DESIGN A NOVEL THRUSTER MAGNETISM MOTOR (TMM) FOR UNDERWATER VEHICLE APPLICATION

MUHAMMAD NUR BIN OTHMAN (PRINCIPAL)

MOHD SHAHRIEEL BIN MOHD ARAS

FADILAH BIN ABD AZIS

MOHD FARUQ BIN ABDUL LATIF

AHMAD NIZAM BIN JAMALUDIN

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"We hereby declared that this report is a result of our own work except for the excerpts that have been cited clearly in the references."

Signature	:	
Name	:	Muhammad Nur bin Othman (principal)
Date	:	September 2013

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ABSTRACT

Recently, Remotely Operated Vehicles (ROV) is one of the most important vehicles in underwater industry. The ROV is very valuable device to accomplish a wide range of underwater tasks. A task that cannot be done by a diver is taken by the ROV. The performance of ROV will affect the industry itself. The thrusters are one of the most critical underwater technologies that define ROVs overall performance in term of performances and stability. In a non controllable environment such as sea, the thrusters faced the certain problem such as over pressure, corrosion and shatter. These all will lead leaking to the thrusters. A magnetic contactless of underwater thruster which called Thruster Magnetism Motor (TMM) or other named as TMM thruster is designed to avoid the occurrence of such problems. The CAD software is used as a tool to design these all parts of TMM thruster. The thruster is designed and fabricated into two separate parts which are housed for motor and housing for propeller. Both parts have a plate that holds a magnet. Both plates are printed by using rapid prototyping machine before doing machining process. The rare permanent magnetic material called a Neo magnet with size 2.0 cm for height and 1.3 cm in diameter is used. The 12V Brushless DC motor and 4 blade propeller with 10 cm diameter is chosen for this thruster. PVC is used for both housing with 11.1 cm diameter each. All these materials are chosen based on some criteria such as performance and price. The experimental test is done by the thruster at the swimming pool and laboratory pool. The thruster moves forward with speed 0.214 m/s and the propeller is rotated with 231 RPM. The results from these trials and demonstrations are recorded and shown.

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LIST OF ABBREVIATIONS

ROV - Remotely Operated Vehicle

UUV - Ummanned Underwater Vehicle

AUV - Automated Underwater Vehicle

CAD - Computer Aided Design

CFD - Computational Fluid Dynamic

Cd - Coefficient of Drag

DC - Directional Current

PM - Permanent Magnet

VRPM - Variable Reluctance Permanent Magnet

RPM - Revolution Per Minute

NURBS - Non Uniform Rational B Splines

CAA - Component Application Architecture

PVC - Polyvinyl Chloride

CHAPTER 1

INTRODUCTION

This chapter describes the project background, problem statement, objectives and scope of the project. Problem statement explains about the problem occurred based on previous Research of Remotely Operated Vehicle (ROV) thruster by Underwater Technology Research Group (UTeRG) from Faculty of Electrical Engineering, UTeM. Project objective is the description of the result and goal of this project. Project scope explains the limitations and boundaries of this project.

1.1 Introduction

Nowadays, Underwater Technology Research Group (UTeRG), Faculty of Electrical Engineering, UTeM have stepped forward in underwater research. UTeRG team has been made an ROV prototype. Design and specification of designing ROV can refer [1-3]. Based on the ROV prototype, the thruster of this ROV has been damaged due to leakage occurred. To overcome this problem, the new thruster is proposed. The new thruster is different from other thrusters in the world because this thruster uses a new system. By using a contactless magnetic system, the performance in term of speed of the thruster is compared to other thruster in UTeRG and some thruster that already in underwater industry. By doing a new thing, all of these were taken as challenges for completed this project.

1.2 Project Background

This project is designed a magnetic contactless for underwater thruster which is to demonstrate the movement of the thruster by using magnetic contactless system. The project is to show the performance between the magnetic contactless system thruster and previous thruster of UTeRG in term of speed.

1.3 Problem Statement

In the present Remotely Operated Vehicle (ROV) research, the thruster is the main propulsion device [4]. The thruster is an assembly that provides thrust by the spinning of the propeller. The thruster typically includes a motor, propeller and housing. Generally the thruster design, the motor and propeller are permanently connected. Due to undetermined pressure and environment in underwater, there are several problems occur such as leakage, corrosion and shatter. After the ROVs finish their task, they moved up to the surface and this situation makes it easier to rust. The corrosion makes the body less resistant. The body must be resistant to take more pressure in deep underwater. Within the less resistant body and less sealing, the thruster faced the leakage situation. Based on previous thruster of UTeRG ROV, the previous thruster was leaking. The leakage occurs at the propeller shaft. When the thruster leak, possibility of all parts is damaged included the motor is high. Thus, to overcome those problems, a magnetic contactless thruster is proposed. The thruster is designed with the motor and propeller is separated. This means the body is divided into two, which contain a motor and propeller. Respectively, if one part of the thruster damaged or leakage it does not damage the other parts. Besides that, the new design which is contactless thruster is made up with anti corrosion material and waterproof. Therefore, the introduction of contactless magnetic system of underwater thruster will avoid the problem that occurred and automatically reduced the cost of maintenance.

1.4 Objective

The objectives of this project are:

1. To design a Thruster Magnetism Motor (TMM) for unmanned underwater vehicle application.

2. To study the contactless gap within two magnets at the separate body which has given good performances.

3. To analyze the speed of a contactless magnetic system of underwater thruster and its compatibility on the UTeRG Remotely Operated Vehicles (ROVs).

1.5 Scope of project

The scopes and limitations of this project are:

1. Design and fabricate a prototype of magnetic contactless thrusters.
2. The contactless gap is set up at 21mm, 24mm, 27mm and 30mm.
3. The rare magnetic material (Neo Magnet) with 1.0-1.4 T of magnetic field is used.
4. The maneuverability is only on forward motion.
5. The depth of testing the prototype is 1 meter deep.
6. The testing environment is controllable which is laboratory pool and a swimming pool.
7. 12V DC Motor Permanent Magnet Brushless is used.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will detail about ROVs and will be focused on thrusters, literature review on the parts and the system used in this project which is magnetic contactless thrusters. It includes explanation of individual character and advantages of particular of components that used in this project. This chapter will explain about ROVs, thrusters, propeller, magnetic principle and the basic design for the thrusters.

2.2 Remotely Operated Vehicle (ROV) Classification

The ROV can be divided into two basic categories which are manned and Unmanned Underwater Vehicles (UUV). The unmanned vehicles divide into two groups which are tethered and un-tethered. The resident moniker for a un-tethered underwater vehicle is the Automated Underwater Vehicle (AUV), which mean freedom from a tether and can run either a pre-programmed or logic-driven course. The difference between the AUV and the ROV is the presence or absence of hard wire communication between the vehicle and the surface [5]. The ROVs aid in performing a variety of underwater tasks, many of which cannot be performed by divers [6]. Generally, the ROV can be classified into three types which are inspection class, research/observation class, and working class. These types of ROVs class are determined by their performance and their classifications to carry out the tasks [7] [8].

Table 2.2: The types of ROVs class

Inspection Class	Research/Observation Class	Work Class
		
▪ Very simple machines. ▪ Typically compact, light and easily maneuvered. ▪ Deployed in water no greater than 300m deep.	▪ Highly versatile and adaptable. ▪ Backbone of many ROV research ▪ Deployed in water up to 600m deep.	▪ Necessary to any major subsea endover. ▪ Their ability to be adapted to literally any work makes them indispensable as a system. ▪ Working in waters measuring up to 3000m deep. ▪ Boasts horsepower ranging from 100 to 250.

The performance of the thrusters includes the speed of the ROV move either vertical or horizontal axis. The speed is calculated or measure in velocity by use relationship between distance travels over time taken.

$$V = \frac{x}{t} \qquad (1)$$

where,

V= Velocity

x=Distance travel [m]

t= Time is taken [s]

2.3 Thruster

The thrusters are commonly used as underwater vehicle's main propulsion device. It enables the vehicle to perform maneuvers in horizontal or vertical axis [9]. The thrusters consist of the motor, propeller, and housing.

2.3.1 Thruster Design

The thruster should produce good results. The thruster is comprised of propellers driven by a motor [10]. But as state before, this project is designing a new design of thrusters which is magnetic contactless thrusters. There are a few major steps for design of these thrusters. They are enumerated as follows [5]:

i. Determination of Technical requirement, 3D CAD Drawing.
ii. CFD (Computational Fluid Dynamic) analysis for performance prediction [8].
iii. Finite Element Analysis of construction strength.
iv. Detail Drawing and manufacture.
v. Testing.

The process of designing the thrusters can be explained with the flow chart below. The thruster's specifications are given based on the environment where the ROV supposes to be operated. This will decide the thrust that required to generate by the thrusters. With the certain specifications, the propeller must be designed first to meet the thrust requirement [11].

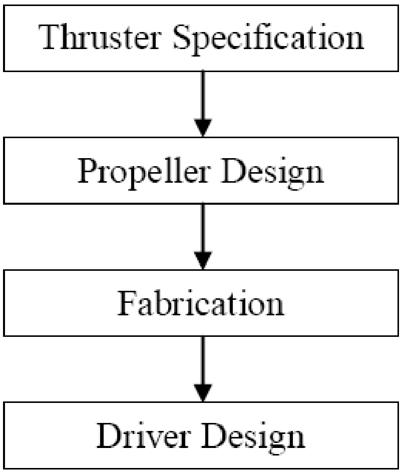


Figure 2.3.1: Design process flow chart

2.3.2 Thruster Power

Thrusters' power originally suspected as the most sensitive factor in determining the size and performance of an ROV. Dissimilar aspects of the performance conditions are analyzed in terms of the required thruster's power [12]. The power necessary for the thrusters is in terms of the total fluid power, and do not include efficiency losses from the propeller and drive train. These factors are measured during motor selection. The drag force F on the ROV is determined by the coefficient of drag, Cd, the surface area, A, and velocity, v.

$$F = \frac{1}{2}\rho C_d A U v^2 \quad (2)$$

The drag coefficient is empirically determined using the above formula. The Reynolds number is a relation between the fluid density p, velocity, U, length, L, and fluid viscosity.

$$Re = \frac{\rho U L}{\mu} \quad (3)$$

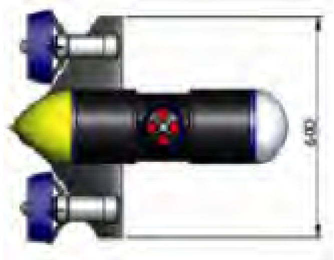
The maximum steady-state speed for ROV is a function of the max motor power output P for the thruster motors [8] [13].

$$P_{\max\_motors} = F_{drag} V_{max} \quad (4)$$

2.3.3 Thruster Model in Industry

There are a lot of thrusters have been made in nowadays. The designing of the thrusters is made to overcome the problem in underwater industry and create a better performance as customer demand. Table 2.2 shows the type of thrusters that available in the underwater industry [5] [11] [14].

Table 2.3.3: The type of thrusters that available in underwater industry

Name	Rim Driven	SHRIMP ROV - ITB	3 Phase DC Brushless
Thruster			
Type of Motor	Brushless Permanent Magnet DC	Brushless Permanent Magnet DC	Brushless Permanent Magnet DC
Power [W]	825	400	1500
Thrust [N]	100	75	150
Rotation Speed [RPM]	1500	1300	1850
Torque [Nm].	5.25	2.5	6.5
Thrusters Body	The motor is attached in the duct	Motor shaft and propeller connected.	Motor shaft and propeller connected

Based on Table 2.2 the highest power consumption of all the thrusters is 3- phase DC Brushless thruster which is 1500 W and it also produce the highest thrust and torque which are 150 N 6.5 Nm respectively. Based on equation 15 and 16, to get higher thrust and torque the power that supply to the motor must be high. But for economic and marketing demand, 3-phase DC Brushless thruster is not the suitable due to high power consumption. The specification of these three thrusters is shown too compared with the new thruster of this project.

2.4 Motor

Motor come in many size, shape, and technology, as well as each designed for different uses. The thruster motor on ROV systems is selected based on its availability, power, reliability, variety, and ease of interfaces [15]. The motor is the part in thrusters that influenced the thruster's performance. The motor drives its shaft to move the propeller hence the thrusters. There are several types of motor that commonly use in ROV thrusters. The motor is selected by its ability to give out higher torque and speed. Lower power consumption also must be considered in selection of motor for reducing the maintenance cost.

2.4.1 Type of Motor

Table 2.3 showed the comparison of various motor needs in underwater industry technologies. As a driven for the thrusters, the suitable motor should be chosen with output (torque or speed) that can produce. For example, the working class ROV must have a higher torque thruster because of the bigger size of the ROV. Basically, the work class ROV using hydraulic motors this due the hydraulic motors are able to produce a higher specific torque when compared to electric motors. If the electric motors were used to drive work class ROV thrusters they would result in a much larger electric thruster unit [16]. However, with the use of hydraulic thruster has disadvantages compared to electric counterparts [16]. This is due to the mechanical part in a hydraulic thruster system that tend to wear with time, with broken seals and water leakage into the system being amongst some of the common faults. A hydraulic system is a big system and the maintenance is costly and takes a long time to repair. In addition, hydraulic thruster systems are inefficient.

Table 2.4.1: Comparison of various motor needs in underwater industry technologies.

Motor	Advantages	Disadvantages
Hydraulic Motors	A high specific torque	Many mechanical parts make reliability an issue The efficiency of a hydraulic motor system is low
Brushed DC Motors	Proven technology Simple control	Low specific torque Wear on brushes make reliability an issue Due to brushes there are also interference noises
Induction Motors	Robust and inexpensive The technology is well understood.	Construction is robust and simple Bulk of the losses appear on the stator which is easy to cook Torque is independent of the polarity of phase current which allows the reduction of Semiconductor switches in the controller in certain applications
Brushless Permanent Magnet (PM) Motors	Brushes are eliminated hence removing the problems of speed limitation and electromagnetic interference, as well as has a better reliability when compared to Brushed DC motors The armature is on the outside stator which allows better cooling and higher specific outputs Permanent magnet	Rare earth magnets are costly Magnets can suffer from corrosion and demagnetization under fault conditions

	excitation reduces rotor losses and improves efficiency	
Variable Reluctance	A high specific torque	Suffers from high axial flux losses Technology is not well understood

Advances made in permanent magnet material and alternative electric motor topologies have made the use of all-electric thruster systems feasible. Electric motors can now be designed to have similar efficiencies and torque outputs for a much smaller size compared to traditional electric motors, albeit at a significant increase in cost if expensive rare earth magnets are used. There are many advantages to the use of electric thruster systems. Electric motors used for thruster systems have a linear response of torque to control signal when compared to hydraulic motors that have dead bands at low velocities. In conclusion, the most suitable motor is the Brushless Permanent Magnet (PM) Motors due to the elimination of brush hence removing the problems of speed limitation and electromagnetic interference, as well as having a better reliability when compared to brush DC motors. The permanent magnet excitation can reduce rotor losses and will improve the efficiency. So this motor will produce higher torque and rotation speed of the shaft.

2.5 Propeller

The propeller is a turning lifting body which is designed to move and vector water opposite to the way of motion [4]. Propeller gives effect to the efficiency of the thruster. There are two types of propellers which are:

1. Ducted Propeller
2. Un-ducted Propeller (Open Propeller)

Thruster propeller is designed by which their efficiency is much higher in one direction mostly, often in the forward and the down ways than in the other. Propellers have a nominal speed of max efficiency, which is confidently near the vehicle's normal operating speed. While selecting a propeller, decide one with the ROV's operating envelope in mind. Besides that, the size of propeller is directly proportional to speed [6].

Table 2.5: Types of propeller

Type of propeller	Un-ducted 	Ducted 
Drag Force [N]	0	30
Inflow Force [N]	2	2.6
Rotational Speed [rpm]	1400	1500
Rated Torque [Nm]	6.5	5.25
Propeller Efficiency [%]	50	53

Table 2.5 shows that the ducted propeller is more efficient than un-ducted propeller. The duct is able to increase the water flow rate through the propeller.

2.6 Magnetic Principle

The magnet is a material that produces a magnetic field. Magnetic fields are invisible but the result is shown when there is movement when magnet and magnetic materials put in one place. The attraction between the two magnets or movement is produced by magnetic fields. A permanent magnet is an item made from a substance that creates its own persistent magnetic field. The end of a freely pivoted magnet will always point in the North-South direction. The end point at the North is called the North Pole of the magnet and the end point south is called the South Pole of the magnet. It has been established by experiments that similar to magnetic poles repel each other whereas unlike poles attract each other [14].

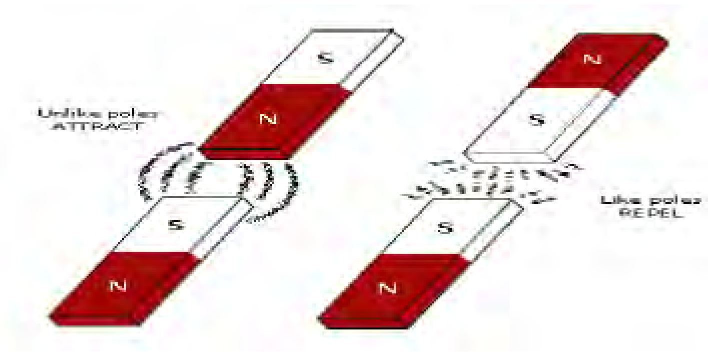


Figure 2.6: Force between two magnets

The magnetic objects like pieces of iron, steel, nickel and cobalt. Magnetic materials also know as ferromagnetic materials. Ferromagnetic materials are divided into two groups which are soft materials which are can be magnetized but do not have a tendency to stay magnetized and hard materials which are can be magnetized but do have a tendency to stay magnetized. The general strength of a magnet is measured by its total magnetic flux that produces by itself. The strength of magnetism is measured by its magnetization.

2.6.1 Magnetic Analysis

In a non-contact system, a permanent magnet is used to produce a magnetizing field strength H (Nm). A magnetic flux density B (T) is produced by the field [3].

$$B = \mu H \quad (5)$$

Where,

Permeability of the material [H/m]

Magnetizing field strength H based on the internal magnetism, which is measured by magnetization M which vanishes in non-magnetic materials.

$M = \pi H$ (6)

Where,

The susceptibility of the material. In all units, it is convenient to employ two types of magnetic field, B and H, as well as the magnetization M, defined as the magnetic moment per unit volume [13].

i. The magnetic flux density (B) is given in units of teslas (T). B is the magnetic field, whose time variation produces, by Faraday's Law, circulating electric fields. Magnetic field also produces a deflection force on moving charged particles. The T is equivalent to the magnetic flux (in Webers) per unit area (in meters squared), thus giving B the unit of a flux density.

ii. The magnetic field intensity H is given in units of ampere-turns per meter (A-turn/m). The turns appear because when H is formed by a current carrying wire, its value is proportional to the number of turns of that wire.

iii. In units, the relation B = μ0 (H + M) holds, where μ0 is the permeability of free space, which equals 4π×10−7 T•m/A

Force between two magnetic poles

$F = \frac{\mu q_{m1} qm2}{4\pi r^2}$ (7)

Where,

Force [N]

The magnitudes of magnetic poles [A.m]

Permeability of the material [T.m]

The distance between two magnets [m]

The thruster system works based on the electric machines (DC motor) which rotate about an axis which is known as the shaft. Due to a rotational nature of machinery, a basic understanding of rotational motion is important to have in mind. In this thruster system the shaft is contact with a plate that contains a magnet. The speed of the plate is calculated in angular velocity. Angular velocity or speed is the rate of change in angular position in angular position with respect to time [15].

$$\omega = \frac{d\theta}{dt} \tag{8}$$

Where,
: Angular velocity [rad/s]
: Angular velocity [rev/s]
: Angular velocity [rev/m]

These measures of rotation speed are related to each other by the following equations:

$$n = 60f \tag{9}$$

$$f = \frac{\omega}{2\pi} \tag{10}$$

The torque is now calculated when force is applied to the point and the smallest distance between the line of action of the force and the object's axis of rotation. If r is a vector point from the axis of rotation to the point of the force, and if F is the applied force, then the torque can be described as:

$$\tau = Fr \tag{11}$$

Newton's law of rotation, is given by the equation

$$\tau = J\alpha \tag{12}$$

Where,

= Net torque in newton meters
= Resulting angular acceleration

Moment of inertia Angular acceleration is a measure of the rate of change in angular velocity with respect to time.

$$\alpha = \frac{dv}{dt} \tag{13}$$

Work is the application of a torque through an angle in rotational motion. Below is the equation for work is:

$$W = \int \tau d\theta \tag{14}$$

If the torque is constant,

$$W = \tau\theta \tag{15}$$

From the torque, the power can be calculated by using the equation:

$$P = \frac{dW}{dt} \tag{16}$$

$$P = VI \tag{17}$$

Where,

P = Power [W]

V =Voltage [V]

I = Current [A]

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter is discussed about the design and development of the magnetic contactless thruster. Hence, this chapter discusses the materials and the methods used in the design and fabrication of the project, as well as its manner of operation. It shows all steps and techniques for completing the project from the starting stage until it is completed.