THEORETICAL AND EXPERIMENTAL STUDY OF SMALL SCALE MAGNETO-HYDRODYNAMIC (MHD) SHIP PROPULSION

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Article history
Received
30 November 2017
Received in revised form
12 December 2017
Accepted
21December 2017

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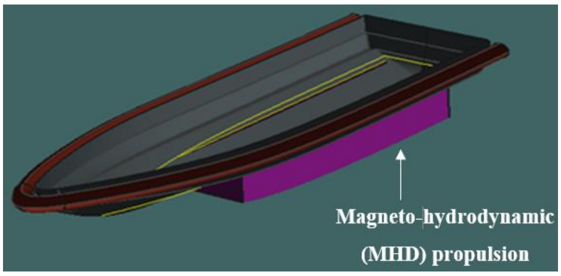
GRAPHICAL ABSTRACT



ABSTRACT

There are various types of ship propulsion system nowadays. Most of the ships are still using a traditional propulsion system which is fixed propeller. The existing propulsion system is very complicated, especially its mechanical system. This mechanical system is subjected to vibration and noise problems that will affect the comfort of passengers. Hence this study introduces magneto-hydrodynamic propulsion system which will solve the vibration and noise problems. The main objective is to create a model to show the magneto-hydrodynamic ship propulsion concept. Also, appropriate parameters will be determined for improvement. Both theoretical and experimental methods have been used in the study. It was found that the magneto-hydrodynamic propulsion system can be used in the propulsion system of the vessel, however the performance is not a conventional type of propulsion system. Nevertheless magneto-hydrodynamic propulsion system can still be improved in the future.

KEYWORDS

Magneto-hydrodynamic system; Faraday law; Model test; Propulsion system

INTRODUCTION

Magneto-hydrodynamic (MHD) propulsion was proposed in the 1870's, and in the 1980's many people namely George Geelong in University of Kobe, Japan applied the superconducting magnet to MHD propulsion and developed the corresponding setting [1]. The fundamental idea of MHD propulsion is to exploit the force that is experienced from the electric current which is emitted from a pair of electrodes and flow in a liquid. The force is transferred to the liquid which moves accordingly and the electrodes for the third Newton's law is applied a force equal in magnitude and opposite in direction with respect to the force applied to the liquid [2].

MHD is defined as a physical-mathematical framework concerned with the dynamics of fluids that are good conductors of electricity and specifically with those effects that arise through the intersection of motion of the fluid and any ambient magnetic field B(X,t) that may be present [3]. Such a field is produced by electric current sources which may be either external to the fluid or induced within the fluid itself. The Lorentz force is given by $F = qE + qv\times B$, where q is a charged particle moving with velocity v through an electric E and magnetic field B. An interaction which not only leads to modification of well-understood flow of conventional fluid dynamics but also is responsible for completely new phenomena that simply do not exist in non-conducting fluids [4]. Understanding MHD propulsion as potential naval propulsion systems to be installed in vessels where the reduction of acoustic emission is a key issue [5]. The superconducting MHD propulsion is essentially on electro-magnetic pump operating in seawater. It is a potentially attractive technology ship due to such system eliminates the conventional propellers as well as other rotating shaft-gear component [6].

YAMATO 1 is the first superconducting electro- MHD propulsion ship in the world. This ship was designed to propel directly using electromagnetic force generated by sending electric current through a magnetic field created in a seawater by superconducting magnets [7]. MHD has also been demonstrated using both alternating current (AC) and direct current (DC) by many researchers with varying degree of success. MHD micro-pumps contain no moving parts and capable of generating a continuous flow in any ionic fluid offer ideal solution for biological application [8].

cThe MHD force and efficiency are strongly related to the intensity of the magnetic field [9]. The former Soviet Union mainly focused on aspects of improving the intensity of magnetic field and putting forward the superconducting magnet with the structure of spiral pipeline [10]. Other than that, MHD force and efficiency are also affected by the geometry of the fluid channel of the system. The velocity of fluid is highly affected by the geometry channel. Improvement of MHD propulsion can be tackled in many aspects. Increasing the intensity of magnetic field along fluid channel is one of the ways to improve the MHD propulsion. On the other hand, the geometry of fluids channels such as adjusting the dimension can also be considered since it might give an impact to the velocity and pressure in the fluid channel.

New design of direct-drive marine's engine and ships propellers has reached an advanced stage of development and only incremental advances in performance may be expected in the future without the introduction of new technology and new propulsion concepts [11]. MHD propulsion might be the key to the future ship propulsion system. This brand-new propulsion system might also be the key to overcome the pollution caused by the marine craft. Good energy efficiency design index (EEDI) and energy efficiency operational indicator (EEOI) can be attained by any ship if MHD propulsion system is being installed in a ship.

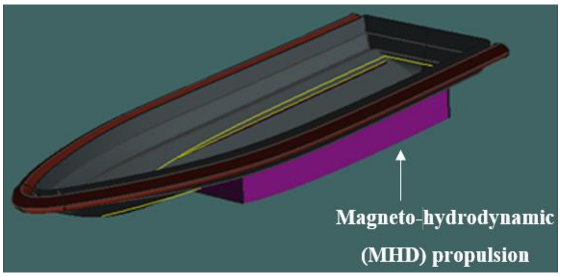
The research on MHD concept had already been conducted by many researchers in many areas of research either in marines or other areas. This concept attracted many researchers due to its mechanical simplicity in eliminating the moving part in the system. Even though much research have been done in MHD propulsion that address or focus on the intensity of magnetic field and geometry of fluid channel, some improvement can be done in this specific area. The scope of this research is only limited to the improvement of MHD propulsion covering the intensity of magnetic field and geometry of fluid channel.

MATERIALS AND METHOD

Magneto-hydrodynamicPropulsion Boat Design

Figure 1 shows the MHD boat model design utilizing the Maxsurf software. The model consists of the boat hull form as well as the MHD propulsion unit. Meanwhile, the lines plan of the MHD propulsion boat model is shown in Figure 2. The main particulars of the MHD boat model are shown in Table 1.

Figure 1: Isometric view of the MHD propulsion boat model



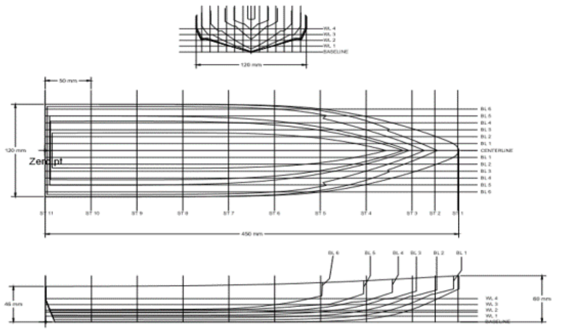


Figure 2: Lines plan of the boat model

Table 1: Main particular of the MHD boat model

Measurement	Value	Unit
Displacement	1.3	Kg
Volume	1.3	m^3
Draft	4	cm
WL Length	38	cm
Prismatic Coefficient	0.795	-
Block coefficient	0.404	-
Length	40	cm

Breadth	12	cm
Depth	6	cm

Before designing the propulsion system, the resistance of the modelled boat needs to be initially determined. This step is crucial as to predict the resistance of the model and its required power. The boat is tested at several speeds and its corresponding resistance is determined as shown in Table 2. The scale used in this study is $\lambda = 15$.

Table 2: The total model resistance results, R_{TM} at several speeds, V_m

Model Speed, V_m (m/s)	Model Total Resistance, R_{TM} (N)
0.45	0.20
1.11	1.25
1.78	1.83
2.45	2.09
3.12	2.20
3.56	2.23
4.01	2.22

Figure 3 shows the arrangement of the MHD propulsion boat model which are divided into three main components namely the boat hull, power supply and the MHD propulsion. For the power supply, there are 6 rechargeable batteries installed with each battery having current and voltage capacity of 3600 mAh and 3.6 V.

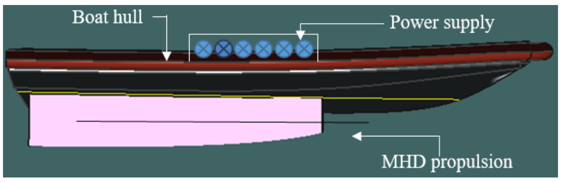


Figure 3: MHD propulsion boat model system arrangement

Meanwhile, for the MHD propulsion unit, three neodymium magnets have been tested in this study which are N31, N50 and N52. It is noted that each magnet was installed to produce different MHD propulsion power. The neodymium magnet is the best choice since the magnetic strength supplied is stronger compared to another magnet of small size. Due to its strong magnetic properties, extreme precaution should be taken to prevent any accident with the magnet especially during the magnet installation process.

The steel electrode is connected to the power supply that will function as the anode and cathode terminal, placed perpendicular to the magnetic field inside the MHD propulsion system. The electrode creates a current field inside the fluid channel. Six Lithium rechargeable batteries were installed to supply the terminals. The configuration and arrangement of the all the component can be referred in Figure 4.

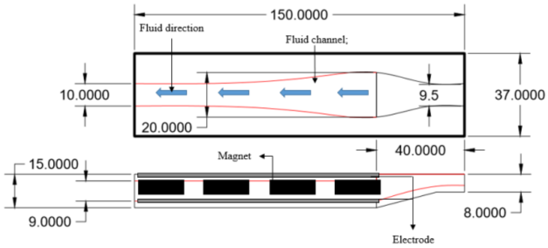


Figure 4: Magneto-hydrodynamic propulsion design

Theoretical Analysis of the MHD Propulsion Boat

By applying Newton's second law of motion on the free body diagram above the sum of force acting on the moving vessel in horizontal axis can be expressed as[12]

$$\sum F = ma$$
$$= F_{Engine} - F_{Friction} \qquad (1)$$

Figure 5 shows the free body diagram of a moving vessel. In a MHD propulsion vessel, the thrust force of the ship is equivalent to the Lorentz force of the v thruster.

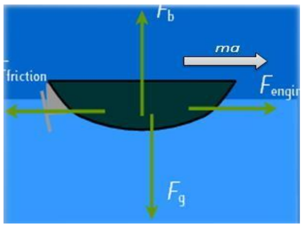


Figure 5: Free body diagram of moving vessel

$$F_{Engine} = F_{Lorentz}$$
$$ma = F_{Lorentz} - F_{Frictio} \qquad (2)$$

The velocity of the vessel is influenced by the capacity of the Lorentz force where the force is the product of [13]:

$$F_{Loren} = BIL \qquad (3)$$

Where

B = Magnetics strength (T) or (Wb/m^2)
I =Current Intensity (A)
L = Length of the water channel (m)

The maximum speed of the boat was obtained by determining the point at which the resistance of the boat is equal to the Lorentz force according to Equation (3). The formula is inserted in Microsoft Excel at a given input such as the resistance of the boat at a corresponding speed of the MHD propulsion boat model. Three magnetic fluxes were used, 0.6, 0.8 and 1.0 Wb/m^2. The Lorentz forces generated by the respective fluxes are labelled as Lorentz Force 1, Lorentz Force 2, and Lorentz Force 3. The length of the electrodes is 0.1m. Figure 6 shows the Lorentz force produced at different currents. It can be seen that the Lorentz Force 3 gives the highest value compared to others.

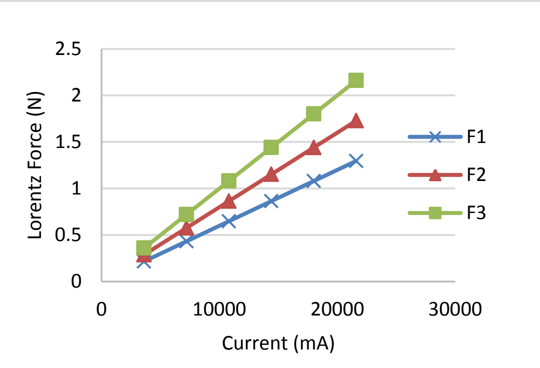


Figure 6: Lorentz force with constant magnetic strength corresponding to currentintensity

Fabrication of the MHD Propulsion Boat

Figure 7 shows the complete MHD propulsion boat model made using polystyrene. The power supply of the model boat is located inside of the boat that can supply up to 21.6 V voltage and 21600 mAh current. 6 lithium batteries are installed in the boat model where each battery has 3.6 V and 3600 mAh current capacity. The power supply is connected to the MHD propulsion prototype that is located on the keel of the boat model hull. The total weight of the model is 1.3 kg.

Figure 7: Isometric view of the MHD propulsion boat model

Experimental and Test of the MHD Propulsion Boat

The experiment was conducted in a small rectangular tank to measure the speed of the MHD propulsion boat model. The speed was obtained by measuring the time taken for the boat to traverse a distance of 60cm.The test of the MHD propulsion boat model was conducted in saltwater. The saltwater was produced using Sodium Chloride (NaCl) . The depth of water in the tank was 10cm.Figure 8 shows the testing of the MHD propulsion boat model.

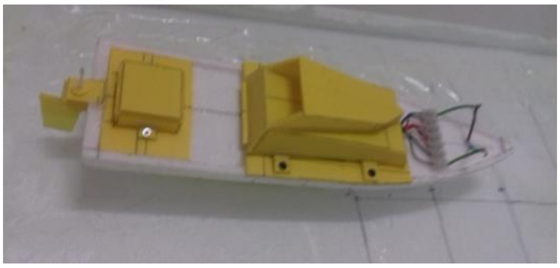


Figure 8: Sailing test of the MHD propulsion boat model

RESULTS AND DISCUSSION

Based on the tabulation of data from Tables 3 and 4, the maximum speed at a corresponding magnetic strength and current intensity is plotted. The theoretical results performance is higher compared to the experimental performance in both cases. Even though the performance is different, but the pattern of graph is almost similar since the increase in magnetic strength and current intensity increases the speed of the MHD propulsion boat. The pattern of the graph shows that the speed of the propulsion boat model is strongly related to the capacity of current intensity and magnetic strength being installed to the boat model.

Table 3: Comparison between experimental and theoretical results for current intensity

Experimental		Theoretical	
Current Intensity (mA)	Maximum Speed (m/s)	Current Intensity (mA)	Maximum Speed (m/s)
0	0	0	0
3600	0.29	3600	0.45
7200	0.32	7200	0.67
10800	0.31	10800	0.89
14400	0.47	14400	1.11
18000	0.90	18000	1.56
21600	1.30	21600	2.67

For clearer view, Figures 9 and 10 show the current intensity and magnetic strength against the propulsion boat speed. It can be seen clearly that the actual results from the experiments are lower compared to the theoretical results.

Table 4: Comparison between experimental and theoretical results for magnetic strength

Experimental		Theoretical	
Magnetic strength (T)	Maximum Speed (m/s)	Magnetic strength (T)	Maximum Speed (m/s)
0	0	0	0
0.60	0.91	0.60	1.11
0.80	1.13	0.80	1.56
1.00	1.33	1.00	2.67

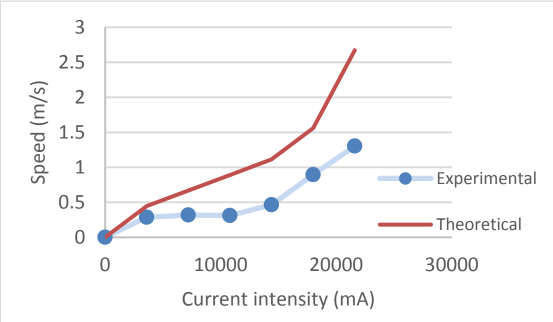


Figure 9: Speed against the current intensity

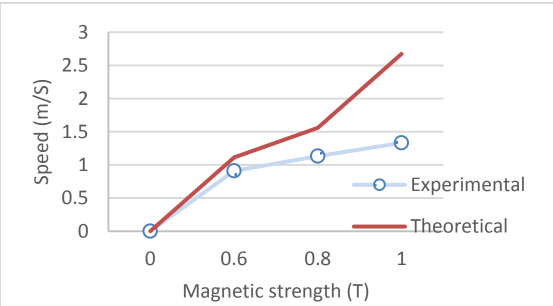


Figure 4: Speed against magnetic strength

Conclusions

In conclusion, the study shows that the MHD propulsion system parameter of improvement can be done through the magnetic field strength and current intensity that are being installed to the propulsion system. The performance of the MHD propulsion boat model is strongly influenced by the magnetic field and current intensity. By fabricating the MHD propulsion boat model, the functionality of the model boat can be demonstrated and at the same time a test can be done. The test that had been conducted and the results obtained in this research show that MHD propulsion vessels a marine transport without moving parts in the propulsion system is something possible and can be achieved. It is not just a theory.

Acknowledgements

We are grateful for the UTM scholarship awarded to the first author.

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