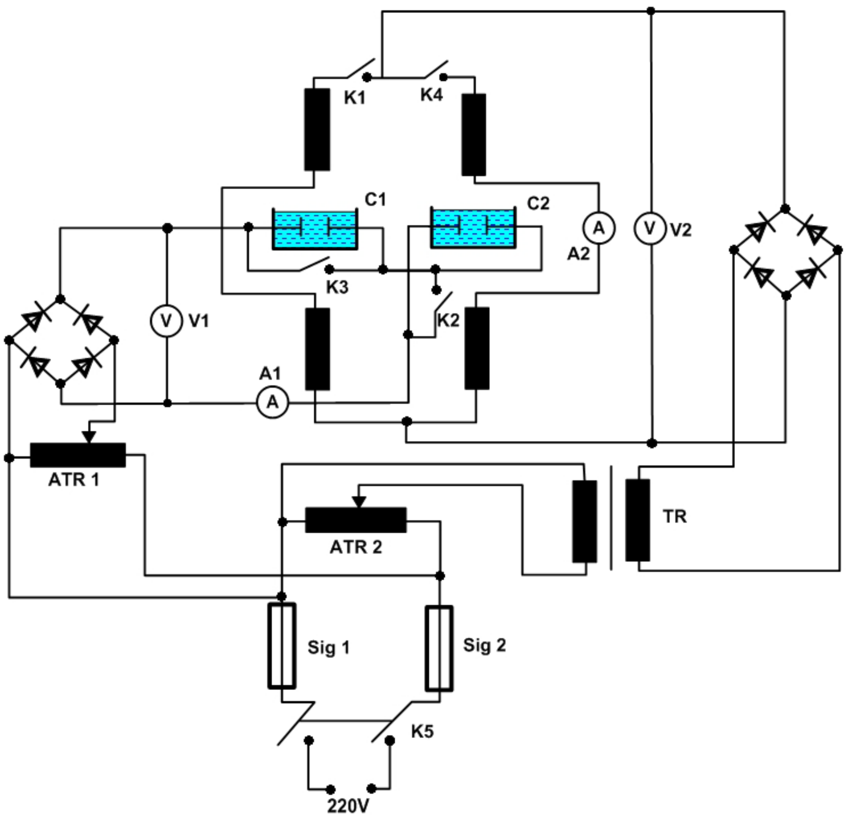

Figure 4. Wiring diagram of the electrical circuit

3. Results and discussion:

3.1 Seawater velocity profile on the axis of the channel.

The sea water has a salt concentration 25 g/l, and the temperature was 19^0 C. It has been determined the water flow rate at different levels of intensity of the current I injected into the liquid and at different values of magnetization current I_B, respectively of the intensity of the magnetic field.

Table 1

Flow rate to the axis of the channel [cm/s]								
I[A]	I_B=3 A B=0,15T Ha=0,56		I_B=5A B=0 ,17T Ha=0,96		I_B=10A B=0,35T Ha=1,98		I_B=20A B=0,62T Ha=3,5	
0.5	3.2	2	4.9	6	8	8	17	16
1	7	5	9	9	14	13	23	18
2	8	7	13	12	18.8	18	29.2	25
3	12	10	16.3	14	23	22	35.1	30.5
4	16	12	20	18	28	24	42.2	32
5	18.2	18	22	20	31.5	30	42.3	42
6	20.3	18.2	22.5	22.5	33	32	46	45
7	23	20	26.8	26	37.4	34	54.2	49
8	24	24	28.5	27	40	38	56.1	49.3
9	25	22	30	28.3	40.2	38	59	52
10	25.7	24	30.8	30.5	46	42	60.1	56
11	27	25	32	30.5	45.1	44	60.1	58
12	26.5	24.8	36	32	49.8	47.3	63.5	58
13	29	26.5	38	35	50.1	48	64.6	60.5
14	28	27.5	37.3	36	51	48	67.1	62
15	29	27.8	42	35.5	56	52	68	66
16	29.2	30	36	36	54.2	53	-	66
17	31	29.9	40	38	58.3	54	-	-
18	33.6	29.4	41	40	58.6	58	-	-
	extension	*parallel*	*extension*	*parallel*	*extension*	*parallel*	*extension*	*parallel*

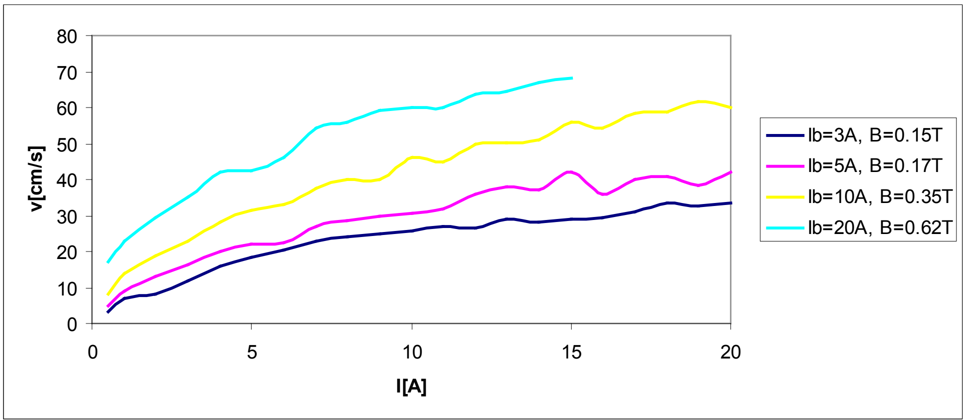

Figure 5. The experiment results for extended channels

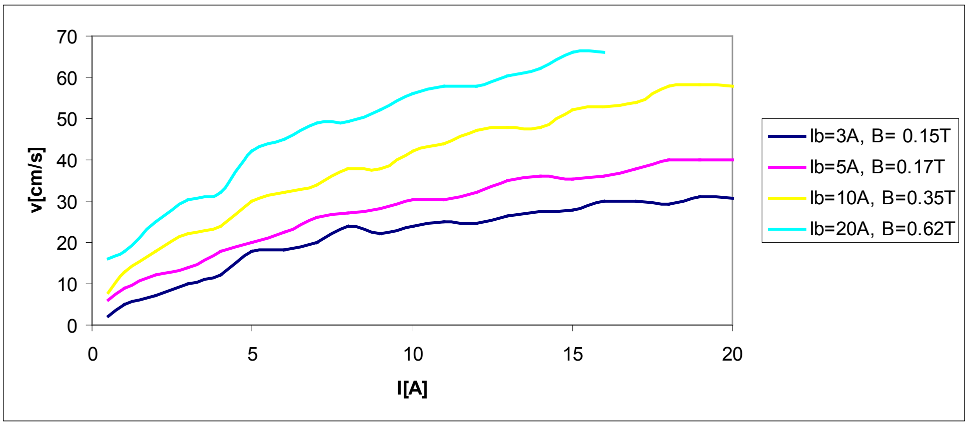

Figure 6. The experiment results for parallel (adjacent) channel

The experiment was repeated five times and the averages rates are shown in table.1 and are plotted in the diagrams of figure 5, for the two MHD channels arranged in tandem (the extension) and in the diagrams of figure 6 for the case of channels arranged in parallel.

3.2 Cross section velocity profile on the channel axis .

There were two sets of experiments: first was used a magnetizing current I_B = 10 A, where the electromagnetic field generated a 0.35 T magnetic flux density, and a second current I_B = 20 A, who achieved B = 0,62T. The current I between the electrodes was set in order to obtain a given speed on the axis of the channel (arbitrarily chosen values were 20, 30, 40 cm/s).

For each of these speeds, velocity profile was determined at the two values of the magnetic field induction.

Table 2

X[cm]	0	0.5	1	1.5	2	2.5	3	3.5	
v[cm/s]	40	40	38	35.2	32	25	21.5	9.2	B=0,62 T I=4,3A
	40	39	37	33.2	30.5	26	17	10.2	B=0,35 T I=8,3A
	30	29	29	25.5	23.5	20	15.1	7	B=0,62 T I=2A
	30	29.5	27	24.6	22	20	13	8	B=0,35 T I=5A
	20	19.8	19	17	15	13.2	10	4	B=0.62 T I=1A
	20	19.5	18	15.5	14	11	9	6.5	B=0,35 T I=2,5A

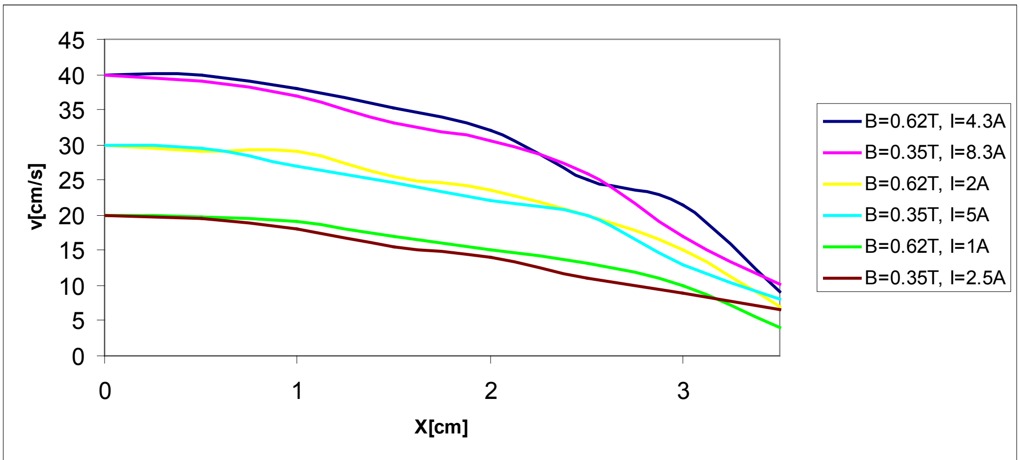

Figure 7. The experiment results for extended channels

Measurements performed with I_B = 20 A were performed in a short time, with large intervals between measurements, to not thermally overloaded the windings

The experiment results are found listed in table 2 for extended channels and table 3 for adjacent channels and diagrams are plotted in figure 7, where the channels arranged in extension and figure 8 in the case of parallel (adjacent) channels

Table 3

X[cm]	0	0.5	1	1.5	2	2.5	3	3.5	
v[cm/s]	40	40	39.5	36	35	25	22.5	9.8	B=0,62T I=5A
	40	39.5	38.4	33.8	31	27	17	11	B=0,35T I=8,3A
	30	29.5	29	26	24.2	20.7	16.1	7	B=0,62T I=3.2A
	30	29	28	25	22.5	21	13	8	B=0,35T I=5A
	20	20	19	11.7	16	14.1	11	5	B=0.62T I=1A
	20	19.5	19	16.3	16	12.5	10	7	B=0,35T I=3A

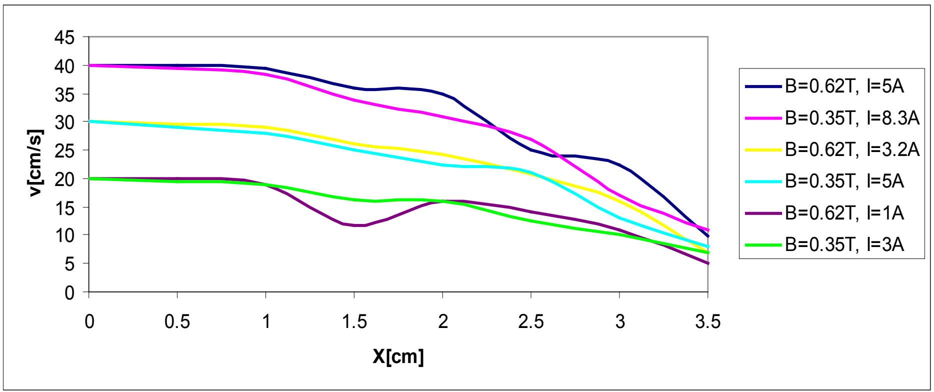

Figure 8. The experiment results for adjacent channels

4. Comments of results

4.1 Velocity profile on the axis of the channel.

The speed v_0 which the water flows on the channel axis in the vicinity of the free surface, is clearly dependent on the applied magnetic field and the current intensity that crosses the channel perpendicular to its axis.

For great length of the channel and the two channels of the separating blade it was seen a vortex flow. If the rate exceeds 25 cm/s, vortices appear visible to the contact with the walls. At a speed of 30 cm/s, vortices begin to fall off the wall, to move with water and diffuse into. At this speed the flow channel axis and its vicinity is still laminar, so that the speed measurements carried out are sufficiently reliable.

At more than 43 cm/s velocity, turbulence become important, but there are long period when the seawater flow is laminar on channel axis and intervals when the turbulence occur on axis. At speeds above 65 cm/s, the flow becomes very turbulent.

From the figures that represent the rate of flow, depending on the current intensity at different values of magnetic field induction, it is noted that the dispersion value is greater when the disturbance is advanced.

Therefore, the edge effect occurs only at the entrance and exit of the channel. In this situation it cannot quantitatively assess if the presence of this separator significantly increases the efficiency.

4.2 Observations on experiments for cross channel velocity profile

It is noted that the speed has maximum value on axis and small value near the wall. Speed variation with **y** distance measured from the channel axis is lower for small values of y and becomes more pronounced as we get closer to the wall. There is an obvious trend for flattening velocity profile when the magnetic field induction are increased. The phenomenon is visible, even if the intensity of induced currents in water is quite low. It is also obviously a flattened velocity profile for extended channels, which can be explained by the existence, in this case of a greater turbulence.

In this case, the flow velocity is higher and therefore it is considered and some effect of induced currents. In any case, it is obvious the deviation velocity cross channel profile from the classic profile of a parabola.

5. Conclusions. The experiments were carried out on a DC homopolar model having two channels arranged in series or parallel. Each time the speed distribution was followed over the channel axis and perpendicular.

Experiments have revealed a notable deviation from the classical parabolic velocity distribution in depth and, therefore, the authors accepted the velocity distribution as a basis for mathematical modeling of physical phenomena occurring.

Mathematical modeling of magneto hydrodynamic phenomena is based mainly on solving the Navier-Stokes equation with a term due Laplace force. Navier-Stokes equation was solved in the vicinity of the free surface, obtaining similar results with results of other authors and which accords quite well with the experimental results.

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