CERTIFICATION OF APPROVAL

Effect of Performance of A DC Motor by Replacing Ferrite Magnet with Melt Spun NdFeB Magnet

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

Permanent magnets have been used in many applications and industries a long time ago since earlier 20^{th} century. It has been used for consumer electronics, appliances and tools, factories automation and also for medical and educational purposes. Nowadays, peoples are coming with researches to produce permanent magnet with greater strength for heavy applications and also to reduce the volume of the magnet without compromising the magnetic properties. One of its applications is in Permanent Magnet DC Motor (PMDC motor). The author studied the effect of performance of a DC motor by replacing a ferrite magnet with the melt spun NdFeB Magnet. In this project the author fabricated a bonded NdFeB for a DC motor from NdFeB alloy powders which are produced from melt spinning process. The magnet is fabricated by using compression moulding technique and using epoxy as its binder. The fabricated magnet is then magnetised by using magnetizer. Besides, microstructure and chemical properties of the magnet is checked by using optical microscope and also Scanning Electron Microscopy (SEM) with chemical analysis. Magnetic properties of the magnet is also analysed by using Vibrating Sample Magnetometer (VSM). Physical properties of the magnet such as the density is also will be analysed. After all the work done, the DC motor speed increased for 38.3%. This result shows that by replacing ferrite magnet with bonded NdFeB magnet able to build a more efficient motor.

ACKNOWLEDGEMENTS

Thanks to merciful Allah SWT and His Prophet Muhammad SAW bless giving me a chance to finish my Final Year Project (FYP). Also, thanks to all who's gave me support, encouragements, concerns and helps along during my entire project.

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ABBREVIATIONS AND NOMENCLATURES

DC	Direct current
NdFeB	Neodymium Iron Boron
T	Tesla
G	Gauss
Oe	Oersted
PMDC	Permanent magnet direct current
SmCo	Samarium cobalt
SEM	Scanning electron microscopy
VSM	Vibrating sample magnetometer

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Increase in demand of good characteristic magnet in industries nowadays is very high. Application such as Permanent Magnet DC Motor is one of it. By having higher value of the magnet strength will also increase the speed of the motor. Thus, the author would like to take the challenge to study the effect of a DC motor performance by replacing a ferrite magnet with the bonded melt spun NdFeB magnet. It is supported by Mohd. Abdus Salam in his book [10] that says whenever current carrying conductor is placed in a magnetic field would experience a force that tends to move it. The direction of this force is determined by applying Fleming's left-hand rule. By applying this rule, it is found that the forces produce by each conductor under the poles produces by each conductor under the pole produces a torque which tends to rotate the amature in a clockwise direction. All this force add together to produce a powerful driving torque, which set the amature rotating. In this study the speed of the motor is measure before and after he speed of the motor is measured and compared for both DC motor with NdFeB magnet and Ferrite magnet.

1.2 Problem Statement

Permanent magnets have been used in many application and industries a long time ago since early 20th century. It has been used for consumer electronics, appliance and tools, factories automation and also for medical and educational purposes. Meanwhile, Neodymium-Iron-Boron (normally know as NdFeB in industries) magnet is a rare earth group nowadays has been developed as magnetic material in 1980's with its magnetic characteristic far exceeding from those of the

Samarium-Cobalt, Alnico, ceramic or ferrite types. NdFeB magnets have some excellent advantages. It is also mechanically much stronger and very high energy product can be achieved. Bonded magnet is also having more resistance to corrosion. The advantages of having those properties is that unit that using magnet can be build smaller, lighter and more efficient unit can be design to produce wide range of application. However, these magnets are slightly expensive as compare to ferrite magnets since the main element Neodymium (Nd) and Iron (Fe) are rare [2]. Thus, by developing magnet with good characteristic we can remain competitive in industries nowadays. DC motor performance with higher magnetic strength is also can be improved. Rotational speed of the motor is also can be improved.

1.3 Objectives and Scope of Study

In this study, the primary objective is to study the DC motor performance before and after replacing the ferrite magnet with bonded NdFeB magnet. The study is focusing in terms of its rotational speed.

To achieve the objective bonded NdFeB magnet were fabricated. The magnets were fabricated by using die and plunger compression method. The performance of the DC motor was evaluated before replacing the permanent magnet with the new bonded NdFeB magnet. The motor was then assembled with the new magnet. The performance of the DC Motor after with the new NdFeB magnet was evaluated again. Besides the motor performance, properties such as the microstructure, magnetic properties and density were also analyzed using optical microscope, Scanning Electron Microscope (SEM) and Vibrating Sample Magnetometer (VSM).

CHAPTER 2
LITERATURE REVIEW

2.1 Prospect of NdFeB Magnet in Market

The author believes that this project is pointless if there is no demand of magnet. Thus, this section will explain the market need of the magnet and also the future of magnet industries. From M.L Patel, S. Pandian and B.D Pathak [2], there is a sufficient global reserve of Neodymium to at least for another 100 years. Besides, the existing world capacity to separate Neodymium from its salt is very high up to 4000 tons per annum. This shows the supply of Neodymium is sufficient for mass production and will guarantee attractive profit margin.

2.1.1 Current Trends

In 2005 the global market of magnet was around $7.6 billion. The market for permanent magnet is expected to grow 7.8% per year, from $8.1 billion currently to $11.8 billion in 2011. The most rapid growth is expected in China, Indonesia, Russia, Mexico, Taiwan, India, and Malaysia (refer Figure 2.1)

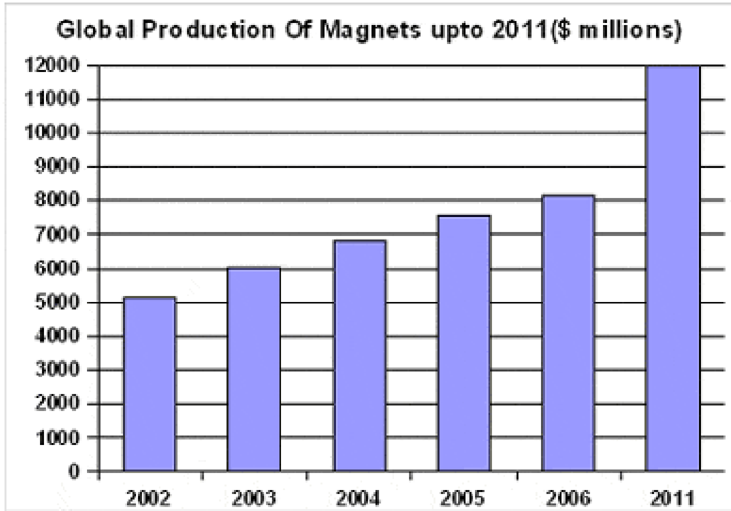

Figure 2.1: Global production of magnet up to 2011 (In million US dollar)[15].

2.1.2 Market Drivers

Due to rapid industrialization in the developing world, the demand of magnet is increasing every year. Year 2006 saw a rapid growth in magnet industry. The maximum consumption of magnets took place in the big industries. Other major consumers were Instrumentation and consumer electronics. The consumption of magnets in various industries can be represented in a chart below.

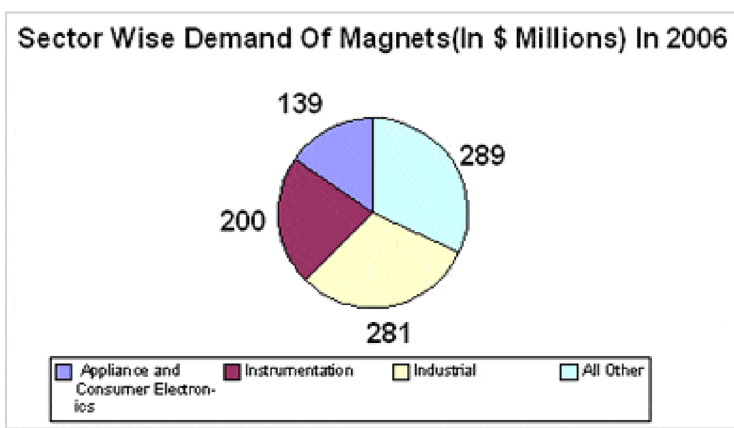

Figure 2.2: Sector wise demand of magnet in 2006 (in million US dollar)[15].

2.2 Magnet

A magnet is a material or object that produces a magnetic field. A "hard" or "permanent" magnet is one which stays magnetized for a long time, such as magnets often used in refrigerator doors. A "soft" or "impermanent" magnet is one which loses its memory of previous magnetizations. "Soft" magnetic materials are often used in electromagnets to enhance (often hundreds or thousands of times) the magnetic field of a wire that carries an electrical current and is wrapped around the magnet; the field of the "soft" magnet increases with the current. Permanent magnets occur naturally in some rocks, particularly lodestone, but are now more commonly manufactured. A magnet's magnetism decreases when it is heated and increases when it is cooled [4].

Two measures of a material's magnetic properties are its magnetic moment and its magnetization. A material without a permanent magnetic moment can be attracted (paramagnetic), or repelled (diamagnetic) in the presence of magnetic fields. Liquid oxygen is paramagnetic; graphite is diamagnetic. Paramagnets tend to intensify the magnetic field in their vicinity, where as diamagnet tend to weaken it. "Soft" magnets, which are strongly attracted to magnetic fields can be thought of as strongly paramagnetic; superconductors, which are strongly repelled by magnetic fields, can be thought of as strongly diamagnetic [4].

2.2.1 Magnetism

Magnetic fields and forces originate from the movement of the basic electric charge, the electron. When electron moves along in conducting wire, a magnetic field is produced around the wire. Magnetism in material is also due to the motion of electrons, but in this case the magnetic field and forces are caused by the intrinstic spin of electron and their orbital motion about their nuclei (see figure 2.3).

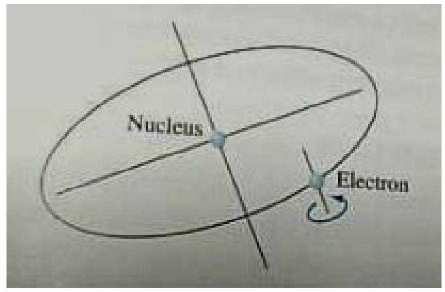

Figure 2.3: Illustration of electron spins which produce magnetism [4].

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2.2.2 Magnetic Induction

A demagnetized iron bar is placed inside a solenoid and was applied a magnetizing current to the solenoid. Now, the magnetic field outside the solenoid is stronger with the magnetized bar inside the solenoid. The enhanced magnetic field outside the solenoid is due to the sum of the solenoid field itself and the external magnetic field of the magnetized bar. The new additive magnetic field is called the magnetic induction or flux density or simply induction, and is given by the symbol *B*

The magnetic induction B is the sum of the applied H and the external field that arises from the magnetization of the bar inside the solenoid. The induced magnetic moment per unit volume due to the bar is called the intensity of magnetization or simply magnetization.

$$B = \mu_o H + \mu_o M$$

Where μ_o is permeability of free space with $4\pi \times 10^{-7}$ tesla-meter per ampere (T.m/A)[2] The Si unit for B are webers[3] per square meter or Tesla(T), and the SI units for H and M are amperes per meter (A/m) The british unit for B is the gauss (G) and for M is the oersted (Oe)

An important point to note is that for ferromagnetic material, in many cases the magnetization μ_oM is often greater than the applied field μ_oH .Thus the relation $\mathbf{B} \approx \mu_o M$. Thus for ferromagnetic materials sometimes the quantities B (magnetic induction) and M (magnetization) are used interchangeably [4]

2.2.3 Magnetic Permeability and Susceptibility

When a ferromagnetic material is placed in an applied magnetic field, the intensity of the magnetic material field will be increased. The increase in magnetization is measured by a quantity called magnetic permeability μ , which is defined as the ration of the magnetic induction B to the applied field H, or

$$\mu = \frac{B}{H}$$

Since the magnetization of a magnetic material is proportional to the applied field, a proportionality factor called the magnetic susceptibility, χ_m and defined by

$$\chi_m = \frac{M}{H}$$

which is a dimensionless quantity. Weak magnetic response of materials are often measured in terms of magnetic susceptibility [4]

2.2.4 Type of Magnetism

Magnetic fields and forces originate from the movement of the basic electric charge, the electron. When electrons move in a conducting wire, a magnetic field is produced around the wire. Magnetism in materials is also due to the motion of electrons, but in this case the magnetic fields and forces are caused by the intrinsic spin of electrons and their orbital motion about their nuclei [4].

An external magnetic field acting on the atoms of a material slightly unbalances their orbiting electrons and creates small magnetic dipoles within the atoms that oppose the applied field. This action produces a negative magnetic effect known as diagmanetism.[4]

Materials that exhibit a small positive magnetic susceptibility in the presence of a magnetic field are called paramagnetism. The paramagnetic effect in materials disappears when the applied magnetic field is removed. Paramagnetism produced susceptibilities in material ranging from about 10^{-6} to 10^{-2} and produced in many materials. The atoms of some transition and rare earth element posse incompletely filled inner shells with unpaired electrons. These unpaired inner electrons in atoms, since they are not counterbalanced by other bonding electrons in solids, cause strong paramagnetic effect [4].

The third type of magnetism, called ferromagnetism, is of great engineering importance. Large magnetic field that can be retained or eliminated as desired can be produced in ferromagnetic materials. The most important ferromagnetic element from industrial standpoint is iron (Fe), cobalt (Co) and nickel (Ni). The ferromagnetic properties element is due to the way the spins of the inner unpaired electrons are aligned in their crystal lattices. The inner shells of individual atoms are filled with pairs of electrons with opposed spins, and so there are no resultant magnetic dipole moments due to them [4].

In some ceramic materials, different ions have different magnitudes for their magnetic moments, and when these magnetic moment are aligned in an antiparallel manner, there is a net magnetic moment in one direction, as a group, ferromagnetic material are called ferrites [4].

2.2.5 Magnetization and Demagnetization of a Ferromagnetic Metal.

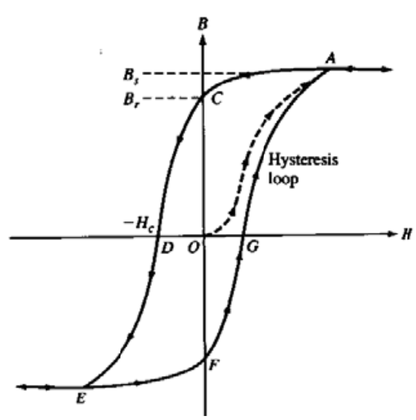

Figure 2.4: Hysteresis loop of ferromagnetic metal

Ferromagnetic metals such as Fe, Co, and Ni acquire large magnetizations when placed in a magnetizing field, and they remain in the magnetized condition to a lesser extent after the magnetized is removed. Lets applied field H on the magnetic induction B of a magnetic induction B of a ferromagnetic metal during magnetizing and demagnetizing as shown in the hysteresis loop in the figure above. First, demagnetize a ferromagnetic metal such as iron by slowly cooling it from above its Curie temperature. Then, let us apply a magnetizing field to the sample and follow the effect of the applied field on the magnetic induction of the sample.

As the applied field increased from zero, B increases from zero along curve OA (see figure 2.4) until saturation induction is reached at point A. Upon decreasing the applied field to zero, the original magnetization curve is not retraced, and there remains a magnetic flux density called the remanent induction B_r (point C in figure 2.4). To decrease the magnetic induction to zero, a reverse (negative) applied field of the amount H_c , called the coercive force, must be applied (point D from the figure 2.4) If the negative applied field is still more, eventually the material will reach saturation induction in the reverse field at point E from the figure 2.4. When the reversed field is removed, the magnetic induction will return to the remanent induction at point F in the figure and upon application of the positive applied field, the B-H curve will follow FGA to complete a loop. Further application of reverse and forward applied field to saturation induction will produce the repetitive loop of ACDEFGA. This magnetization loop is referred to as a Hysteresis loop, and its internal area is a measure of energy lost of the work done by the magnetizing and demagnetizing cycle [4][12].

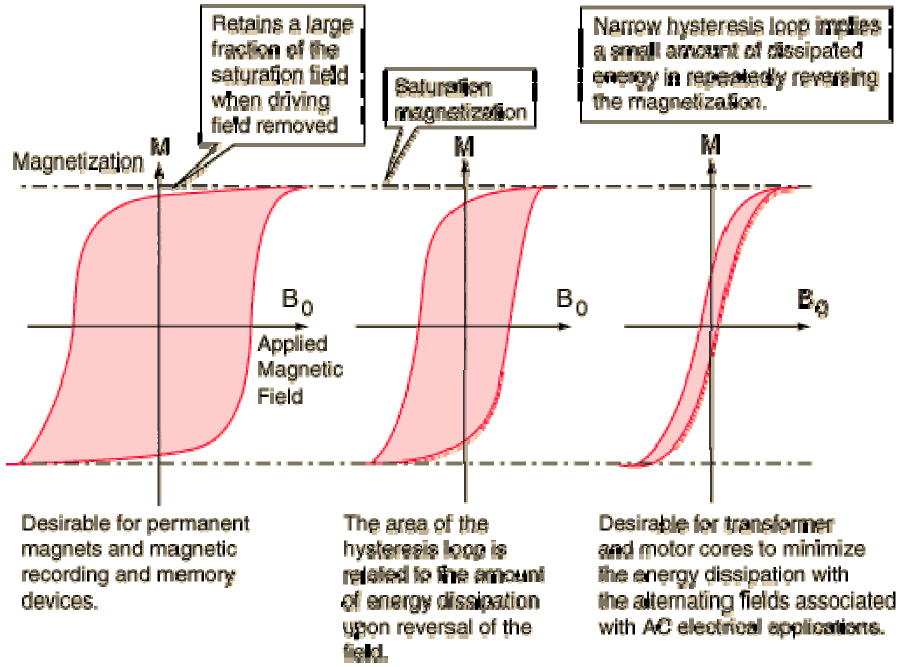

Figure 2.5: Comparison of hysteresis of soft and hard magnet

The hysteresis loop from the figure 2.5 shows the difference of hard magnet and soft magnet. In this study, the author would like to produce hard bonded magnet which is shown on the left loop from the figure shown above.

2.2.6 Neodymium-Iron-Boron Magnetic Alloys

Hard NdFeB magnetic material with $(BH)_{max}$ product as high as $300kJ/m^3$(45 MG.Oe) were discovered in about 1984, and today these materials are produced by both powder metallurgy and rapid-solidification melt-spun ribbon processes.

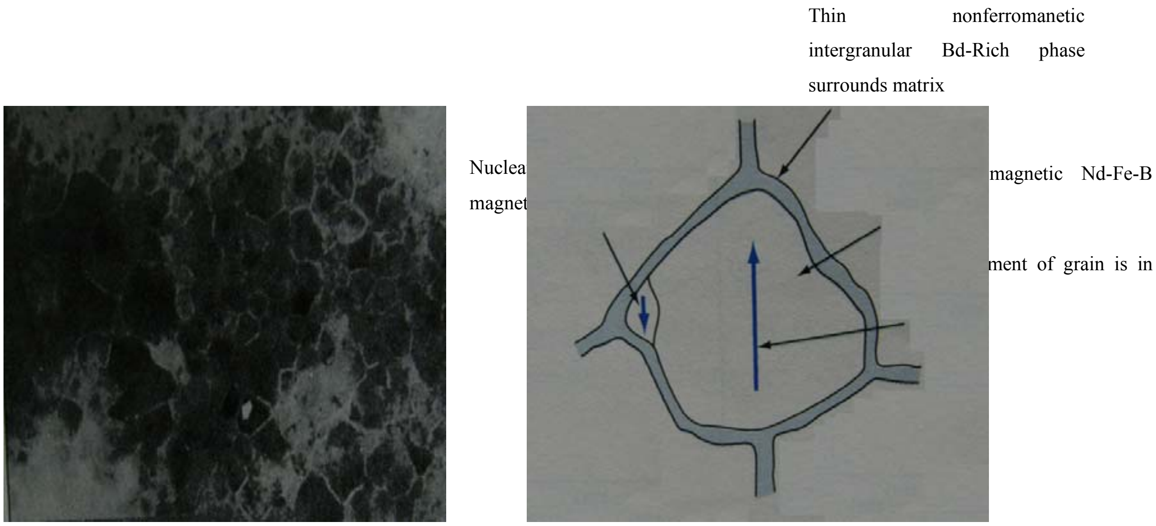

Figure 2.6: Scanning Electron Microscopy image and illustration of NdFeB Magnetic material

Figure 2.6 shows the microstructure of a $Nd_2Fe_{14}B$-type rapidly solidified ribbon. In this structure highly ferromagnetic $Nd_2Fe_{14}B$ matrix grains are surrounded by a nonferromagnetic Nd-rich thin intergranular phase. The high coercivity and associated $(BH)_{max}$ energy product of this material result from the difficulty of nucleating reverse magnetic domains that usually nucleate at the grain boundries of the matrix grains. The intergranular nonferromagnetic Nd-rich phase forces the $Nd_2Fe_{14}B$ ma trix grains to nucleate the reverse domains in order to reverse the magnetization of the material. This process maximizes H_c and $(BH)_{max}$ for the whole bulk aggregate of the material.[4]

2.2.7 Parameter to describe magnetization curve

- <u>Saturation</u>

- Maximum induction *Bs* when the curve starts to level off.
- The asymptotic maximum of the magnetization term.

- <u>Remanence</u>

- The induction Br remaining after H has returned to zero.

- The magnetization left behind in a medium after an external magnetic field is removed

▪ Coercivity

- The field H_c required to cancel the remaining induction.
- Is the intensity of the applied magnetic field required to reduce the magnetization of that material to zero after the magnetization of the sample has been driven to saturation.

For characterization of permanent magnet materials the demagnetization curve (second quadrant of hysteresis loop) is of importance. The magnetic quality of a permanent magnet is given by the energy product $(BH)_{max}$ [2]

2.3 Design Advantages and Advancement using NdFeB magnet

The choice of magnet material is one of the first factors to be considered during designing devices. The most important factor or issues that need to be considered are its:

2.3.1 Remenent flux density, Br

Remenent flux density (or residual induction) is the value of the flux-density at the surface of the magnet when it is surrounded by a magnetically perfect medium. This, of course is never the case in any magnetic device but it is still a useful parameter in the design process when a comparison between materials is made. The value is compared by simply measure the magnetic flux different of a same size and for a given distance.

2.3.2 Energy product, BH_{max}

When looking at the amount of magnet material needed in a particular device, a high energy material is always preferable. Given a certain flux required at some fixed distance from the magnet, we can use this information to estimate what volume will be required for different magnet material. For example, what volume of Ceramic 5 magnet would give the same flux as a Neo 35 magnet at a given distance? Simply divide the BHmax of neo 35 by BH_{max} of Ceramic 5 (35/3.6) to get 9.7. This means that the volume of Ceramic 5magnet would have to be 9.7 times than the size of the Neo 35. Therefore in addition to the cost saving from using less NdFeB material than other magnet For comparison of same common magnet in industries, the graph below shows the maximum energy rating of NdFeB magnet and other competitors' magnet.

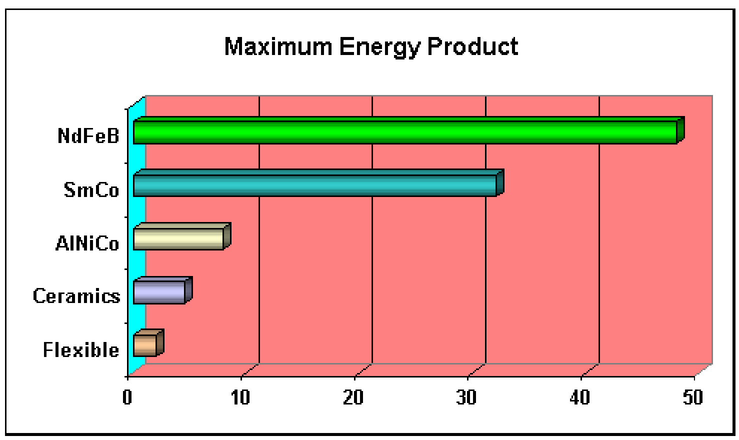

Figure 2.7: Comparison of NdFeB magnet maximum energy with other competitor in market in Mg.Oe [2].

2.3.3 Temperature Coefficient

Magnet materials have specific values for coefficients, which describe the effect of temperature on the value of B and H in the demagnetization characteristics. The magnet specification may be given at one temperature (usually 20^{o}C) and the designer must take into account the effect of the operating temperature range in the performance. For example for NdFeB, the flux density drops by 0.58% for every degree C (ie: 58% over a 100^{o}C range). These amounts appear to be significant at high temperature when compared with SmCo magnet (0.04%/^{o}C and 0.12%/^{o}C respectively) but can be acceptable as a result of using this magnet material. Some forms of neodymium magnets with cobalt can have coefficient as low as 0.07%/^{o}C and would therefore, be more suited for high-temperature applications

2.3.4 Magnetizing force

The magnetizing force recommended by the magnet manufacturer is the external magnetic force which must be applied to the material to fully saturate it. A magnet does not have one particular value of magnetizing force to which reference can be made. It is rather, a range of values of magnetizing force resulting in various levels of saturation. The NdFeB material has advantages over SmCo magnet since it required lower value of force to reach similar percentage of saturation

2.3.5 Curie Temperature

Each magnet material has a specific temperature at which all magnetic properties are lost. This is called the Curie temperature. The operating temperature of magnet material is well below this value and is determined primarily by how much drop in performance acceptable is compared to that at room temperature. The Curie temperature is also the temperature at which a permanent magnet must be heated in order to ensure full demagnetization. This process is required if the magnet needs to be remagnetized or magnetized differently from the previous state. It is extremely difficult and the results are unpredictable if a magnet is remagnetized without demagnetizing. This is especially true of high energy magnets.

The NdFeB magnets have a Curie temperature lower than all other magnet than lower than SmCo magnets. It is, therefore, easier to demagnetize a NdFeB magnet than other magnet with a medium temperature oven

2.3.6 Thermal Expansion

NdFeB magnet material have coefficient of thermal expansion of about half of that of SmCo. This means that for a particular temperature range, an NdFeB magnet would experience a much smaller change in dimension than a SmCo magnet of the same dimension. The amount of this change is important in determining the fit between the magnet and the surrounding materials.

2.3.7 Cost

On cost-per-pound basis, NdFeB magnets seem very costly. However by using a more powerful magnet, the entire device that the magnet goes into can be miniaturised, yielding cost saving that favour more powerful magnet materials. In other words, the powerful magnets can assure us of smaller size and lighter weight in designing devices.

2.4 Vibrating Sample Magnetometer (VSM)

The most important analysis in this project is the VSM analysis. This analysis had been done in AMREC, SIRIM Berhad. Vibrating Sample Magnetometer (VSM) measures the magnetic properties of materials. When a material is placed within a uniform magnetic field and made to undergo sinusoidal motion (i.e. mechanically vibrated), there is some magnetic flux change. This induces a voltage in the pick-up coils, which is proportional to the magnetic moment of the sample [23].

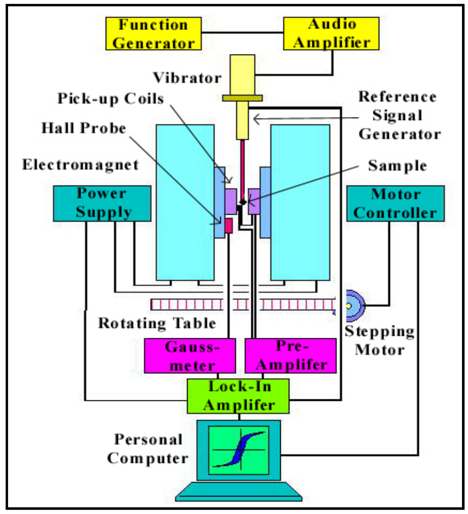

Figure 2.8: System diagram of VSM

2.5 Epoxy Binder

Advantages:

-High Magnetic Strength

-Good Chemical Resistance

-Tight Tolerances Possible

-Good Mechanical Strength

-Lower Tooling Costs

Disadvantages:

- Lower Temperature Resistance
- Susceptible to Surface Oxidation
- Corrosion

2.5.1 Binder

There are two components need to be mixed to produce epoxy binder with a certain ratio which are the resin and the hardener

2.5.2 Epoxy Resins

Most common epoxy resins are produced from a reaction between epichorohydrin & Bisphenol A. Other materials can become part of the reaction yielding Bis F resins, Novolac resins, and multifunctional resins. The reaction product is high in viscosity and can either undergo further reaction processes to yield a lower viscosity.

Epoxy resins are often modified using other products to improve some measured property of the final product such as toughness or tensileness. Epoxy resins and their additives contribute to the viscosity of the system and to the shrinking characteristics. The amount of the fillers and diluents will impact both the physical and handling properties of the resin system. Epoxy resins are part of a two-component thermo-set plastic that requires an epoxy hardener to determine the majority of the handling and physical properties of the base. The use of several variations of unmodified and modified epoxy resins with the same epoxy hardener will produce some variations in their properties. However, the epoxy hardener is the primary factor in the base property [13].

2.5.3 Epoxy Hardeners

Epoxy hardeners are not catalysts and they react with the epoxy resins, greatly contributing to the ultimate properties of the cured epoxy resin system. Epoxy hardeners provide:

- gel time
- mixed viscosity
- demold time of the epoxy resin system.

Physical properties of the epoxy resin system such as tensility, compression, flexural properties, are also influenced by epoxy hardeners. The performance of epoxy hardeners in the epoxy resins system depend on the chemical characteristics of the epoxy resins and the physical characteristics while applying the epoxy resins system. The chemical characteristics of the epoxy resins that influence epoxy hardeners are: viscosity amount and kind of diluents and filers in epoxy resins. The physical characteristics of the epoxy resins system influencing the behaviour of epoxy hardeners in the epoxy resins system are temperature of the work area, temperature of the resins system and moisture [22].

2.6 DC Motor Operating Mechanism

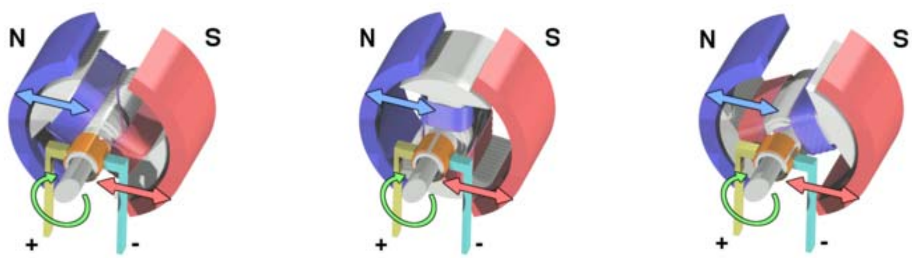

Figure 2.9 (a) Figure 2.9 (b) Figure 2.9 (c)

Figure 2.9: DC motor operating mechanism

`A simple DC electric motor, when the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn toward the right; causing rotation (Figure 2.9 (a)).The armature continues to rotate (Figure 2.9 (b)). When the armature becomes horizontally aligned, the commutator reverses the direction of current through the coil, reversing the magnetic field. The process then repeats (Figure 2.9(c)) [15].

2.7 Permanent Magnet DC Motor

A permanent-magnet DC motor (PMDC) is a motor whose poles are made of permanent magnets. Permanent-magnet dc motors offer a number of benefits compares with shunt dc motors in some applications. Since these motor do not require an external field circuit, they do not have the circuit copper losses associated with shunt dc motor. Because no field windings are required, they can be smaller than corresponding shunt dc motors. PMDC motors are especially common in smaller than corresponding shunt dc motor. PMDC motors are especially common in smaller fractional- and subfractional-horsepower sizes, where expense and space of a separate field circuit cannot be justified.

However, PMDC motors also have disadvantages. Permanent magnets cannot produce as high a flux density as an externally supplied shunt field, so a PMDC motor will have a lower induced torque τ_{ind} per ampere of ampere of amature current I_A than a shunt motor of the same size and construction. In addition, PMDC motors run the risk of demagnetization. The amature current, I_A in a dc machine produces an amature magnetic field of its own. The amature mmf subtracts from the mmf of the poles under other portions of the poles faces, reducing the overall net flux of the machine. In PMDC motor, the pole flux is just the residual flux in the permanent magnets. If the amature current becomes very large, there is some risk that the armature mmf may demagnetize the poles, permanently reducing and reorienting the residual flux in them. Demagnetization may also be caused by the excessive heat which can occur during prolonged period of overload [10].

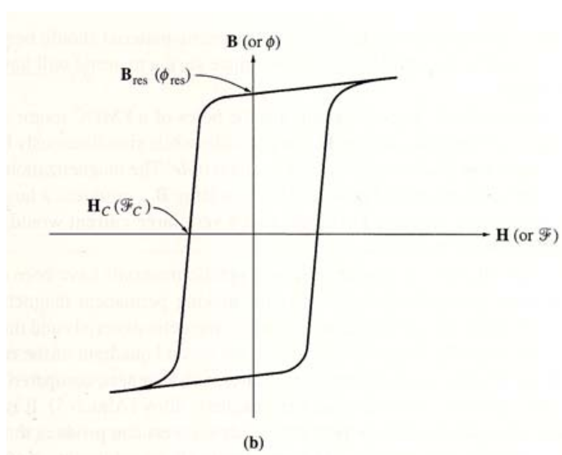

Figure 2.10: The magnetization curve of a ferromagnetic material suitable for use in permanent magnets. Note high residual flux density, B_{res} and the relatively large coercive magnetizing intensity H_C

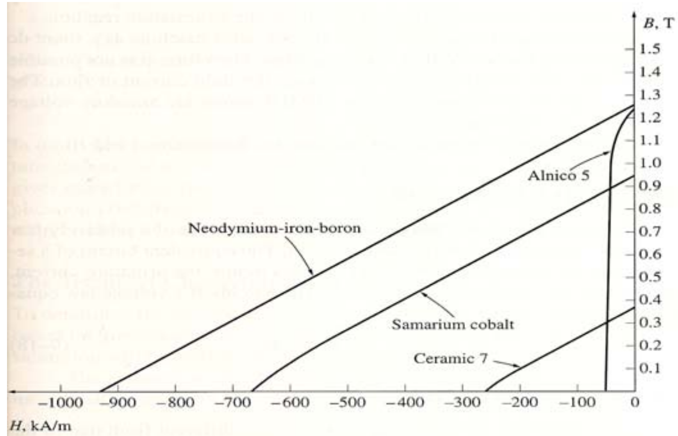

Figure 2.11: The second quadrant of the magnetization curves of some typical magnetic materials. Note that the rare-earth magnets combine both a high residual flux and a high coercive magnetizing intensity.

A good material for the poles of a PMDC motor should have as large a residual B_{res} as possible, while simultaneously having as large a coercive magnetizing intensity H_c as possible. The magnetization curve of such a material is shown in the figure. The large B_{res} produces a large flux in the machine, while the large H_c means that a very large current would be required to demagnetize the poles. [10]

CHAPTER 3
METHODOLOGY

This project was conducted through several steps. First, several literatures were collected to analyze the data and gain the required knowledge regarding the composition of magnets, technique to produce high-energy product of bonded NdFeB magnet, and to study on characteristic of the binders that will be used. In addition to literature reviews, the internet including message boards, websites and electronics books and journals were used to find any further information and references.

Second steps, to identify the material and consumables needed for this project such as epoxy that would be used to mix with the magnetic powder. After that, the materials needed were purchased and was fabricated such as die for the experiment purpose. Types of the experiment that would undergo with further analysis such as hardness test, density-measurement, and analyze magnetic properties that were conducted at SIRIM.

At the end of the preliminary work, the requirements, advantages and drawback of energy product of bonded NdFeB magnet were defined. Hypothesis and estimation also was drawn during this stage.

3.1 Planning

Planning step was conducted during the first week of the project. In this step, several process identification and organization were done with the help from supervisor to fit all the process well in the FYP time frame.

3.2 Study and Research

In this data mining process, several information sources were browsed through to gather as much information on related topics. Some information was gathered from books and journals while some were located in online literatures as well as magazines and technical reports.

3.3 Equipments and Tools familiarization

In order to complete this project, several machines have been used. During experiment phase, Auto Press machine was used to compress the powder and Auto Mounting machine for mounting the sample in order to do an analysis using Scanning Electron Microscopy (SEM). For Analysis phase, five machines were used. Those are Optical Microscope, SEM, Vibrating Sample Magnetometer (VSM), and Magnetizer.

3.4 Procedures for Fabricating Bonded NdFeB Magnet

1. NdFeB powder was weighed for 21.2g.
2. 5 wt% of epoxy binder which is 1.06g was weighed.
3. Both powder and binder were mixed in acetone. The mixture was blended by a mixer until the acetone evaporated and left the mixture in a paste form.
4. The paste was then compressed in a die using auto press machine. The compression load used was 5 tonne.
5. The samples prepared were cured in an oven for 1 hour at 150 °C.
6. The dimensions and weight of each sample were measured to calculate the density of the samples.
7. All samples were then analysed by using optical microscope, Scanning Electron Microscope (SEM), Vibrating Sample Magnetometer (VSM)

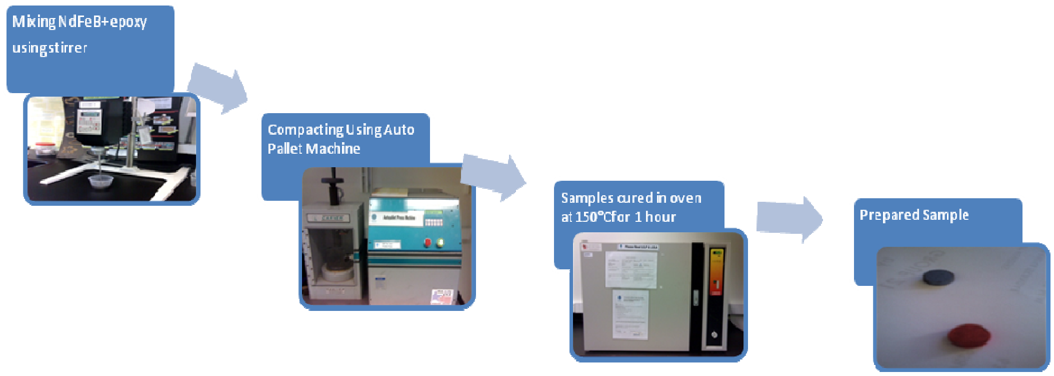

Figure 3.1: Flow chart for fabricating the sample

3.5 Procedure for testing of the DC Motor

1) The necessary connection for the power supply and motor is performed
2) NdFeB magnet is placed at the motor body
3) Voltage is increased until the motor start to rotate.
4) Reading of the speed is taken and recorded using Tachometer.
5) The voltage is increased for 0.5V and take the reading
6) Step 5 is repeated for the same voltage increment up to 6 V
7) Step 1 to 6 is repeated for ferrite magnet

Tachometer

DC Motor

DC Power

Magnet

Figure 3.2: Configuration for the DC motor testing

CHAPTER 4

RESULT AND DISCUSSION

4.1 Analysis of DC Motor Performance

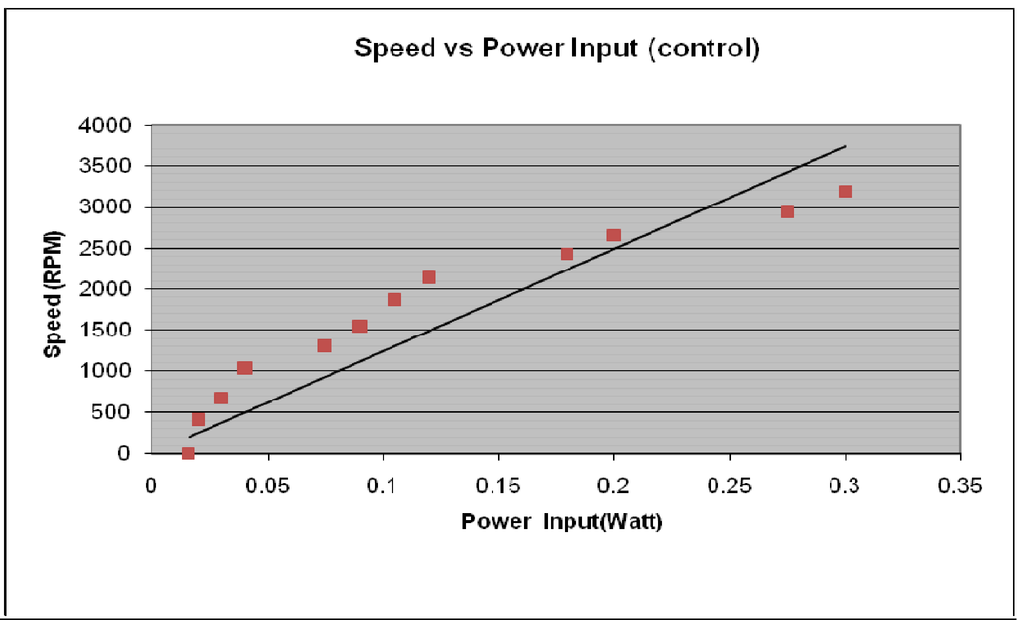

Figure 4.1: Graph of Speed vs Input Power for DC motor (control)

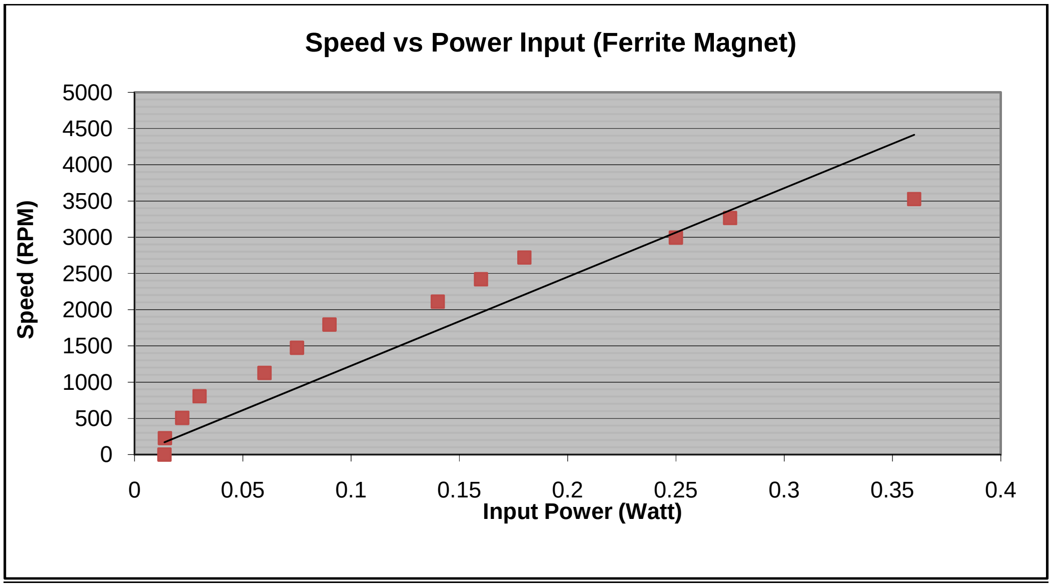

Figure 4.2: Graph of Speed vs Power Input for a DC Motor by using Ferrite Magnet

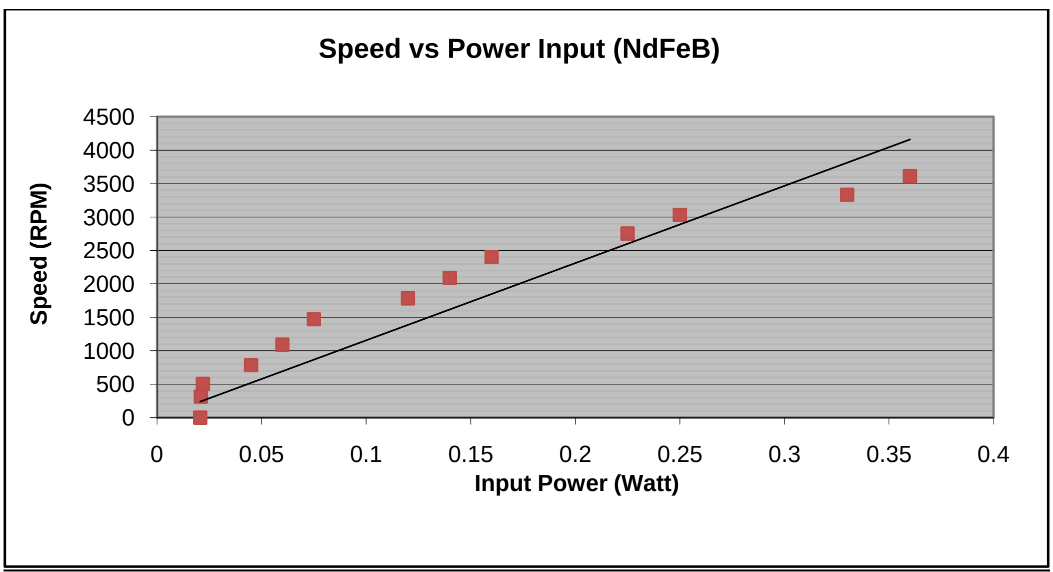

Figure 4.3: Graph of Speed vs Power Input for a DC Motor by using NdFeB Magnet

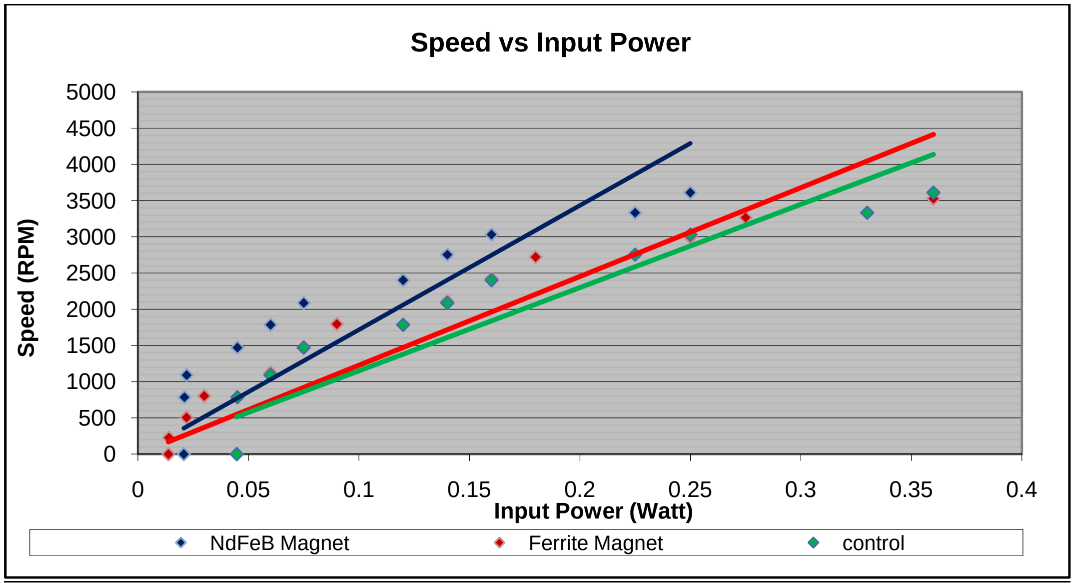

Figure 4.4: Graph of Speed vs Power Input for a DC Motor by using Ferrite Magnet, NdFeB Magnet and control plotted in same axis

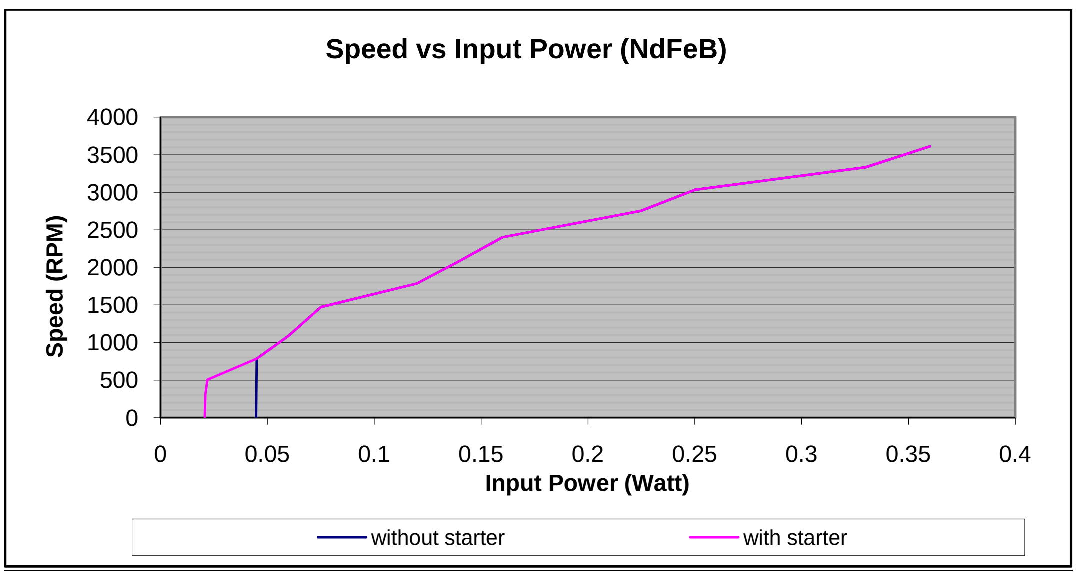

Figure 4.5: Graph of speed vs power input for a DC motor by using NdFeB Magnet scattered plotted with and without starter assist

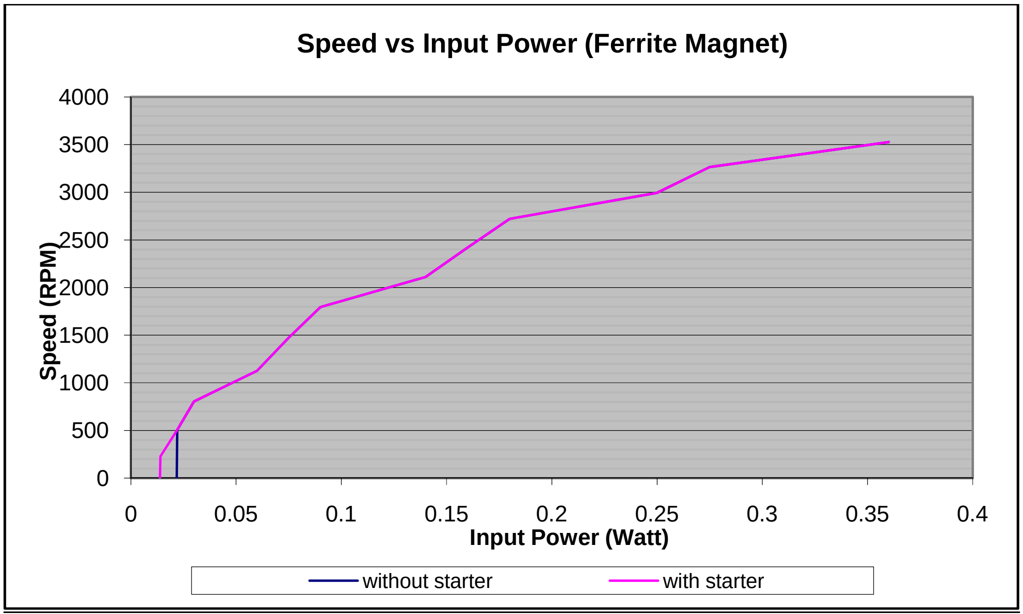

Figure 4.6: Graph of speed vs power input for a DC motor by using Ferrite Magnet scattered plotted with and without starter assist

Figure 4.1 , 4.2 and 4.3 show the speed of the DC motor read by using tachometer plotted against power input for the control, ferrite magnet and NdFeB magnet respectively. Power input of the motor was varied by regulating the voltage of the power supply. The linear plot of each graph showing the speed increasing linearly starting from zero for a given power input. For comparison purpose, the linear plot of all 3 situations is put on 1 axis as shows in Figure 4.4. Obviously we can see that using NdFeB magnet increases the speed of the DC motor. The percentage of increment of the speed is 38.3%. Please refer to Appendix C for the calculation.

However, when the graph is plot using scatter plot as show in figure 4.5 and 4.6, we can see that the motor is rotating upon the application of current to the ammature. Certain power input is needed to be applied before it starts to rotate. For instance, as shows in Figure 4.6, for DC motor with bonded NdFeb Magnet, it only start to rotate at 0.0447 watt without starter assisted. This is due to the attraction of the permanent magnet to the stator. It starts to rotate when the magnetic field of the armature is able to overcome the strong magnetic field from the permanent magnet.

Meanwhile, DC motor with bonded NdFeB Magnet is able to rotate at low power with start assist.

4.2 Metallography Analysis

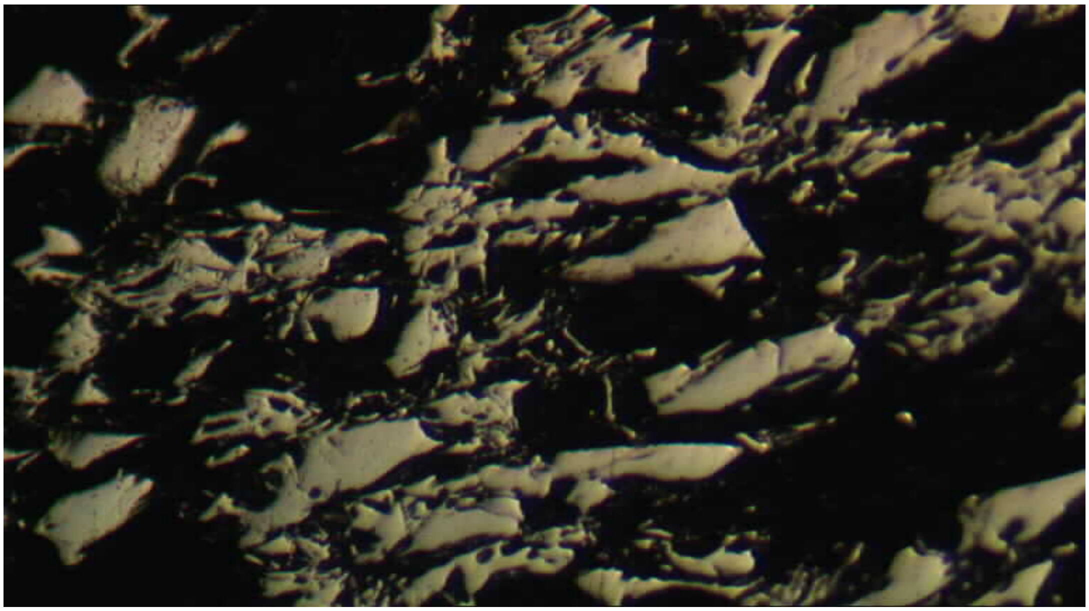

Figure 4.7: Optical microscope image of the NdFeB Magnet

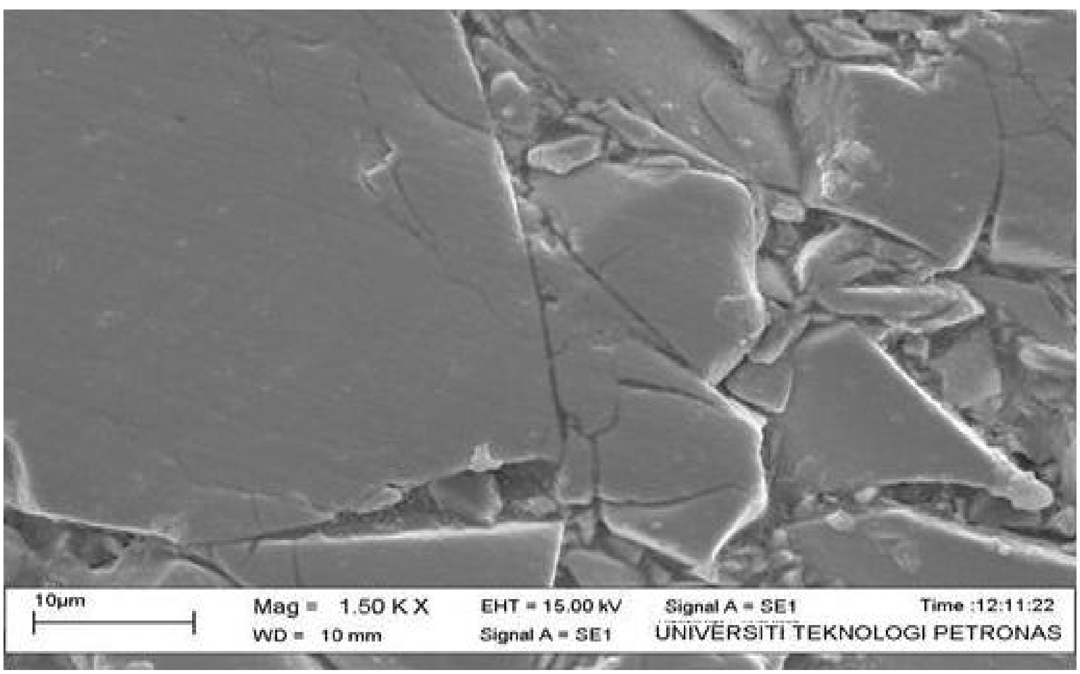

Figure 4.8: Scanning Electron Micrograph (SEM) image of the NdFeB Magnet

The NdFeB alloy powder with 5wt% epoxy was observed under the optical microscope at 100x magnification and these are depicted in Figure 2.7. The above micrographs show that the particles of the powder are bonded to each other closely by epoxy. So far, the pores could not be seen because of the well distribution of the epoxy binder and hardener. The mixing process with acetone to dilute the resin and hardener also helps to obtain homogeneous mixture. The SEM image is also confirmed that there is no large pores exist.

SEM image also show the grain size of the NdFeB alloy which is around 20 to 50 µm. Besides, the image also shows the random or amorphous grain structure of the alloy. It is due to the rapid quench of the melt NdFeB alloy by the melt spinning process.

Chemical Analysis Using SEM with EDAX

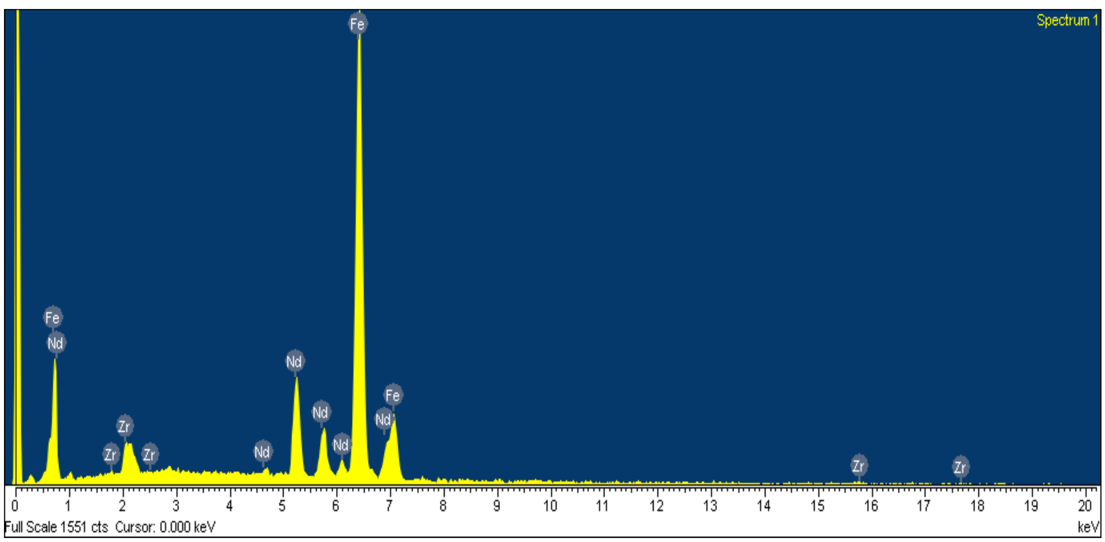

Figure 4.9: Qualitative analysis of NdFeB ribbon (NQP-C)

Element	Weight %	Atomic %
Fe K	70.39	84.81
Zr L	5.09	3.76
Nd L	24.52	11.44
Totals	100.00	100.00

Table 4.1: Qualitative analysis of NdFeB ribbon (NQP-C)

The presence of elements in the alloy were revealed using SEM with EDAX. EDAX analysis shows that not only neodymium, iron and boron appear in the magnetic ribbon NQP-C, elements such as Zirconium was also appeared in the materials. In this analysis, the result shows that the fundamental elements, neodymium and iron, usually found in NdFeB materials are present. Boron is present within the NdFeB magnets, but it is too little and cannot be picked up by the SEM analysis.

4.3 Magnetic Properties Analysis

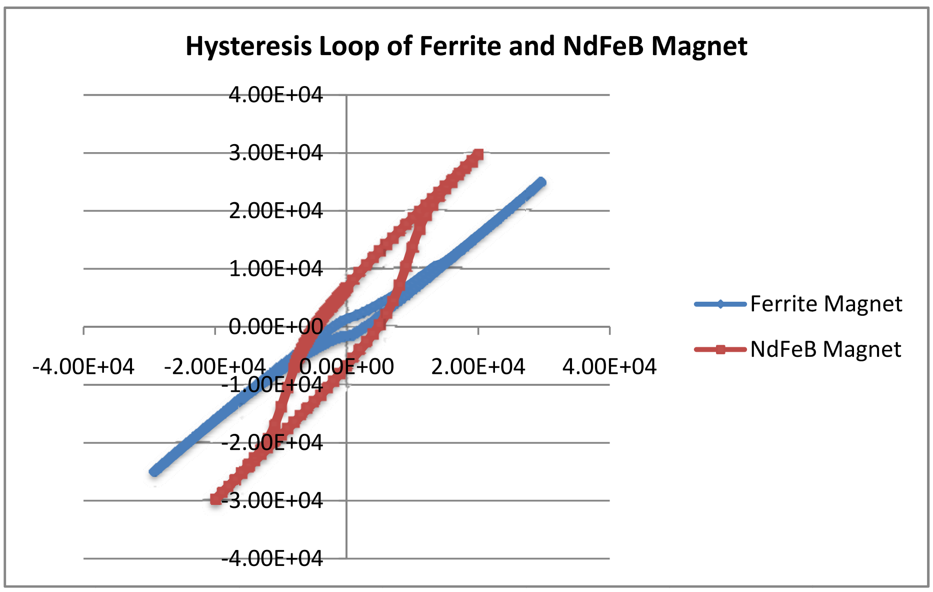

Figure 4.10: Magnetization, B versus Applied Field, H hysteresis loop for the Ferrite and Melt Spun NdFeB Magnet

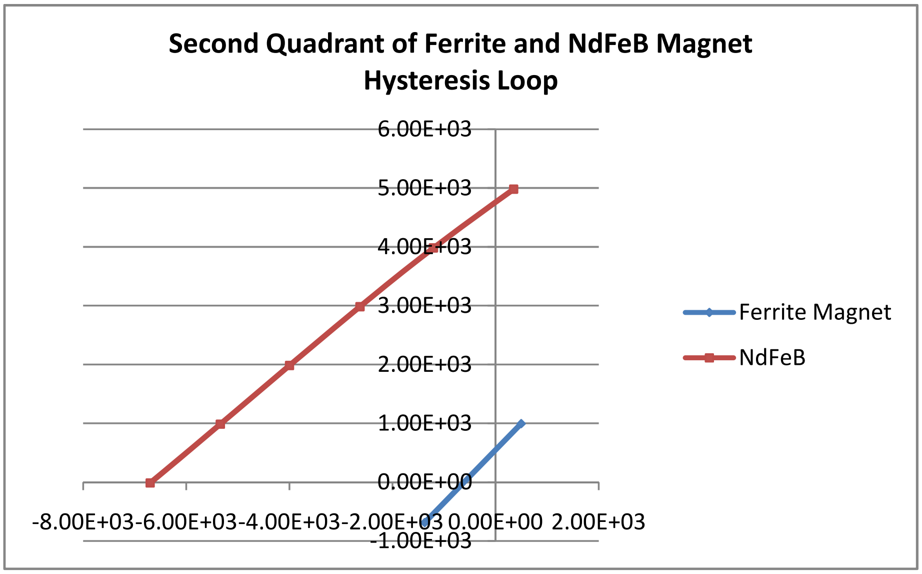

Figure 4.11: Second Quadrant of Ferrite and NdFeB Magnet Hysteresis Loop

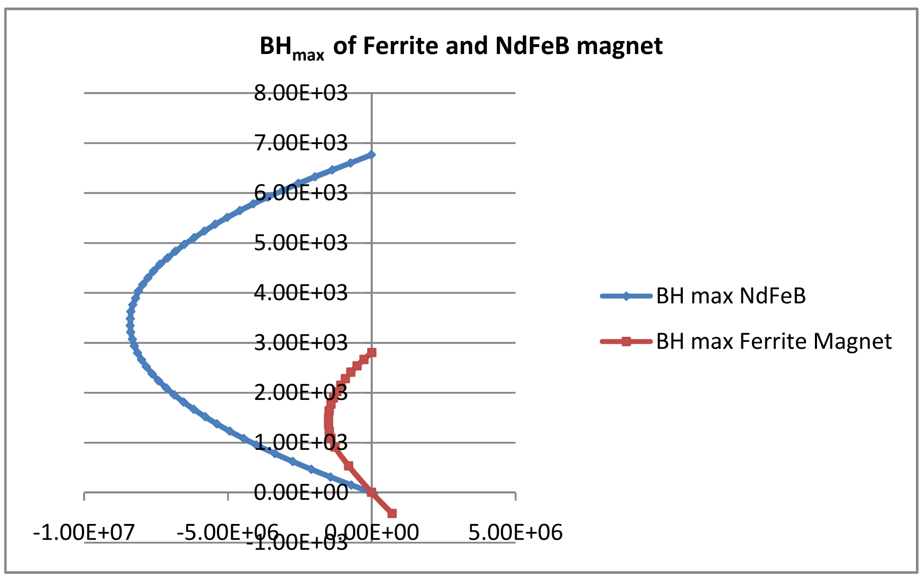

Figure 4.12: Energy Product (B vs BH) of Ferrite Magnet and NdFeB Magnet

From the hysteresis loop of the magnet for NdFeB magnet as in Figure 4.10, we can see that bonded NdFeB Magnet comprise a good properties of a good magnet for DC motor application with High value of M and H. While Figure 4.12 shows the BH_{max} for NdFeB magnet reaches to 8.0 MGOe. As compared to Ferrite Magnet, shows the energy product BH_{max} of 0.7 MGOe. We can say that bonded NdFeB magnet is 11.4 times more energy than ferrite magnet. Theoretically, the stator or the permanent magnet part of a DC motor can be miniaturized 11.4 times smaller when we replace it with bonded NdFeB magnet.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In the nutshell, the speed of the DC motor was improved when replacing the bonded NdFeB magnet. The speed tested improved by 38.3 % as proven from the calculation and data obtained. It is due to the large value of magnetic field from the ammature and permanent magnet that has been cut through. The high energy of the stator which is from the NdFeB Magnet helps to push the rotor or the amature faster. However, at very low power input, DC motor with NdFeB Magnet cannot be started. It is due to the attraction of the magnet to the stator is too strong. The motor only will start to rotate when the magnetic force from the stator is able to push the rotor after the strong magnetic force from the NdFeB magnet. From the above result, it is possible to replace ferrite magnet with NdFeB magnet of the DC motor. Thus, higher performance of the DC motor can be achieved.

5.2 Recommendation

During the testing of the DC motor, it is noted that the reading of the DC motor with ferrite magnet is not consistent. The value measured is slightly increased when it is tested after measuring the speed of the DC motor with NdFeB magnet. It is believe that the strong magnetic field from the NdFeB magnet had retained to the motor's parts. Thus to overcome this problem, we can test the DC Motor with Ferrite magnet first followed by DC motor with NdfeB magnet.

Besides that, due to the limitation of equipment and instrumentation, the torque of the motor cannot be measured. This study can be value added if we can measure the torque of the motor which by having the value we can calculate the output power of the shaft. By having the value we can calculate the efficiency of the motor and compare the overall performance of the motor.

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APPENDICES

APPENDIX A

Tables of Voltage, Current, Power Input, and Speed

Voltage,V	Current,I	Input power, watt	Speed, RPM
0.99	0.02	0.0198	0
1	0.02	0.02	407
1.5	0.02	0.03	670
2	0.02	0.04	1034
2.5	0.03	0.075	1306
3	0.03	0.09	1546
3.5	0.03	0.105	1869
4	0.03	0.12	2135
4.5	0.04	0.18	2425
5	0.04	0.2	2653
5.5	0.05	0.275	2935
6	0.05	0.3	3185

Table A1: Control(without starter)

Voltage,V	Current,I	Input power, watt	Speed, RPM
0.8	0.02	0.016	0
1	0.02	0.02	407
1.5	0.02	0.03	670
2	0.02	0.04	1034
2.5	0.03	0.075	1306
3	0.03	0.09	1546
3.5	0.03	0.105	1869
4	0.03	0.12	2135
4.5	0.04	0.18	2425
5	0.04	0.2	2653
5.5	0.05	0.275	2935
6	0.05	0.3	3185

Table A2: Control (with starter)

Voltage,V	Current,I	Input power, watt	Speed, RPM
1.49	0.03	0.0447	0
1.5	0.03	0.045	785
2	0.03	0.06	1091
2.5	0.03	0.075	1471
3	0.04	0.12	1785
3.5	0.04	0.14	2087
4	0.04	0.16	2401
4.5	0.05	0.225	2753
5	0.05	0.25	3031
5.5	0.06	0.33	3332
6	0.06	0.36	3610

Table A3: NdFeB(without starter)

Voltage,V	Current,I	Input power, watt	Speed, RPM
0.69	0.03	0.0207	0
0.7	0.03	0.021	315
1.1	0.02	0.022	506
1.5	0.03	0.045	785
2	0.03	0.06	1091
2.5	0.03	0.075	1471
3	0.04	0.12	1785
3.5	0.04	0.14	2087
4	0.04	0.16	2401
4.5	0.05	0.225	2753
5	0.05	0.25	3031
5.5	0.06	0.33	3332
6	0.06	0.36	3610

Table A4: NdFeB (With starter)

Voltage,V	Current,I	Input power, watt	Speed, RPM
1.09	0.02	0.0218	0
1.1	0.02	0.022	506
1.5	0.02	0.03	804
2	0.03	0.06	1127
2.5	0.03	0.075	1474
3	0.03	0.09	1795
3.5	0.04	0.14	2111
4	0.04	0.16	2420
4.5	0.04	0.18	2720
5	0.05	0.25	2995
5.5	0.05	0.275	3265
6	0.06	0.36	3527

Table A5: Ferrite (without starter)

Voltage,V	Current,I	Input power, watt	Speed, RPM
0.69	0.02	0.0138	0
0.7	0.02	0.014	227
1.1	0.02	0.022	506
1.5	0.02	0.03	804
2	0.03	0.06	1127
2.5	0.03	0.075	1474
3	0.03	0.09	1795
3.5	0.04	0.14	2111
4	0.04	0.16	2420
4.5	0.04	0.18	2720
5	0.05	0.25	2995
5.5	0.05	0.275	3265
6	0.06	0.36	3527

Table A6: Ferrite (with starter)

APPENDIX B

Density, volume, and surface area calculation

Bonded NdFeB Magnet

In order to get the density of each sample, the weight and volume of the sample was determine. So the diameter and thickness must be measured to get the volume of the sample.

Density, $\rho = m/V$; $V = \pi r^2 h$

m = mass

V = Volume

r = radius

h = thickness

5wt% of binder:

Volume, $V = \pi \times (12/2)^2 \times 4.00mm$

$= 452.39\ mm^3$

Density, $\rho = \dfrac{2.69gram}{452.39\ mm^3} \times \dfrac{1000\ mm^3}{1\ cc}$

$= 5.946\ g/cc$

Surface area= $[\pi 6^2 \times 2] + [2\pi 6 \times 4]$

$=376mm^2$

Theoretical density calculation:

$\rho_{Nd} = 7.4\ g/cc$

$\rho_{epoxy} = 1.3\ g/cc$

$\rho = m/V$

For 5wt%:

$\rho_{mix} = \dfrac{(m_{Nd} + m_{epoxy})}{V_T}$; $m_{Nd} = \rho_{Nd} \times V_T$

$m_{epoxy} = \rho_{epoxy} \times V_T$

$\rho_{mix} = \dfrac{(0.97x\ \rho_{Nd} + 0.03\ \rho_{epoxy})\ V_T}{V_T}$

$= (0.97 \times 7.4) + (0.05 \times 1.3)$

= 7.21 g/cc

For Ferrite Magnet

Weight : 2.891g

Volume = $\Pi[\frac{16.5-3}{2}]^2 X 15 X \frac{90}{360}$

= $536.77mm^3$

Density = ($2.891g$ / $536.77mm^3$) x ($1000mm^3$/1cc)

=5.385g/cc

Surface area = $(2\pi 9.75^2 + 2\pi 8.25^2) /4 + (3x\ 2x\ 15)$

= $565.16mm^2$

APPENDIX C

Speed Increment Calculation

At 0.15 watt

NdFeB magnet DC motor speed = 2550rpm

Ferrite magnet DC motor speed = 1850 rpm

%increment = (2550-1850) / 1850 (x 100%)

= 37%

At 0.2 watt

NdFeB magnet DC motor speed = 3425rpm

Ferrite magnet DC motor speed = 2450 rpm

%increment = (3425-2450) / 2450 (x 100%)

=39%

At 0.25 watt

NdFeB magnet DC motor speed = 4250rpm

Ferrite magnet DC motor speed = 3025 rpm

%increment = (4250- 3050) / 3050 (x 100%)

= 39%

==the average of the speed increment value is calculated to be **38.3%**

Appendix D

Performance of Magnet

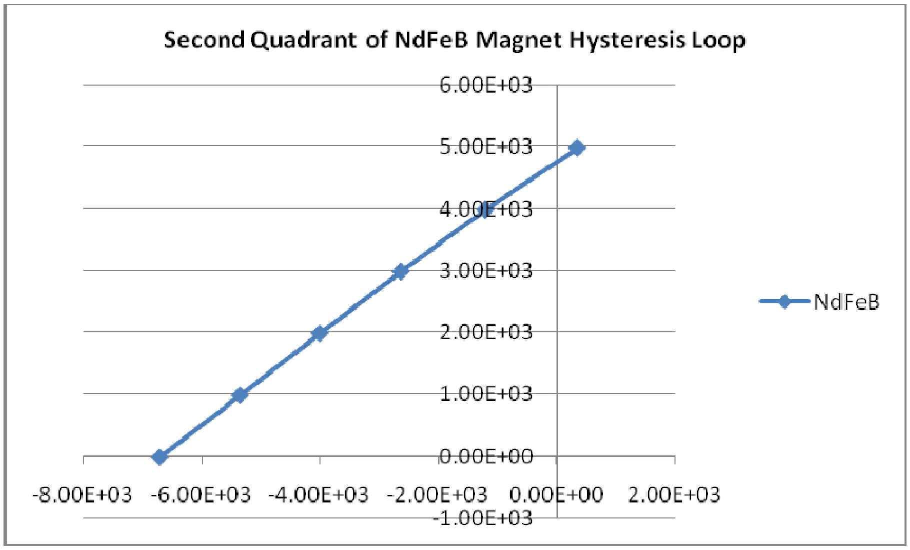

Figure A1: Second quadrant of NdFeB magnet Hysterisis loop

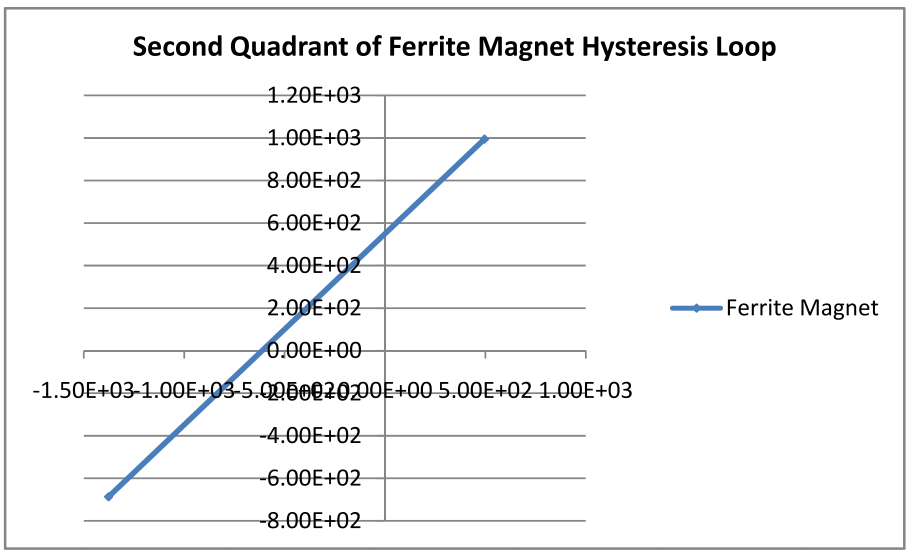

Figure A2: Second quadrant of Ferrite magnet Hysterisis loop

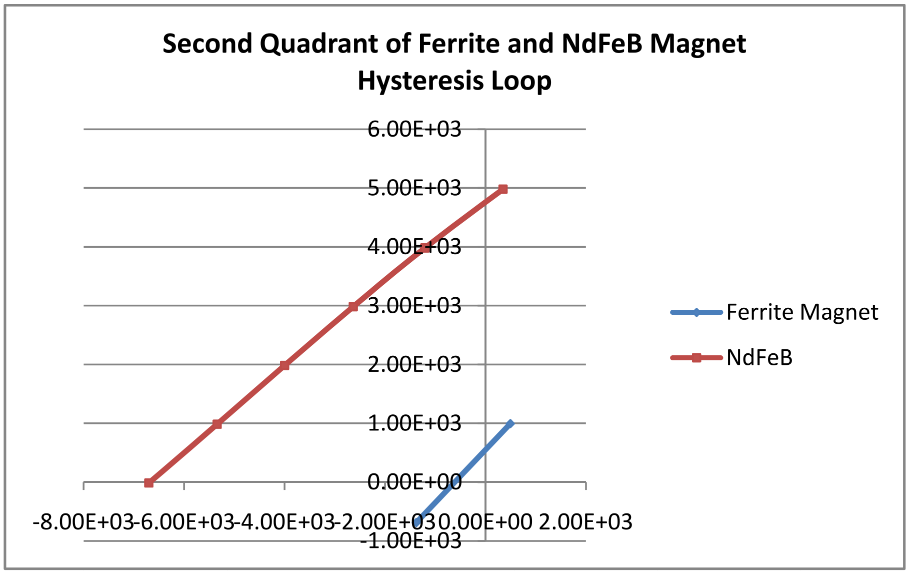

Figure A3: Second quadrant of Ferrite and NdFeB magnet Hysterisis loop

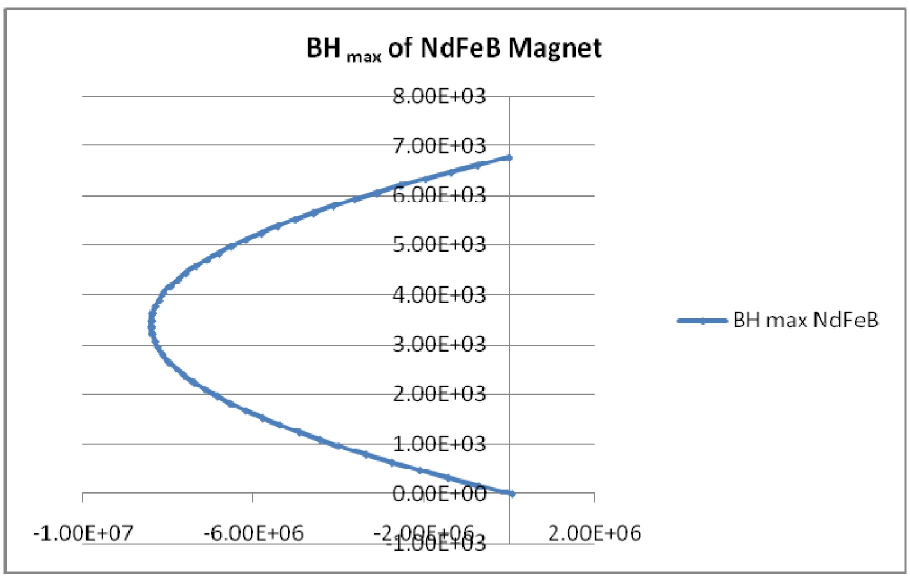

Figure A4: BH_{max} of NdFeB magnet

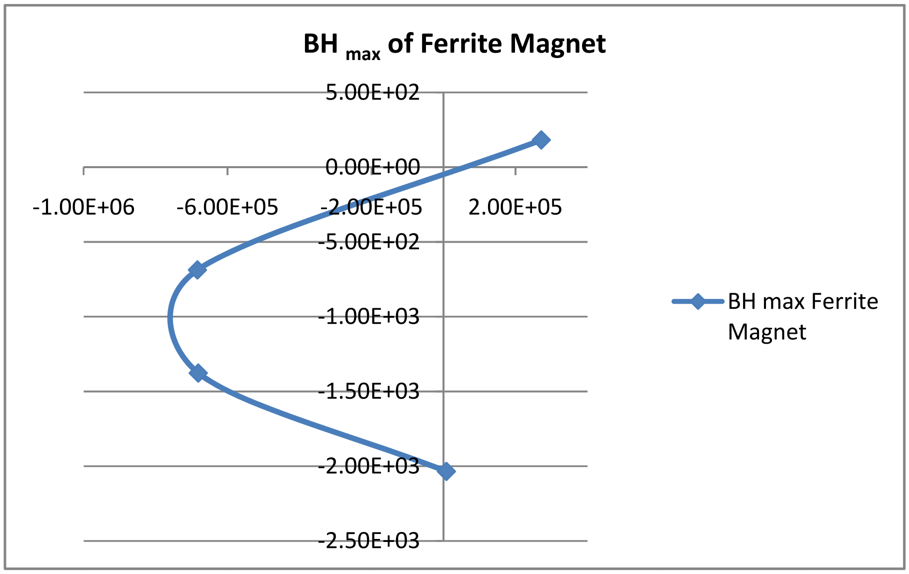

Figure A5: BH_{max} of ferrite magnet

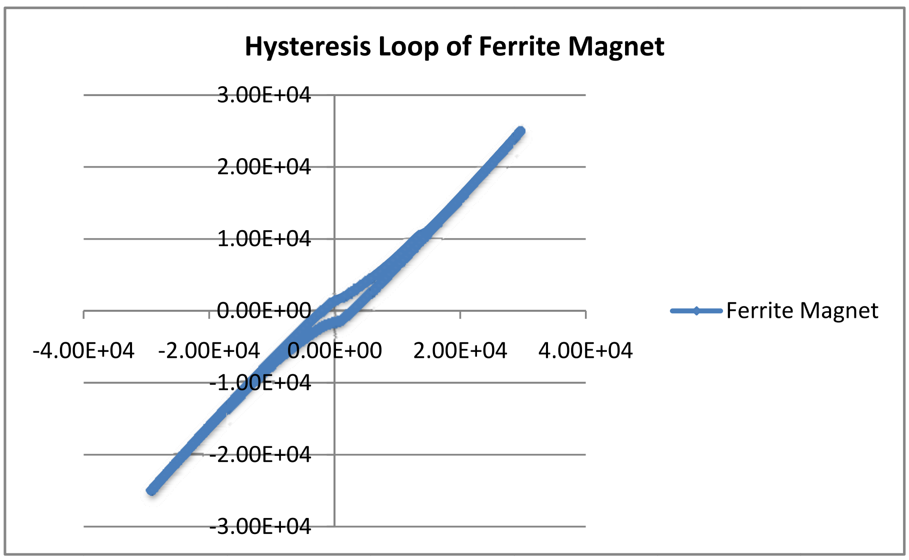

Figure A6: Hysterisis loop of ferrite magnet

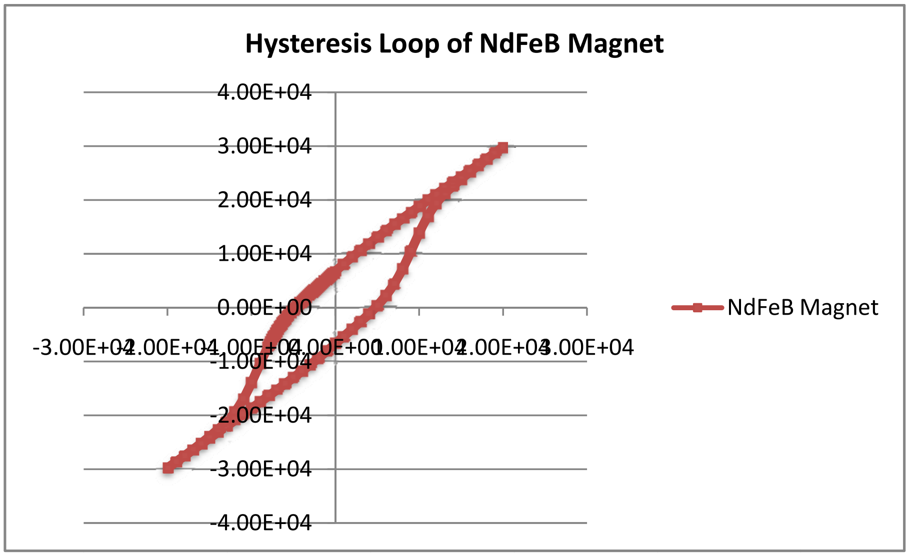

Figure A7: Hysterisis loop of NdFeB magnet