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# Aspects of Optimizing the Magneto Hydrodynamic Naval Thrusters

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**Abstract**. In this paper, the authors analyze several problems relating to the efficiency of an MHD thruster. In this regard have been defined, calculated and shown by graphs the propulsive efficiency as a function of the magnetic field flux density, used for different thruster sizes. Finally, it was draw the conclusions about the number of necessary thrusters for a maximal efficiency.

## 1. Introduction

During ships' history, these have been equipped with a lot of different kinds of propellers. Nowadays the connection between the energetic systems of the ships and the water is the naval propeller. This element, quite simple and, in the same time very efficient, have several drawbacks because of its own operating principle. Beside that, the propeller imprints to the water a circular motion that generates losses and also produces the cavitations phenomenon.

This phenomenon consists in the appearance, at the low pressure region from the propeller surface, of some vapor bubbles and dissolved gases. These have a high pressure and their explosion can produce destroying effects and a characteristic noise. The connection 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 [1].

Due to these aspects, submarine can be located from great distances because of this noise, despite the fact that it are equipped with anti-cavity propellers.

To avoid the propeller's noise, the patrol submarines start to be equipped with reactive thrusters, without propellers. [1, 2]. One of this type is the magneto hydrodynamic thruster. In this case, the seawater is driven by the Laplace force, which is generated by the interaction between a current, injected by a pair of electrodes in water and a magnetic field with perpendicular orientation on the current direction.

The interaction can occur, even the seawater is in the close proximity of the ship, but not often, in a MHD channel. This channel should have a flat rectangular shape and ends with a water absorption hole towards bow and a propulsion nozzle towards aft of the ship, as shown in figure 1.

The current information, in this direction, does not offer too many details regarding the configuration of the pipe and the performances of this type of submarine. The only certain results are those obtained by a Japanese research team in Kobe harbor, from 1989 to 1993.[6]

This experimentally ship, named Yamamoto I, have been used magnetic fields with an magnetic flux density of 4 (T), produced by conductor coils and water injected currents which had values of thousands of amperes. This ship has been reached the speed of 8 knots. On a power of 3600 (KW), the efficiency was not greater than 3%. From a military point of view, we can draw the conclusion that also the submarines with MHD propulsion are used only when the patrol regime requests a maximum silence.

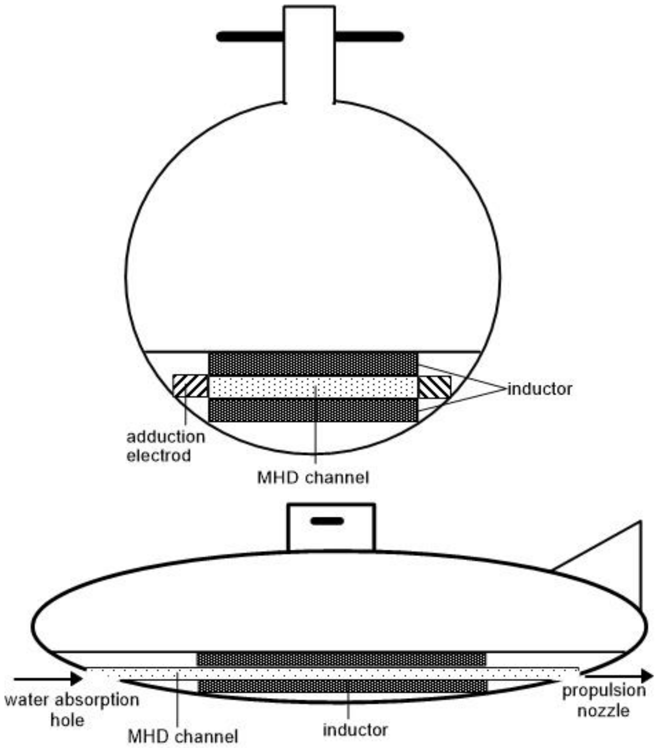

**Figure 1**.The patrol submarines start to be equipped with reactive thrusters

## 2. The propulsive efficiency of MHD thruster

The propulsive efficiency is given by the formula:

$$\eta = \frac{P_m}{P_e} \tag{1}$$

Where: $P_m$ - mechanical power developed by the mobile water, $P_e$ - electrical power injected in the pipe.

Mechanical power is obtained by integrate on the pipe volume the density of mechanical power.

$$P_m = \iiint \frac{\partial F}{\partial V} \cdot v \cdot dV \tag{2}$$

Where:

$\frac{\partial F}{\partial V}$ is the density of the propelling force in the channel and $v$ is the flow speed.

The density of the propelling force it is quite exactly the density of Laplace force and is given by the relation [3; 4; 5]:

$$\frac{\partial F}{\partial V} = -\sigma(\nabla V \times B) \tag{3}$$

Where: sea water conductivity $\sigma = 5\,\Omega^{-1}\mathrm{m}^{-1}$, V = electric field potential into water and B = magnetic flux density.

The flow speed  is not uniform. It has been calculated by solving the Navies- Stokes equation with some simplifying conditions [4]. Finally, for mechanical power, is obtained the equation:

$$P_m = 2a \cdot B_0 I \sqrt{\frac{2E_0 \cdot B_0 \cdot R_H \cdot \sigma}{\lambda \cdot \rho}} \left[ \sqrt{1 + \frac{9B_0^3 \cdot R_H \cdot \sigma}{2\lambda \cdot \rho \cdot E_0 \cdot \left(1 - \frac{thH_a}{H_a}\right)^2}} - \sqrt{\frac{9B_0^3 \cdot R_H \cdot \sigma}{2\lambda \cdot \rho \cdot E_0 \cdot \left(1 - \frac{thH_a}{H_a}\right)^2}} \right] \quad (4)$$

Where:

- *2a* - the width of the channel;
- $R_H$ - hydraulic radius;
- $\lambda$ - hydraulic resistance coefficient;
- $\rho$ - density of sea water;
- $E_0$ - electric field strength between electrodes;
- $B_0$ – magnetic flux density;
- *I* - intensity of the injected current;
- $\eta$ - dynamic viscosity of sea water;
- $H_a$- Hartman's number.

$$H_a = 2a \cdot B \sqrt{\frac{\sigma}{\eta}} \quad (5)$$

Electric power is obtained by integrate on the volume of the pipe the density of Joule power:

$$P_e = \iiint \sigma \cdot E^2 \, dV \quad (6)$$

Intensity of the electric field, E, is given by the formula [5;6]:

$$E = \frac{U}{2a} - \frac{Ue^{-\frac{\pi y}{a}} cos \frac{\pi x}{a}}{a \left[ \frac{32}{3\pi} \left(1 - e^{-\frac{\pi b}{a}}\right) - e^{-\frac{\pi b}{a}} \right]} \quad (7)$$

Where: *2b* - length of the electrodes.

In real work conditions, of an MHD thruster, $b >> a$, and with this approximation, after the calculus, the propulsive efficiency is:

$$\eta = \sqrt{\frac{8\sigma \cdot B_0^3 \cdot R_H}{E \cdot \lambda \cdot \rho}} \left[ \sqrt{1 + \frac{9\sigma \cdot B_0^3 \cdot R_H}{2E \cdot \lambda \cdot \rho \left(1 - \frac{thB_0 \cdot a\sqrt{\frac{\sigma}{\eta}}}{B_0 \cdot a\sqrt{\frac{\sigma}{\eta}}}\right)^2}} - \sqrt{\frac{9\sigma \cdot B_0^3 \cdot R_H}{2E \cdot \lambda \cdot \rho \left(1 - \frac{thB_0 \cdot a\sqrt{\frac{\sigma}{\eta}}}{B_0 \cdot a\sqrt{\frac{\sigma}{\eta}}}\right)^2}} \right] \quad (8)$$

From the resulting experiments made by the author, it was drawn the conclusion that the resulting errors from the approximations become negligible if it is considered: $b/a = 5$ and the high of the channel, $h = 2a/5$. In this case, the hydraulic radius is:

$$R_H \approx \frac{a}{10} \quad (9)$$

Unlike the naval hydraulic flow, the coefficient of the hydraulic resistance, $\lambda$, depends on the Harman's number and also on the flow regime. It will be considered that the flow regime is a rolling one, and in this case, the next relation is valid [7] where $R_e$ - Reynold number:

$$\lambda = \frac{32H_a}{R_e} = \frac{32B_0 \cdot a\sqrt{\frac{\sigma}{\eta}}}{R_e} \tag{10}$$

This number it will be considered 2400 at the upper limit of the rolling flow. The propelling force depends on the intensity of the electric field into the channel. Using the above approximations, the connection between the propelling force and the intensity of electric field into the channel it will be given by the formula:

$$E = \frac{5F}{8\sigma \cdot a^3 \cdot B_0} \tag{11}$$

Using the relations (9), (10) and (11) in relation (8) and considering that $\sigma = 5\Omega^{-1}m^{-1}$; $\rho = 1000kg/m^3$, and $\eta = 10^{-3}Ns/m^2$, it will be obtained the relation:

$$\eta = \sqrt{\frac{0{,}048a^3 \cdot B_0^3}{F}}\left[\sqrt{1 + \frac{0{,}027a^3 \cdot B_0^3}{F\left(1 - \frac{th70B_0 \cdot a}{70B_0 \cdot a}\right)^2}} - \sqrt{\frac{0{,}027a^3 \cdot B_0^3}{F\left(1 - \frac{th70B_0 \cdot a}{70B_0 \cdot a}\right)^2}}\right] \tag{12}$$

It is noticed that in this case, the efficiency depends on the transversal size of the channel, the magnetic flux density and the propelling force. The increased efficiency at low propelling force is explained by the fact that, on high powers, the thermal loss increases with a greater rate than the mechanical power. Even in the case when force tends to become infinite, the efficiency is still subunitary. In real cases, the propelling force depends on the shape of the ship and on its kinematics performances. It must equal the promote resistance. The totals promote resistance can be estimated with the following relation [1]:

$$R_T = \frac{19{,}5 \cdot S \cdot V_N^2}{\sqrt{1 + \varphi\left(\frac{L}{B}\right)^2}} \tag{13}$$

Where: $S$ - the surface of the hull midship frame, $V_N$ - speed in knots, $L$ - length of the hull, $B$ - the width, $\varphi$ - coefficient almost equal to 1,88.

For a constant value of the force F, the efficiency depends on the size of $a$ and $B_0$. Studying the relation (12) it is obvious that the efficiency has a maximum for a special value of the magnetic flux density. In this regard, it was analyzed how the efficiency depends on the magnetic flux density for the channel configuration with different width values.

It was considered: $L/B = 10$, $S = 70m^2$ and the speed $V_N = 10$ knots. In this case, the propelling force is about 10kN. Introducing this force value in equation 12 and represent by a graph the function $\eta = \eta(B)$, a = constant, it will be obtained the diagrams from figure 2.

The diagrams from the figure 2 represent the graph for the function $\eta = \eta(B)$, for MHD thrusters with dimensions of 1m, 2m, 3m, 4m, and 5m. These dimensions are acceptable for a ship with a diameter greater than 10 m at the midship frame.

It is noticed an increase of the efficiency when the transversal size increases, too. The propulsive effort can be obtained if many thrusters are also used and they are working with smaller currents, meaning with lower propelling forces.

The total propelling force from all thrusters equals the total assessed force of 100kN. If we analyze the function $\eta = \eta(B)$ it is noticed a rapid increasing between 0 and 15T. After this value, it is slowly increasing to a maximum; obtained for a value of magnetic flux density, impossible to be reached technologically and then it tends to become zero. The used MHD submarines have a single larger MHD thruster.

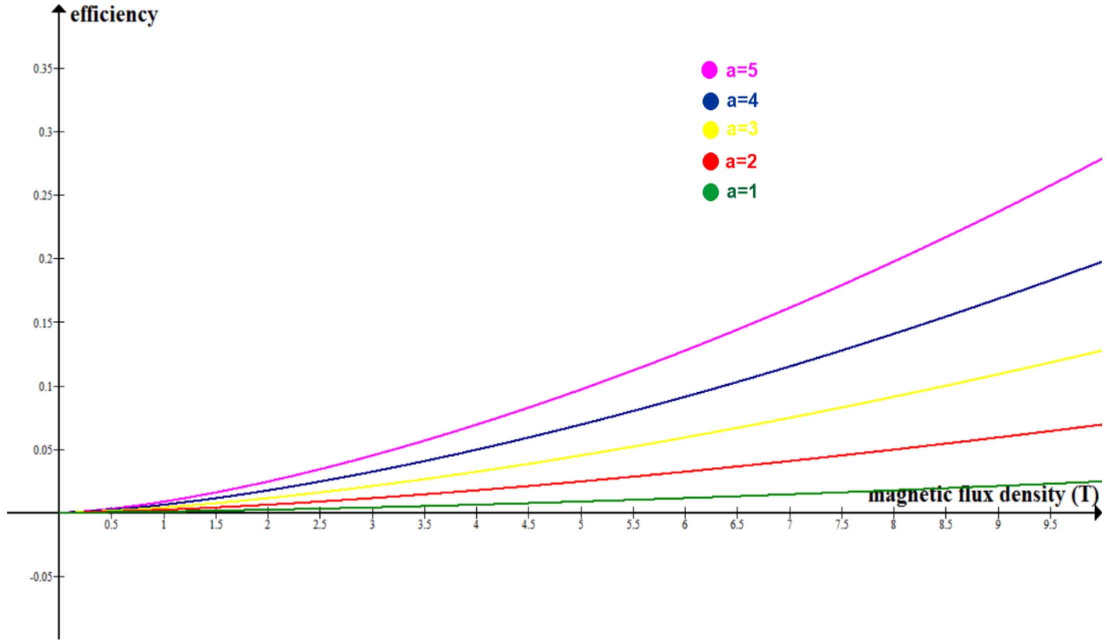


**Figure 2** Graph for the function $\eta = \eta$ (B), for MHD thrusters with different dimensions

## 3. Conclusion

From the author studies it is noticed that the configuration for the best efficiency is to increase transversal size of channel and to use many MHD thrusters. For the last case, each thruster producing a smaller propelling force.

These thrusters can be suitable arranged on the ship's body. It is notice that a configuration made of four thrusters with a 5m width for the channel is able to provide an efficiency of 30% when B = 12T. This efficiency is exactly the efficiency of the over cavity propellers on high speeds.

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