EXPERIMENTAL WORKS AND ANALYSIS TO DETERMINE THE DEGRADATION OF PERMANENT MAGNET FORCE UNDER CYCLIC MAGNETIC FIELD

(FINAL YEAR PROJECT DISSERTATION)

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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 won expect 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 magnet is widely used in today's application such motors we used in car or generator in power stations. Materials commonly used are neodymium, alnico, and also soft ferrites. Its unique ability to retain its magnet force for such a long time is one of the attributes it excels in. However, loss of magnet's strength or demagnetization can bring major impact in applications. External field or electric current is one of the method where a magnet can be magnetized and demagnetized by altering the number of domains of electrons which the mechanism of magnetism is present. Permanent magnet – permanent magnet interactions in cyclic motion resembles what happen in both motor and generators. Their magnetic strength is indeed all acting differently before, during and after the application to be specific, in cyclic motion. Hence, further research must be done followed by in-depth analysis to know how these magnets would react under cyclic motion.

ACKNOWLEDGEMENTS

To the light, our god, who guided us through the way. To Dr. Ir. Masri, for his great efforts of supervising and leading us, to accomplish this fine work. To our friends and families, they were a great support and encouragement, we thank them all and wish them all the bet in their lives. To our mothers and fathers, for their warm, kind encourage, and love. To every person gave us something to light our pathway, we thank them for believing in us.

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ABBREVIATIONS AND NOMENCLATURES

PM	Permanent Magnet

CHAPTER 1: INTRODUCTION

1.1 Background of project

Permanent magnet is a manmade object from a material which is magnetized and it's independently produces its own magnetic field. A permanent magnet always having a magnetic field and will show magnetic behaviour of all times. That is the main reason permanent magnet is vastly used in modern applications, such as telecommunication, transportation and others.

One of the remarkable usage of permanent magnet that it is commonly used in motor system. Like any other types of motor, permanent magnets were usually used in stator and some of other part of the rotor itself. Under prolonged, repetitive operation, there is a limit of circumstances where the performance of the permanent magnet in the motor system is totally unknown.

This study will focus on degradation of permanent magnet's magnetic field under repetitive cyclic magnetic force.

1.2 Problem Statement

The usage of permanent magnet in electric motor and generator system is widely known and indeed the only most effective, cost saving method other than fully utilized electromagnetism concept. Unfortunately, after enormous, very extreme condition of repetitive cycle, the degradation magnitude of the permanent magnet itself after those cycles is unknown.

1.3 Objectives

The main objectives of this research is to conduct experiment on permanent magnets and to analyse any changes or effects on its force under repetitive cyclic magnetic force.

Planning the whole experiment with careful in a very limited timeline is important to increase the feasibility and effectiveness of this research. Method of this research requires deep understanding of fundamentals on magnetism and how it functions to bring this research to its finest form. Henceforth, advice, consultations and supervisions on designs and step-by-steps procedures are compulsory, continuous steps all along this research.

The next following objectives are tabulating, analysing the acquired data throughout the experiment. Those data would be recorded in an organized manner and at the same time, can avoid any confusion during the data graphing and analysis.

Thorough analysis then would be done before stating the conclusions of this research. Only then generating conclusions would take place. Double checking whether hypotheses of this research is parallel to data obtained is necessary at all times throughout this research in order to check the validity of every aspects involved.

1.4 Scope of Study

The scope of the study will focus on permanent magnet's magnetism and material properties of permanent magnet itself. Relationship of magnetism of subject permanent magnet and its material changes of properties will be evaluated. Related reliable scientific theories and concept hence will be applied along the way.

CHAPTER 2: LITERATURE REVIEW

Introduction

Forces of attraction in permanent magnets (PM) are established by means of magnetostatic interactions between them (David Vokoun, 2009). Because of this features, permanent magnet is vastly used in every applications nowadays. As for example, an arrays of permanent magnet are usually being used in a broad range of applications: sensors, magnetic actuators, drug targeting and delivery systems, releasable magnetic fasteners and many others (D. Vokoun G. T., Magnetic forces between arrays of cylindrical permanent magnets, 2011). To get almost full control of devices, knowledge of the magnetic forces is an essential (David Vokoun, 2009). One of the issues raised, is the demagnetization effect that takes place after some times as it is being used in continuous, heavy-duty applications, such as in industrial drives and generators in power plants (Cristian Ruschetti, 2013).

In this research, author is going to investigate the demagnetization or degradation of magnetic force under cyclic magnetic force. There are debates ongoing regarding whether the effect is very small, hence making it negligible and can be omitted somehow. Although for generators and industrial drives, faults are responsible for high costs due to maintenance and downtime (Cristian Ruschetti, 2013), degradation of magnetic forces of PM is indeed still giving a significant effects for high-accuracy equipment (D. Vokoun G. T., Magnetic forces between arrays of cylindrical permanent magnets, 2011). This can give rise to decreasing performance of motors, drop in accuracy, hence, inflicting valuable resources of manpower, cost, and time. Hence, this research would revolve on the investigation of the degradation of magnetic force under cyclic operations.

Permanent Magnet Arrays

Permanent magnets may be arranged into arrays to utilise their mutual magnetostatic interaction and hence, the force acting upon them (D. Vokoun G. T., 2011). Commonly, permanent magnet arrays has been put into its fullest potentials in many applications; among others: eddy current dampers (B. Ebrahimi, 2010), magnetic refrigerators (S.J. Lee, 2002), micro pumps (Y. Su, 2006). In the literature and research papers related to permanent magnets, calculations of magnetic forces between the magnets of different geometries and shapes have their relevance on their usage and solely purpose (D. Vokoun G. T., 2011).

Such like one of researches that has been done, some formulas had been derived for evaluating force between two permanent magnet arrays, uniformly spaced over a square lattice (D. Vokoun M. B., 2014). There were three basic shapes put into considerations: cylinder sphere, and rectangular prism. These shapes were put into considerations for this paper since its easy-to-available basis, cheap at its cost, and for purpose to reduce unnecessary complexity due to time constraints. In the previous David Vokoun's study (D. Vokoun M. B., 2008), they have introduced a semi-analytical formula for the magnetostatic interaction between two isoradii cylindrical magnets (D. Vokoun G. T., 2011). Based on Gilbert's model;

$$F = \left[\frac{B_0^2 A^2 (L^2 + R^2)}{\pi \mu_0 L^2}\right] \left[\frac{1}{x^2} + \frac{1}{(x+2L)^2} - \frac{2}{(x+L^2)}\right]$$

Where,

B_0: magnetic flux density, Tesla

A: area of each pole, m^2

L: length of each magnet, m

R: radius of each magnet, m

x: separation between two magnets, m

$\boldsymbol{B_0} = \frac{\mu_0}{2}\boldsymbol{M}$, the flux density at the pole of the magnet

Alternatively, for force between two cylindrical magnets;

For two magnets with shape of cylinder with height t, and radius R, with their magnetic dipole aligned with each other, the force can be approximated by,

$$F(x) = \frac{\pi\mu_0}{4} M^2 R^4 \left[\frac{1}{x^2} + \frac{1}{(x+2h)^2} - \frac{2}{(x+h)^2}\right]$$

Where M, magnetization of the magnets and x, the distance.

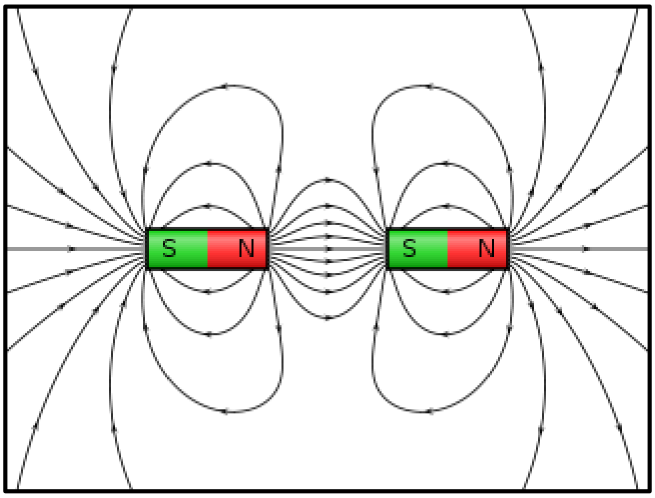


Figure 1: Field of two attracting cylindrical bar magnets

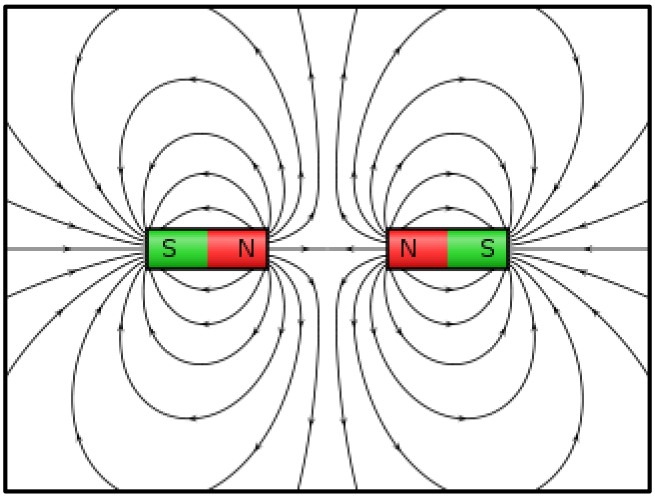


Figure 2: Field of two repelling cylindrical bar magnets

Permanent Magnet Types and Their Usage/Applications in Industry

1. Ferrite Permanent Magnet

Ferrite magnets are made of sintered iron oxide powder and barium/strontium carbonate ceramic (Fe_2O_3). Since the materials and the manufacturing methods is very cheap, its usage in its various shapes is applied in electronic components as for example, radio antennas. In terms of magnetic properties, different ferrite PMs are always classified as “soft” and “hard” which resembles their low or high magnetic coercivity.

Ferrite PMs are being used in transformers, inductors, and electromagnets, and also electric inductors, where the high electrical resistance of ferrite PM brings very low eddy current losses. While its material properties indicated brittle, non-corroding permanent magnet and hence, must be treated like any other ceramic materials. In local markets, this type of magnet is very cheap amongst other magnets since its mass production availability and low-cost manufacturing and magnetizing method.

2. Alnico Permanent Magnets

Alnico is referred to iron alloys which mainly composed of aluminium (Al), nickel (Ni), and cobalt (Co) hence forming AlNiCo. This type of permanent magnets are made by casting or sintering whereas casting delivers high magnetic field and allows for the design to be shaped into different complexities while sintering making the magnet have superior mechanical properties. Trade name for this type of magnet: *Alni*, *Tictional*, *Columax*, *Hycomax*, and *Alcomax* (Brady & Henry R. Clauser, 2002).

Alnico alloys magnet is a strong one, and also can be magnetized to produce magnetic fields with higher degree. Alnico magnets produce magnetic field strength as high as 1500 gauss (0.15 tesla). Some of the alnico brands are in isotropic and hence can be efficiently magnetized into any desired direction. Almost as the same as ferrite PMs, alnico magnets are produced by sintering or casting processes (Campbell, 1996).

Alnico usages are mostly in consumer applications and in industrial where the need of strong permanent magnets are needed. Just to name a few, electric guitar pickups, electric motors, loudspeakers, sensors, and microphones.

Some points to note, unlike ferrite or ceramic magnets, alnico magnets are electrically conductive. While the price of alnico magnet is about \$4.30/BH_{max} or \$44/kg (RM143/kg). This high price is justified where this is the only type of magnets that still have useful magnetism force even heated red-hot (Hubert & Schafer, 1998). Besides of its brittleness, its high melting point is due to intermetallic bonds between all other constituents and aluminium. If being handled properly, alnico PMs are one of the most stable magnets.

Although alnico magnets is superior on its features, among other permanent magnets, alnico were put at intermediate class, which neodymium magnet surpasses its magnetic strength and capacity although alnico magnet is more durable than neodymium. Additionally, alnico is much harder to find nowadays since neodymium PMs are replacing alnico purposes.

3. Neodymium Permanent Magnet

Known as neodymium magnet, or other names of NdFeB, Neo, or NIB magnet. As the most widely used magnets, it is made of iron, alloy of neodymium, and boron to form $Nd_2Fe_{14}B$ tetragonal crystalline structure (Fraden, 2010). This class of magnet are the strongest type of available magnet commercially (Fraden, 2010). Through these years, neodymium magnets have replaced other magnet in applications.

Tetragonal $Nd_2Fe_{14}B$ crystal structure has high uniaxial anisotropy (HA ~ 7 Teslas), hence giving the compound of potential high coercivity (ability to resist magnetization). Having high saturation magnetization J_s ~ 16 T or 16 kG and commonly 1.3 teslas. Hence, as the maximum energy density is proportional to J_s^2, this type of magnet can store large amounts of magnetic energy. While in practice, magnetic properties of neodymium magnets depends on the microstructure, alloy composition, and manufacturing technique applied.

Until time of writing, there are two principal neodymium magnet manufacturing method: Firstly, powder metallurgy or sintered magnet process and the second one, bonded magnet process or rapid solidification. Sintered $Nd_2Fe_{14}B$ is well known for its vulnerability to corrosion, especially along its grain boundaries of the PMs. This defects can cause serious problems, including spalling surface layers, and also crumbling problems. To overcome this, protective coating apart from other metals plating and also lacquer protective coatings (Drak & L.A., 2007).

Among its existing applications are included head actuators, magnetic resonance imaging (MRI), electric motors and others. Neodymium PMs have replaced ferrite and alnico magnets in a lot of applications where strong magnetic force is required since their great strength allows the use of lighter, smaller magnets for their designs. Regarding the price, **RM 300/kg** is justified regarding its superior features. While, neodymium magnets usually 2 or 3 times more expensive than ferrite magnets in international and local markets.

Regarding choices for usage of this paper, author had decided to choose neodymium magnets as test samples and specimens since its high magnetic force apart from its expensive price. As neodymium PMs becoming more popular, there is no big problem for its availability in the market to find.

Origin of Permanent Magnet Behaviour

The intrinsic atomic magnetic moment associated with such elements as iron, cobalt, nickel and many other compounds is believed to be originate from a net unbalance of electron spins of their electron shells. For instances, in nickel in the third shell there are fewer electrons spinning in the opposite direction than in the one direction only. This condition instantaneously giving effect of ferromagnetism.

By principle, there must be a cooperative interatomic exchange forces that maintain neighbouring atoms parallel. Very few knowledge known of the specific nature or magnitude of all of the forces but observations from physicist suggest they are electrostatic. It has been argued over that in ferromagnetic materials the ratio of interatomic distance to the diameter of the shell in which the unbalance exists in unusually large compared to this ration in materials which do not exhibit ferromagnetism.

In Figure 3 an exploded view of a ferromagnetic volume is shown. The relative dimensions of the atom, domain, crystal and a measurable volume are noted in the figure.

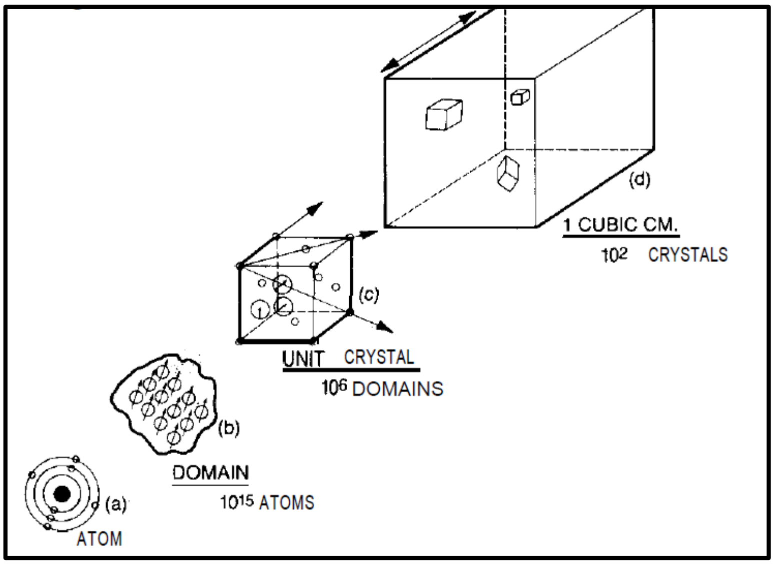


Figure 3: Exploded assembly of ferromagnetic volume (Parker, 1998)

The atomic exchange force also produces magnetostrictive effects and is associated with the crystalline structure of magnetic materials in a way that exhibits anisotropy or directional dependence with respect to the crystal axis.

In Figure 4 the directional dependence is shown for iron. The easy axis of magnetization is the cube (100) edge.

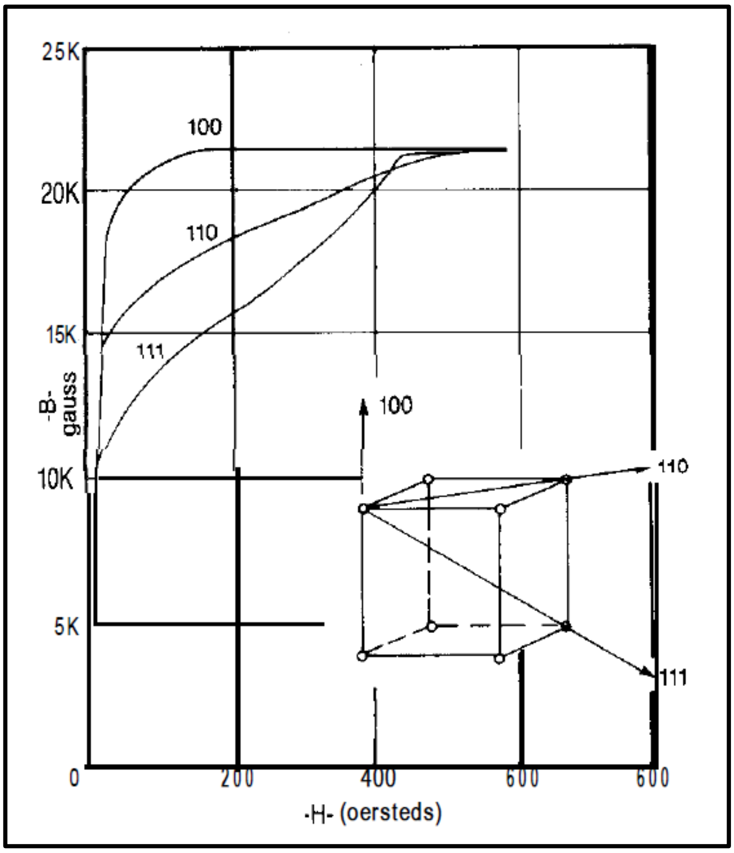


Figure 4: Directional dependence (iron) (Parker, 1998)

Magnetizing and Demagnetizing Requirement

Changing the state of magnetization is a very important consideration in using permanent magnets. For a permanent magnet to exhibit full properties, it must be fully magnetized or saturated. Partial magnetization results in reduced properties, and efficiency and stability are compromised. Recent progress in property development has been largely in terms of increased coercivity. With increased resistance to demagnetization, such materials are proportionately more difficult to magnetize. Successful use of the newer high coercive force magnets requires magnetizing equipment capable of producing very high field levels as well as a good understanding of the magnetization process.

Magnetizing Requirements

To fully magnetize the following must be considered:

1) External field magnitudes.

The net effective field required to saturate a given permanent magnet material can be determined from the hysteresis loop. Figure 5 shows a typical relationship between intrinsic magnetization (J) and magnetizing force (H). As the field is increased J will approach some maximum value (J,) characteristic of the material. The value of saturation field strength (H,) is usually of the order of 3 to 5 times the H_{Ci} of the material.

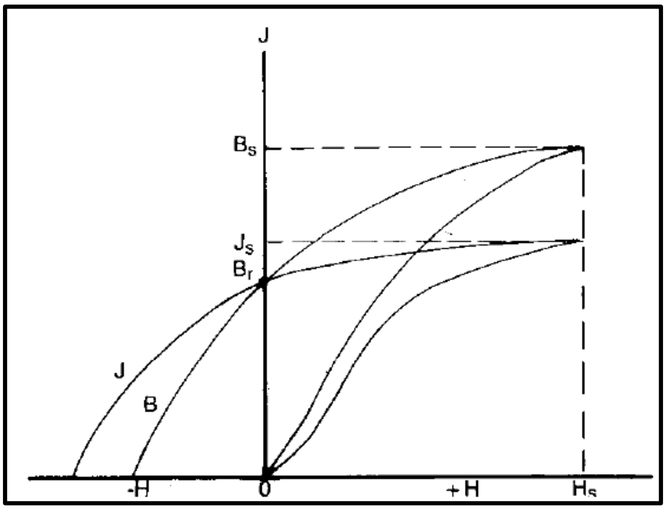


Figure 5: Magnetization Curves (Parker, 1998)

In order to evaluate and compare permanent magnet accurately, magnet materials must be fully magnetized in-ready-state. Figure 6 shows that the sensitivity of magnet properties to levels of magnetizing force for $SmCo_5$. Clearly shown, that partial magnetization would wasteful and properties achieved are nonlinear with applied external field.

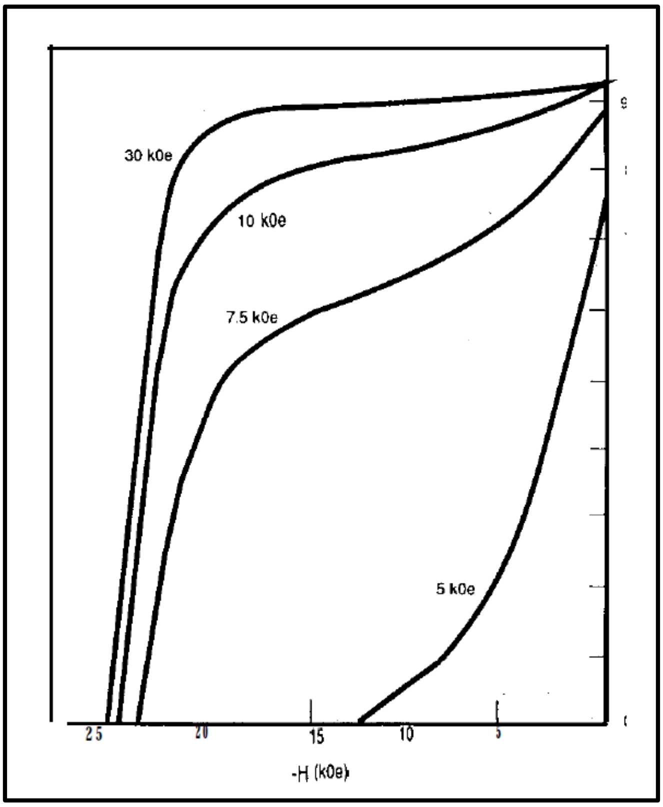


Figure 6: SmCo5 magnetized at various levels of field (Parker, 1998)

2) The effective net field seen by the permanent magnet due to self demagnetization and magnetic circuit influences.

The field levels suggested by magnet producers are always the actual or net field levels as seen by the permanent magnet. In practice, the only time the applied field is the same as the actual field is when the magnet is in essentially a closed low reluctance circuit such as magnetization in an iron yoke electromagnet. In this case the total *F* applied will be very close to the *F* across the magnet.

3) Conformance of the shape of the field to the magnet geometry being magnetized.

Partial magnetization may occur if the field generated does not conform to the configuration of the magnet. The permeability of most permanent magnets is very low and hence, the presence of the magnet does little to shape an applied field. The field should always coincide with the easy axis of the permanent magnet. When magnet configuration and field do not coincide, it is possible to have fields that are too great, which in effect, leave regions magnetized off axis and the result appears as partial magnetization. Figure 7 shows the influence of a field applied at various angles to alnico 5-7, which is a highly anisotropic material.

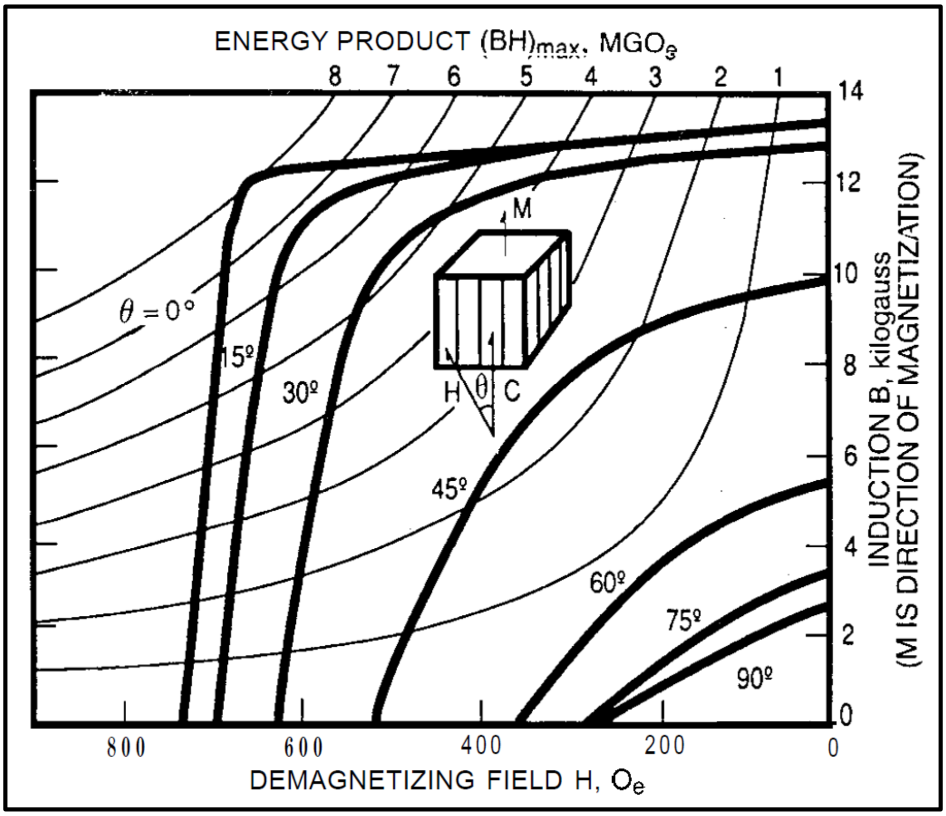


Figure 7: Influence of various angles of field application (Parker, 1998)

4) The time required to magnetize and the problem of field of penetration.

Although the magnetization process is essentially instantaneous, the time duration of the applied field is important because of the existence of eddy currents in metallic materials. Also, with highly inductive electromagnets, the current rise time may be of the order of 1-2 seconds.

Figure 8 shows a relationship inter-relating depth of penetration with resistivity, permeability and frequency of wave form. In general, the frequency must be chosen so that the magnetizing pulse lasts longer than the eddy current. The eddy current path is a function of geometry and for large metallic magnets there are problems with penetration. The general experience with alnico and rare earth magnets has been to use about 10 millisecond minimum pulse width. This width of pulse allows a wide range of magnet configurations and sizes to be fully magnetized.

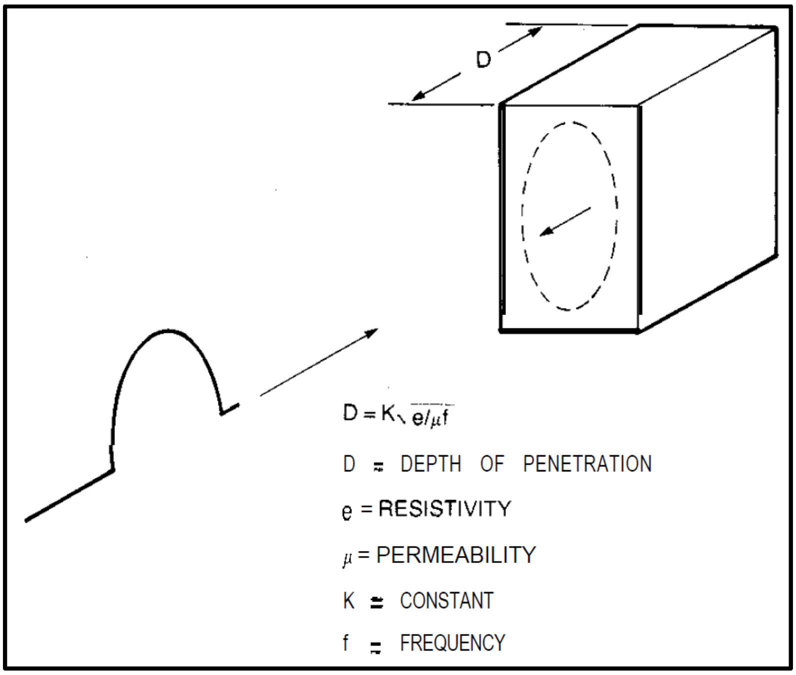


Figure 8: Effects of eddy currents in permanent magnets (Parker, 1998)

5) Field distortion events after magnetization that may leave the magnet partially demagnetized.

After calibration it is possible to inadvertently demagnetize a magnet with improper handling; therefore care must be taken to preserve the original condition of magnetization. A magnetized magnet should not be touched along its length with ferromagnetic objects. Such action will produce consequent poles nhich alters the main flux pattern and reduces the useful fluxs in the gap or at the pole surface of the magnet. Also magnets can be demagnetized by repeated contact with poles in repulsion. Improper handling is most serious with magnets having H_{ci} appreciably less than B_r.

Demagnetization Curve and Its Parameters

In most of hard magnetic materials, the second quadrant of hysteresis curve is very crucial and useful. This quadrant is called curve of demagnetization (Permagsoft : Demagnetization Curve & Parameters, 2014).

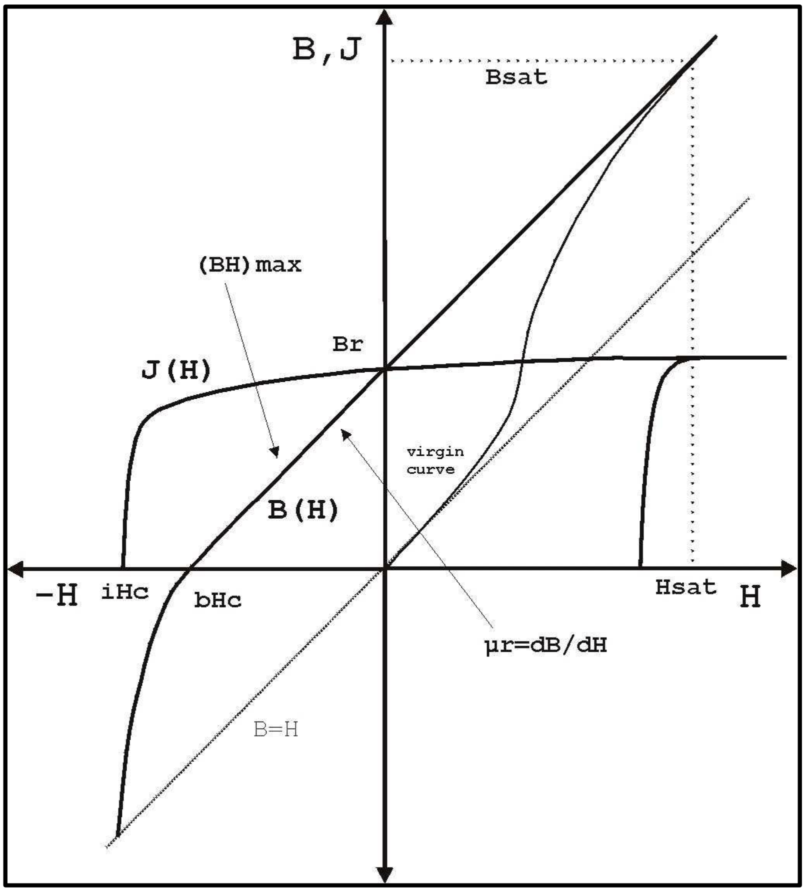


Figure 9: Demagnetization curve (second quadrant) as well as the first and parts of the third (Permagsoft : Demagnetization Curve & Parameters, 2014)

The most important parameters of a demagnetization curve are listed as:

B_r = Remanence induction [T]

${}_jH_c$ = Coercivity of J [A/m], ${}_bH_c$ = Coercivity of B [A/m]

μ_r = Recoil Permeability [no units]

$(BH)_{max}$ = Maximum energy product [kJ/m^3]

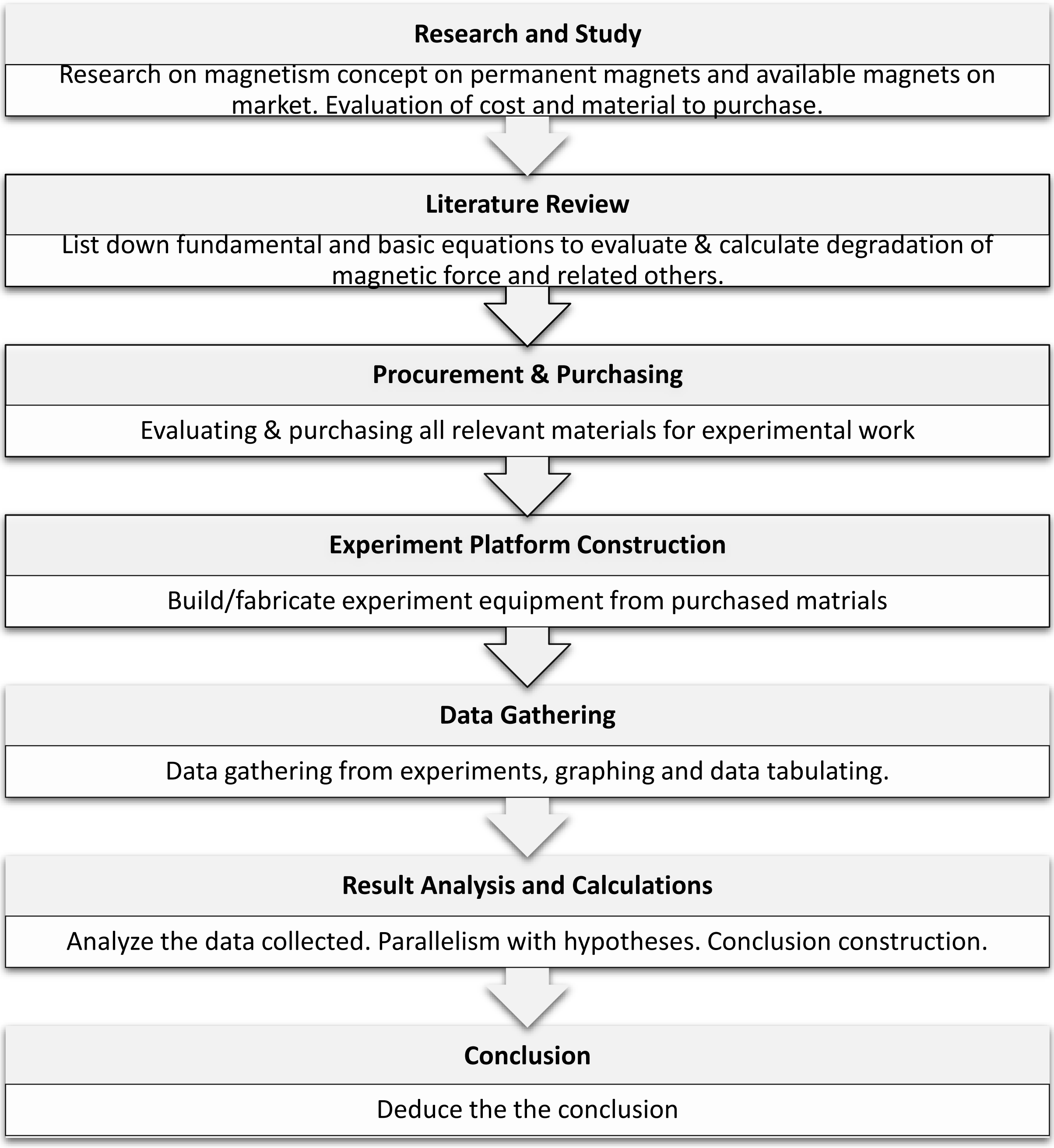
Now lets describe the behaviour of demagnetization curves in more detail. As we examine here only spatial direction, a scalar description is used.

In modern magnetic materials we have a nearly linear behaviour of J(H) and B(H) on the demagnetization curve up to a point where the curve bents down more or less sharply. If the magnets working points are located in this linear area, these points can be moved up and down by external H changes without leaving the demagnetization curve. The behaviour of the magnet is then called to be reversible (Permagsoft : Demagnetization Curve & Parameters, 2014).

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

Figure 3.1 below shows the overview of research methodology flow for the project.



3.2 Project Milestones

1
- Choose a supervisor and title. Submit Final Year Title Selection Form

2
- Gather details needed in understanding about the concept of magnetism on permanent magnet & its degradation of its force(s).

3
- Do corrections and improvements on extended proposal.
- Presenting Extendal Proposal and taking note any change(s) on Supervisor's endorsement.

4
- Survey availability of magnet in local market.
- Evaluation on suitability.
- Procurement on purchasing materials required.

5
- Constructing experiment platform from purchased materials.
- Dry run on platform and R&D on workability of platform.

6
- Book for venue, equipment, and in-charge personnel for any laboratory sessions.
- Executing experiment
- Data gathering

7
- Analysis on data gathered.
- Recheck on literature review
- Few runs of experiment if neccessary

8
- Deep analysis on data interpretation and presentation

9
- FYP report submission

3.3 Project Gantt chart

No.	TASK	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE				JULY				AUG				SEPT			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.0	**Supervisors Consultation**																																				
1.0	**Project Concept Study**																																				
	1.1 Outsource Reading Material																																				
	1.2 Compose Project Proposal																																				
2.0	**Project Preliminary**																																				
	2.1 Conceptual Drawing																																				
	2.2 Material Survey																																				
	2.3 Collecting Material																																				
3.0	**Project Execution**																																				
	3.1 Platform Construction																																				
	3.2 Platform Testing & R&D																																				
	3.3 Experiment Execution																																				
4.0	**Project Analysis**																																				
	4.1 Data Analysis																																				
5.0	**Project Finalization**																																				
	5.1 Develop Conclusion																																				
	5.2 Final Report Preparation																																				

CHAPTER 4: RESULTS & DISCUSSION

4.1 Experiment Test Method

Test method for determining the degradation of permanent magnet force under cyclic magnetic force of other permanent magnet

1. Scope

1.1. This test method addresses the measurement of any change(s) of magnetic force on subject permanent magnet under cyclic magnetic force from other permanent magnet. This test method covers permanent magnets only.

1.2. This test method may involve operations which require the use of appropriate precautions, and does not purport to address all of the safety related matters associated with its use. It is the responsibility of the user of this standard to establish the appropriate safety practices and determine the applicability of regulatory limitations prior to use.

1.3. Units of measure. Measured values may be recorded in Oersteds or Ampere/meter units.

2. Terminology and Definitions

2.1. Air Gap: Any gap between the magnet working surface and the work load surface that is occupied by a non-magnetic material.

2.2. Flux Density: A term describing the number of lines of magnetic flux per unit area emanating from a magnet at a location external to the magnet.

2.3. Magnet: As referred to in this document, a magnet may be a single permanent magnet, a magnet assembly consisting of one or more permanent magnets.

2.4. Pole Pieces: Ferromagnetic components (such as neodymium) of a magnetic assembly which transfer magnetic flux to a workload and which may function as the working surface of the magnet.

2.5. Saturation: (As defined here relates to a ferromagnetic material used in conjunction with a magnet.) A condition which a ferromagnetic material is unable, as an externally applied magnetic field is increased, to conduct any additional lines of magnetic flux. This capacity varies according to the permeability of the material.

2.6. Surface Roughness: A measure of the smoothness of a surface, measured in micrometres.4.2 Future Work & Planning

2.7. Working Surface: That surface pf the magnet that is used to perform the work.

3. Summary of Test Method

3.1. The degradation of permanent magnet force is determined from the measurement of the holding force of a magnet against a test magnet. A gradually decreasing distance is applied in a direction normal to the workload surface and through the center of force of the magnet. The load which separates the magnet form the test plate is defined as the breakaway force.

4. Significance and Use

4.1. The breakaway force capability of any magnet is dependent on various factors, i.e.:

- magnet material and shape
- pole material and configuration
- workload mass, composition, composition, roughness, and flatness
- air gap between magnet and workload magnet
- temperature of magnet

4.2. In order to specify the breakaway force characteristics

4.3. Variations in breakaway force

5. Apparatus

5.1. A cordless BOSCH Scorpion 2 EC Drill to rotate the magnet

5.2. A test fixtures made of stainless steel with holder to hold the cordless drill during experiment

5.3. A platform made of aluminium bars to hold the magnet that being tested. Aluminium is used to avoid magnetization of the platform which will affect the test result or findings

5.4. Gauss meter to check for saturation of test plate and coercivity of the permanent magnets

5.5. Surface roughness and flatness measuring devices

5.6. Screwdriver to tighten and loosen the specimen from its designated place

5.7. G-clamp for the purpose of holding the fixture and the platform at their fixed places

5.8. Stopwatch to record the time taken for each cycle of the experiment

5.9. Plastic ruler for measuring distances between the two magnets that are being tested

5.10. Vernier calliper for measuring relatively small distances

6. Hazards

6.1. Precautions should be taken by the tester to ensure that when experiment is on progress, the magnets and the experiment fixtures do not move out of control causing injury or personnel damage

6.2. When handling the magnet to the test surfaces, ensure that the magnet does not slam against the test surface by its attracting force. Some magnet materials are typically brittle and may crack with impact hence changing the nature of the magnet itself and affecting experiment results and analysis

7. Preparation

7.1. Testing shall be conducted between 10 to 33 degrees Celsius. Verify, no obvious movement or vibration around experiment area

7.2. Verify that the surface of test magnet is perpendicular to the plane of the magnet working surface

7.3. Verify that the test plate is not saturated by measuring the flux density on the surface of the test fixtures. For purposes of this test method, the flux density on the experiment fixtures/platforms surface shall be less than 5 Gauss

8. Calibration

8.1. Any instrumentation to be used as specified in section 5.0 shall have proper calibration certification

9. Procedure

9.1. Perform any calibration steps/methods required for each equipment

9.2. Record ambient temperature

9.3. Record surface roughness and flatness of contact surface of test permanent magnets

9.4. Clamp each platform and the fixtures firmly against the table by using G-clamps. Exert some forces by hand to verify the stability against any vibrations/movement

9.5. Place the working permanent magnet flat against test shaft

9.6. Record the flux density of the working permanent magnet

9.7. Place the test permanent magnet against aluminium platform. Verify the flatness of the magnet position

9.8. Record the flux density of the test permanent magnet

9.9. Run the cordless drill for few minutes to record the average RPM reading

9.10. Apply a gradual distance between two magnets for designated duration of time.

9.11. Turn off the drill, record the flux density on each magnet

9.12. Repeat steps 9.8 through 9.11 for a variety of air gaps distance.

9.13. Calculation of results

9.14. Repeat test until three readings which are within 10% of each other have been obtained. The purpose of this is to ensure that the magnet has been separated from the test plate uniformly from all slides

9.15. Calculate the average of these results and use this as tile tested breakaway force

10. Precision and Bias

10.1. Precision. The precision of the procedure is defined by:

10.2. Repeatability. The difference between successive results obtained by the same operator with the same apparatus under constant operating conditions on identical test material, with results of successful tests shall not exceed a 10% variation between any of the sample lot

10.3. Reproducibility. The difference between two single and independent results obtained by different operators working with different test facilities and assuming identical test materials would have a variation of not more than 10% between any successful test from either lot

10.4. Bias. The procedure in this test method for measuring degradation of permanent force has no bias because the value of each magnet specimen is independent of any other, including specimens of the same material and characteristics.

4.2 Experiment Setup

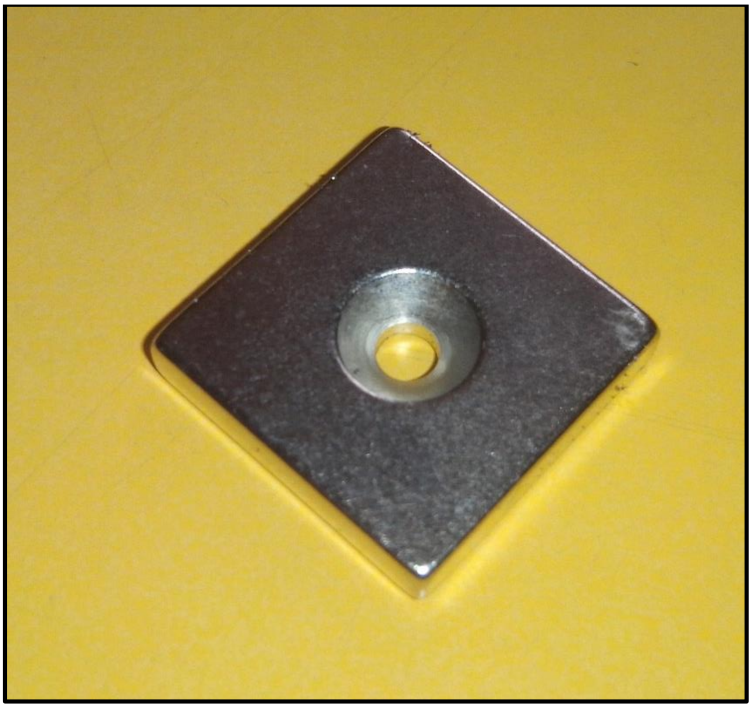


Figure 10: Neodymium Magnet

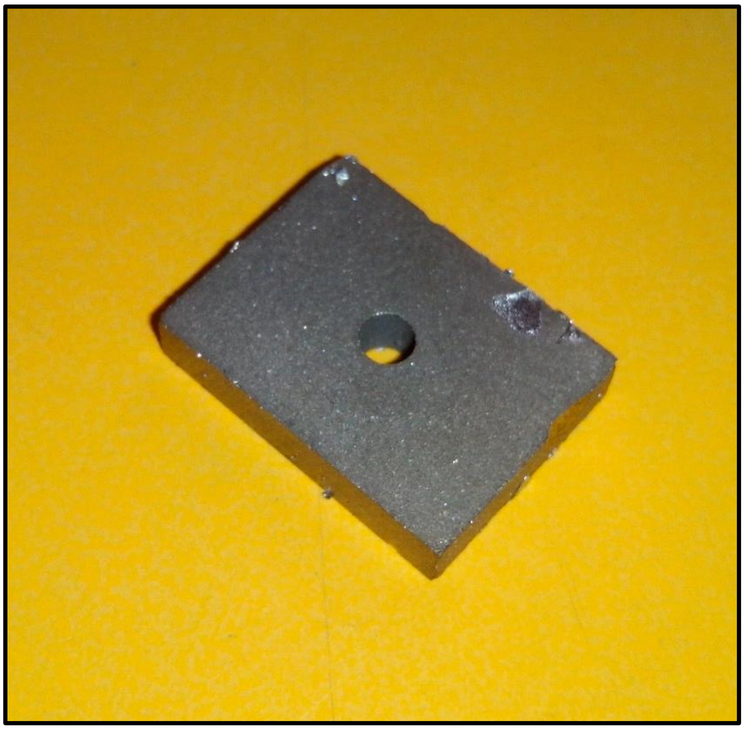


Figure 11: Alnico Magnet

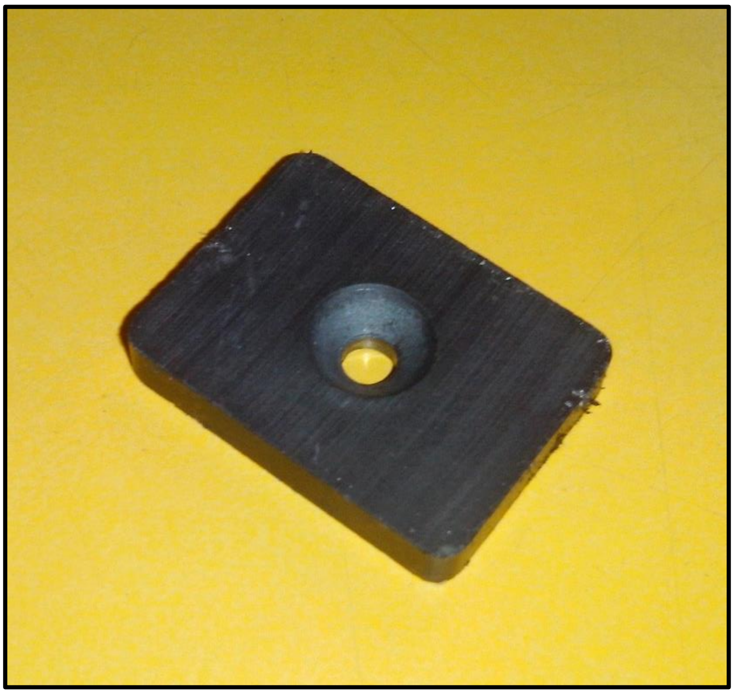


Figure 12: Ferrite Magnet

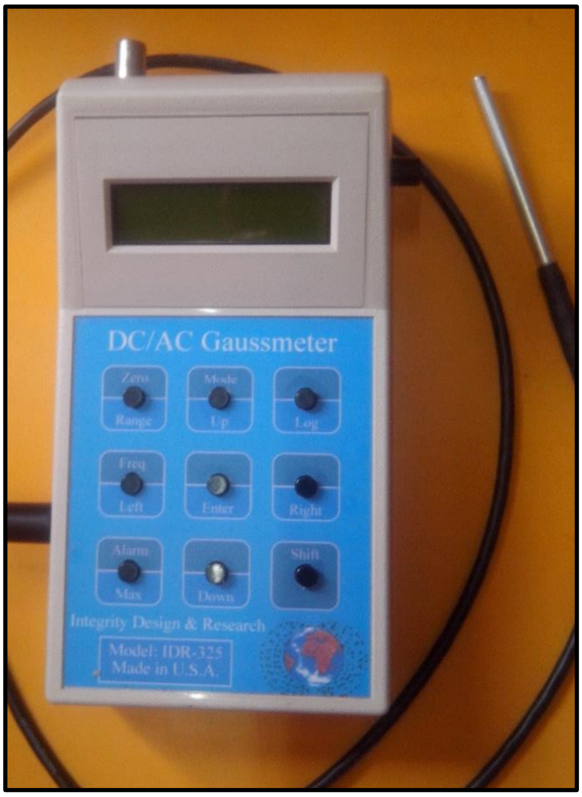


Figure 13: DC/AC Gaussmeter

4.3 Experiment Apparatus

Figure 14: BOSCH Drill and magnet holder

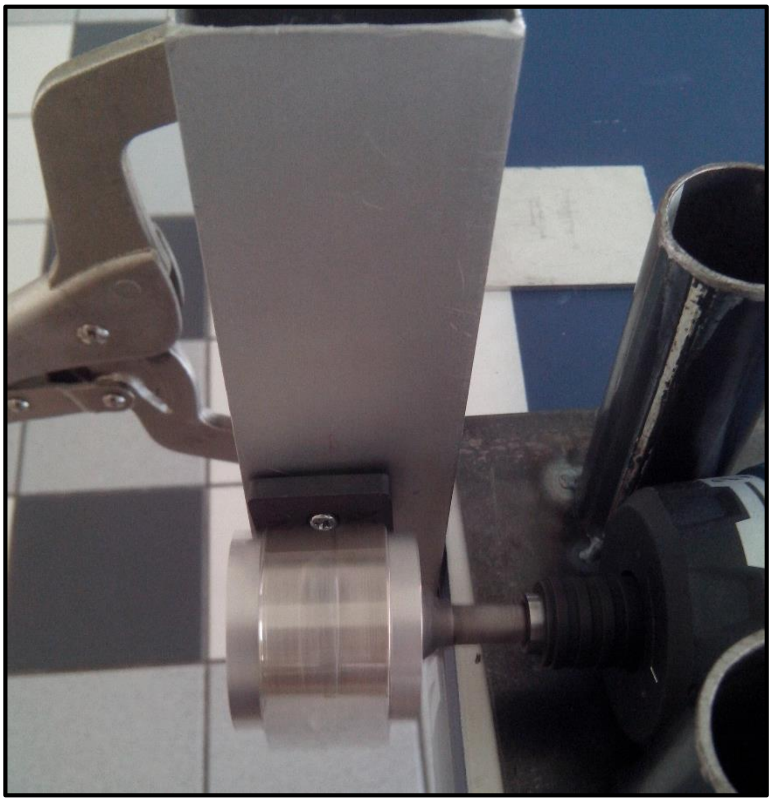


Figure 15: Ferrite and neodymium magnet during experiment

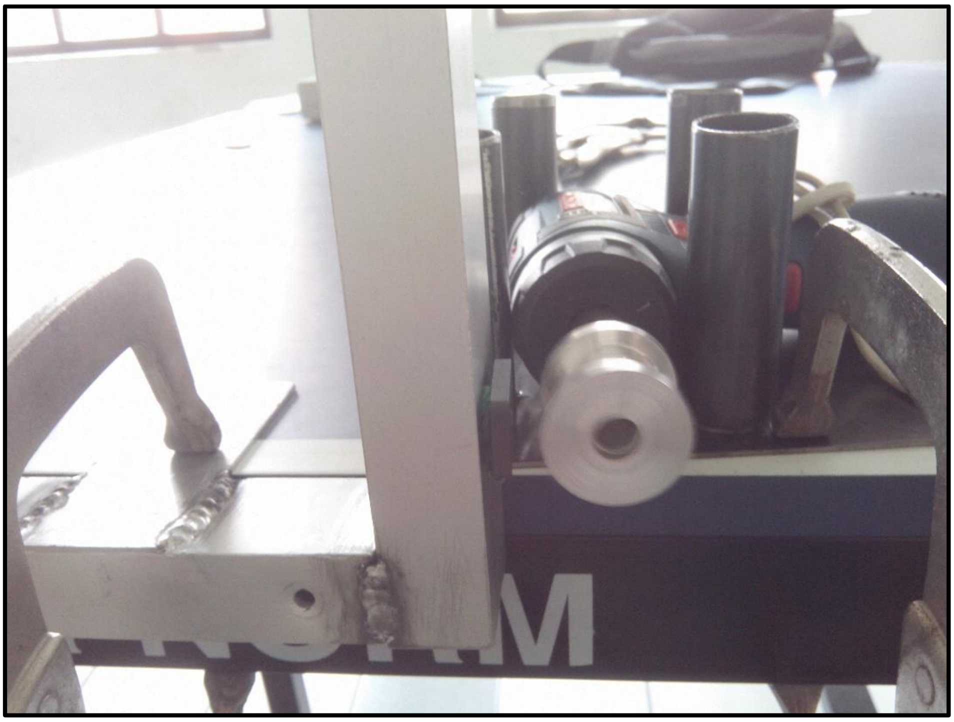


Figure 16: Experiment overview from side

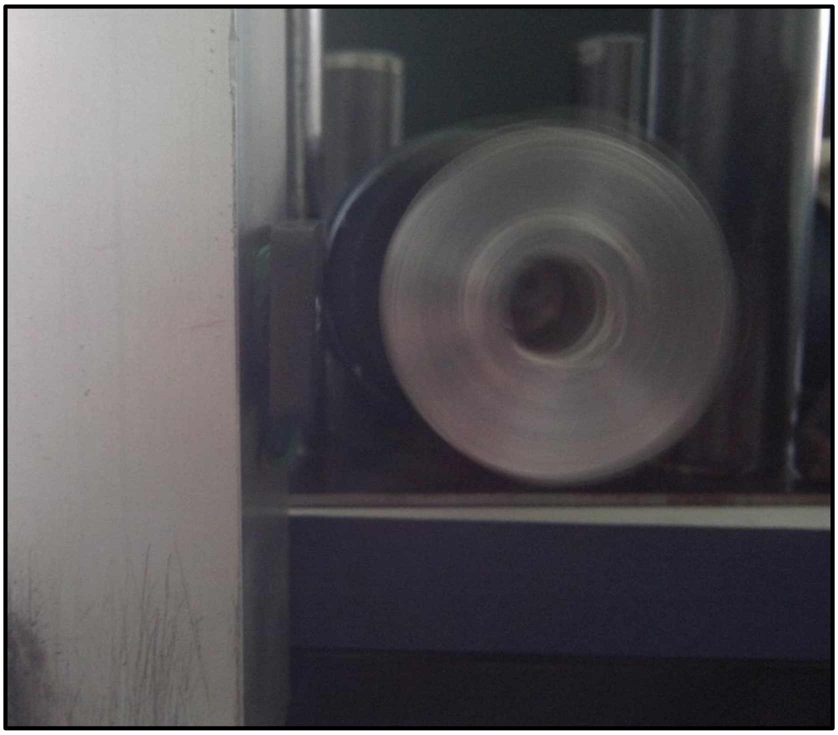


Figure 17: Close-up view neodymium and ferrite experiment

4.4 Data gathering form

No.	Test Duration		Material 1	Flux Density Reading (Gauss, G)						Material 2	Flux Density Reading (Gauss, G)						rpm avg.	Remarks
				Before			After				Before			After				
	Start Time	End Time		1	2	3	1	2	3		1	2	3	1	2	3		
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		

Table 1: Form for data gathering session

4.5 Results and Discussion

Neodymium (North Pole)

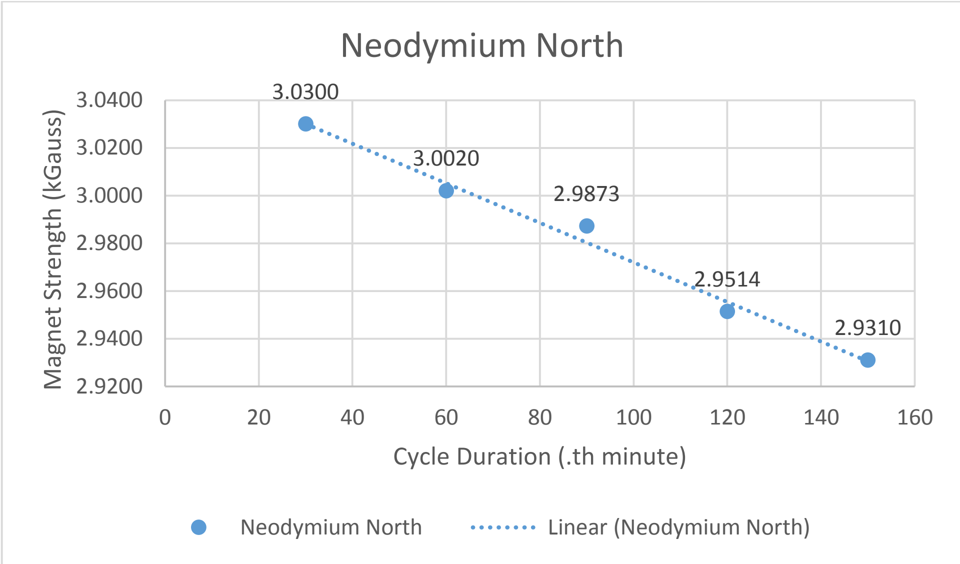


Figure 18: North Pole Neodymium Magnetic Strength vs. Cycle Number

Initial reading of Gaussmeter on first neodymium magnet has been recorded at 3.03 kGauss. Each cycle has been set to be 30 minutes of repulsive interaction with ferrite magnet with 6Hz frequency. Second cycle recorded decrease in value, by only 3.002 kGauss at its state. The trend stays the much less the same until the 5^{th} reading. The total decrement from 1^{st} reading towards 5^{th} reading only by 0.099 kGauss or 3.27 % of changes collectively.

Neodymium or NdFeB magnet is classified as the strongest type of magnet that commercially available. Hence, the characteristics of neodymium having high coercivity (ability to resist demagnetization) is very notable. This explains why the decrement/increment of Gauss value involving neodymium magnet is very small most of the times as compared with other type of commercially available magnet.

All the graph related to this paper's experiment are in form of linear lines since the changes are reversible (Permagsoft : Demagnetization Curve & Parameters, 2014) unless the curve passes downward or upward in term of the changes.

Neodymium (South Pole)

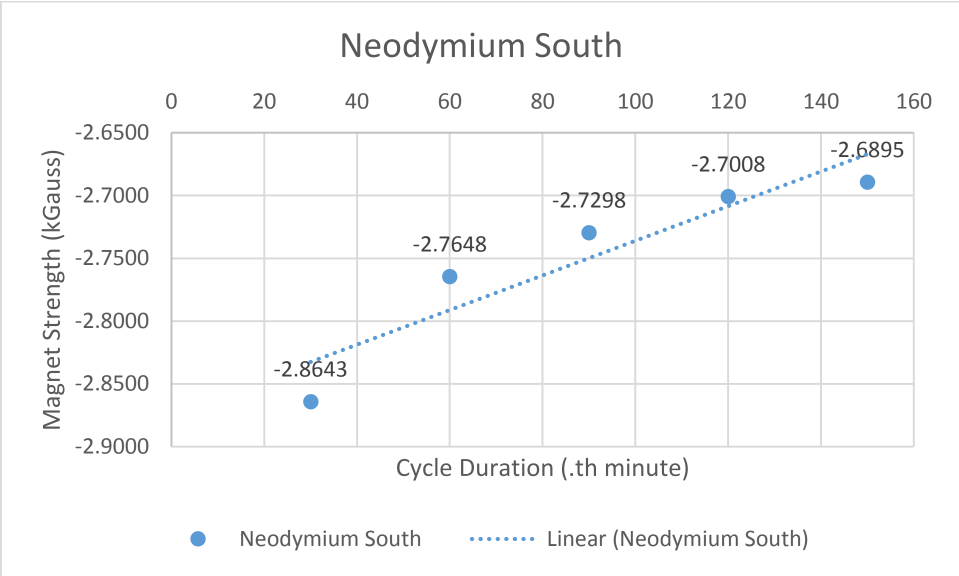


Figure 19: South Pole Neodymium Magnetic Strength vs. Cycle Number

For neodymium's south pole, the initial reading has been recorded at -2.8643 kGauss. The second value has been recorded at -2.7648 kGauss in magnitude noted as a decrease. For subsequent values, the trend is quite similar with decreased pattern. At the 4th cycles or 120th minutes, the value was noted to be -2.7008 kGauss with subsequent slight decrease to -2.6896 kGauss at 5th cycle respectively. Overall changes was calculated as -0.1748 kGauss or 6.10 % of initial value in decrease.

The experiment were carried out in repulsive mode where north-north pole orientation was applied and the other way round for south poles. This condition induces opposite direction of magnetic fluxes to disorient the domains' direction and hence making the overall magnetic force decreases. The overall decrease in strength were recorded as much 0.1748 Gauss which is considerably small.

The decrement on south pole is relatively small than north pole since loss in magnetic flux lines through medium such as air. South pole is where the magnetic flux lines were coming in through the medium.

Alnico Magnet Degradation vs. Cycles (North Pole)

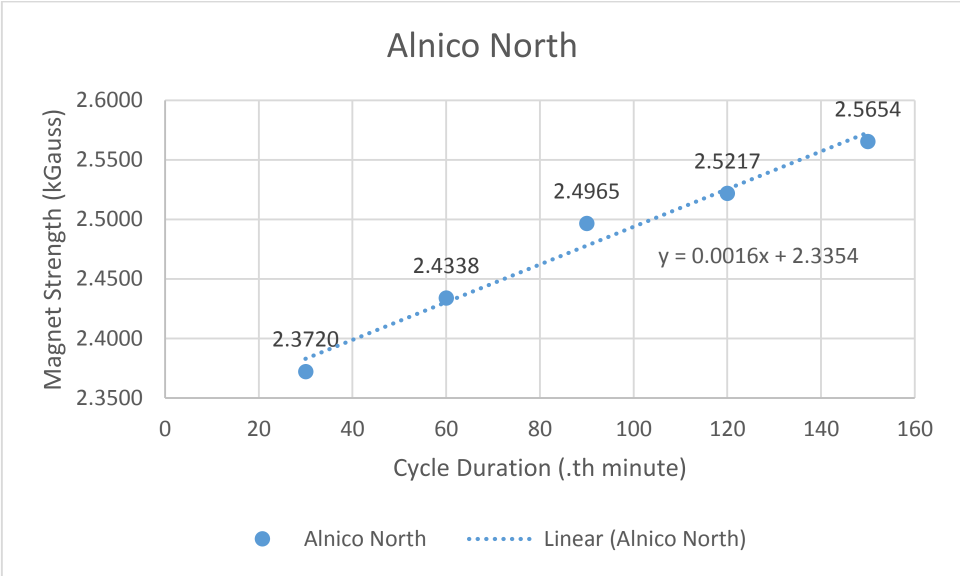


Figure 20: North Pole Alnico Magnetic Strength vs. Cycle Number

Initial reading of the alnico magnet sample is 2.3720 kGauss. After under cyclic interaction with stronger neodymium magnet, on the second cycle, there is slight increase into 2.4338 kGauss. The subsequent trend is quite similar, with increase until at the fifth cycle, at 2.5654 kGauss. The total increment from first cycle towards the fifth cycle is 0.1934 kGauss. There is no sign for steady-state form of trend. The strength for subsequent values may keep increasing until some extent but not far from the fifth value. The overall change percentage was calculated to be 8.15 % throughout the first cycle towards the fifth cycle at 150^{th} minute.

For alnico magnet, this type is the second place for its coercivity value after neodymium at their ‘hardness’ for magnetization. Hence, alnico magnet is the second hardest material between the samples to be magnetized. This claim supported by increase in 8.15 % of value from the initial, compared to 3.27 % only for neodymium magnet.

For the increase in magnitude of magnet strength, this phenomenon may be explained by Fleming’s Right Hand’s variations of field direction in 3D despite being put into repulsive direction of field. Repulsive orientation between two magnets can also be constructive or destructive in term of magnet strength’s magnitude depending on which direction the fields are facing.

Alnico Magnet Degradation vs. Cycles (South Pole)

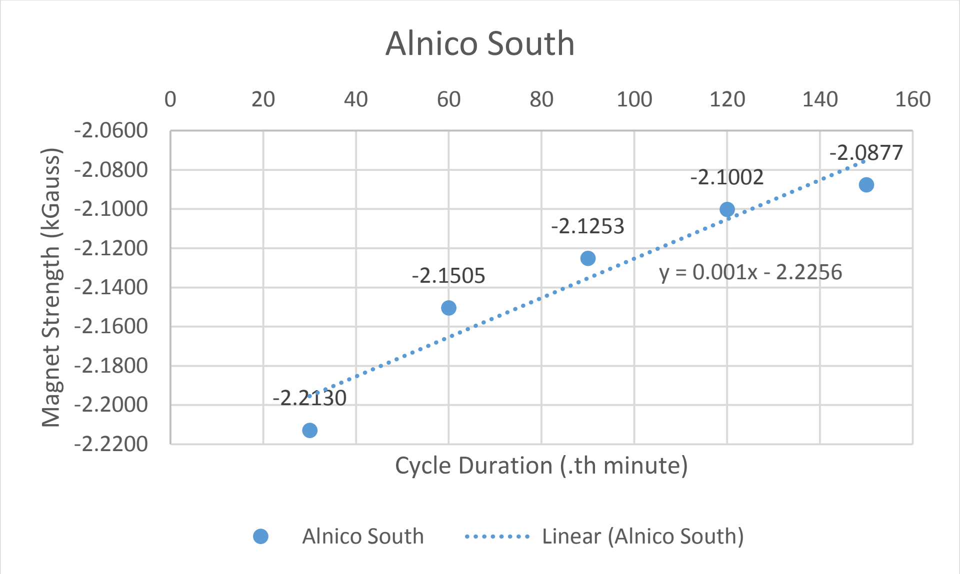


Figure 21: South Pole Alnico Magnetic Strength vs. Cycle Number

Alnico's south pole magnetic strength change respective of cycle graph was plotted. At first cycle at 30th minutes and every subsequent cycle every 30 minutes respective to its cycle, alnico's south pole value was measured by 4 corners in average. The first value was recorded at -2.2130 kGauss. The change in magnitude was noted at the 60th minute at second cycle, with -2.1505 kGauss. Subsequently, the magnitude of ferrite magnet strength had decreased until its final value at 150th minutes to be -2.0877 kGauss. Overall, there was 5.7 % of decrease in magnetic strength magnitude throughout this five cycles.

From this graph, the trend of decreasing magnitude of alnico magnet's strength is very notable with decreasing value from first cycle towards fifth cycle. The decrease in magnitude on its south pole not suit the increase on its opposite side: north pole. However, since the change is considerably small, by around 5%, the change not really significant or perhaps this result may be appeared from irregularities or fault of the experiment.

Ferrite Magnetic Degradation vs. Cycles (North Pole)

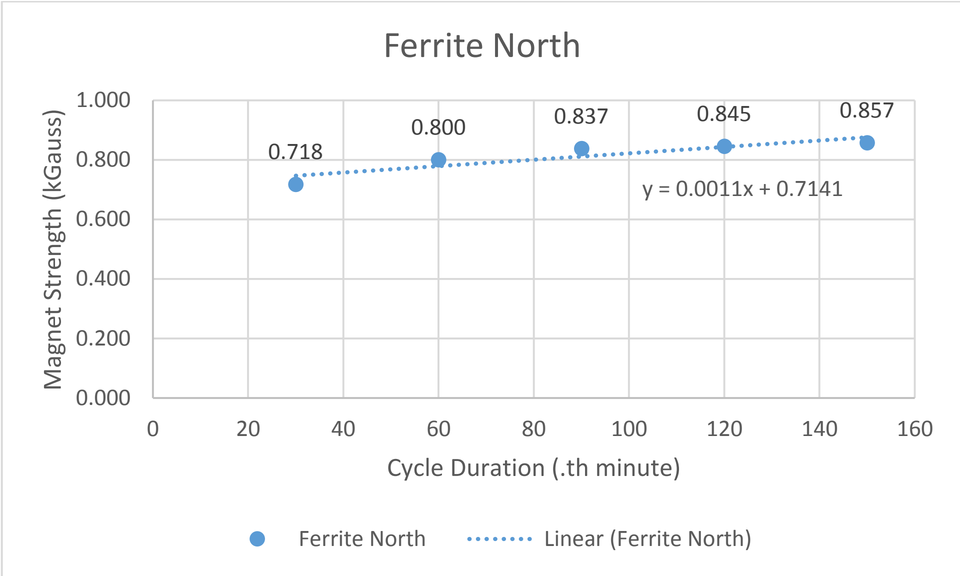


Figure 22: North Pole Ferrite Magnetic Strength vs. Cycle Number

Figure X shows the change of ferrite south pole's magnetic strength versus cyclic cycle of other permanent magnet. The value started to be positive since it is a typical north pole. Initial value has been recorded at first 30 minutes to be 0.7175 kGauss with slight increase in second value at 0.7998 kGauss. The trend is similar troughout the third and fourth cycle with final value at fifth cycle to be 0.8569 kGauss at 150th minutes respectively. The overall change percentage is calculated to be 19.4 % by overall.

For ferrite magnet, the large change of its strength value may be governed mostly by its material characteristics. Ferrite magnet have low 'hardness' or coercivity value which implies ferrite magnet can be easily magnetized and demagnetized compared to neodymium and alnico magnet. The increased magnitude of ferrite magnet strength can be associated by similar direction of field although those two samples: neodymium and ferrite, were put into opposite, repulsive, similar pole between them.

Ferrite Magnetic Degradation vs. Cycles (South Pole)

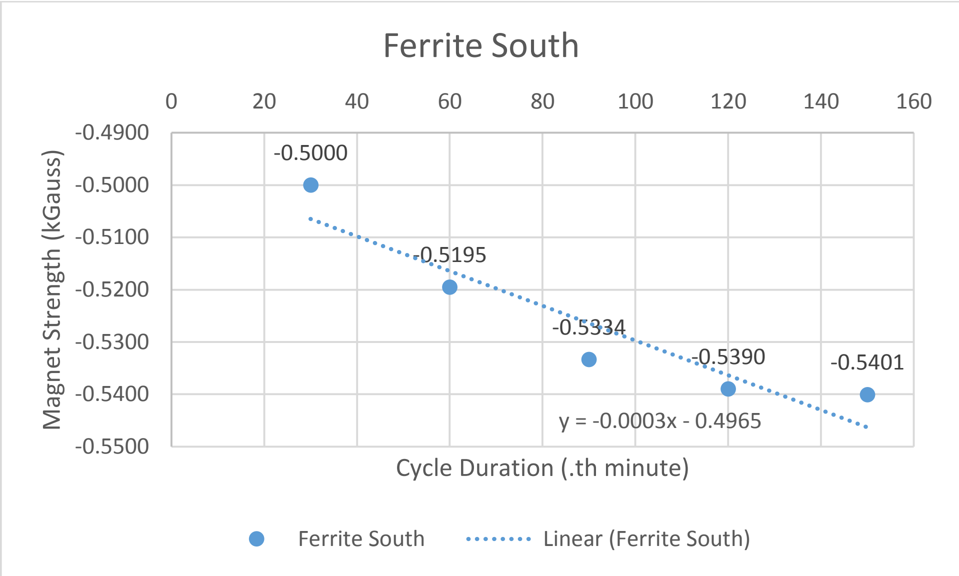


Figure 23: South Pole Ferrite Magnetic Strength vs. Cycle Number

The graph shows the initial value of the test ferrite magnet is noted at -0.05 kGauss. The second reading had increase in magnitude to -0.5195 kGauss. For subsequent values of third and so on, the value can be observed to follow the same pattern with decreasing magnitude of magnet's strength. The trend had continued until fourth cycle, with slight increase from fourth to fifth cycle to -0.5401 kGauss. Total increase in percentage is calculated to be 8.02 % overall from first to fifth cycle at 150^{th} minutes.

From this graph, the increased magnitude of ferrite magnet can be seen throughout the graph. In conjunction of increase of magnitude on south pole of ferrite magnet, the increase of magnitude on north side of the pole is relevant. The increment is being caused by also the increase of the overall magnetic field strength after all 5 cycles cumulated. This fact contributed to the main hypotheses states, cyclic interaction of the PMs is giving effect of increased or decreased magnetic strength.

Forecast of Magnet Degradation

1. Neodymium magnet

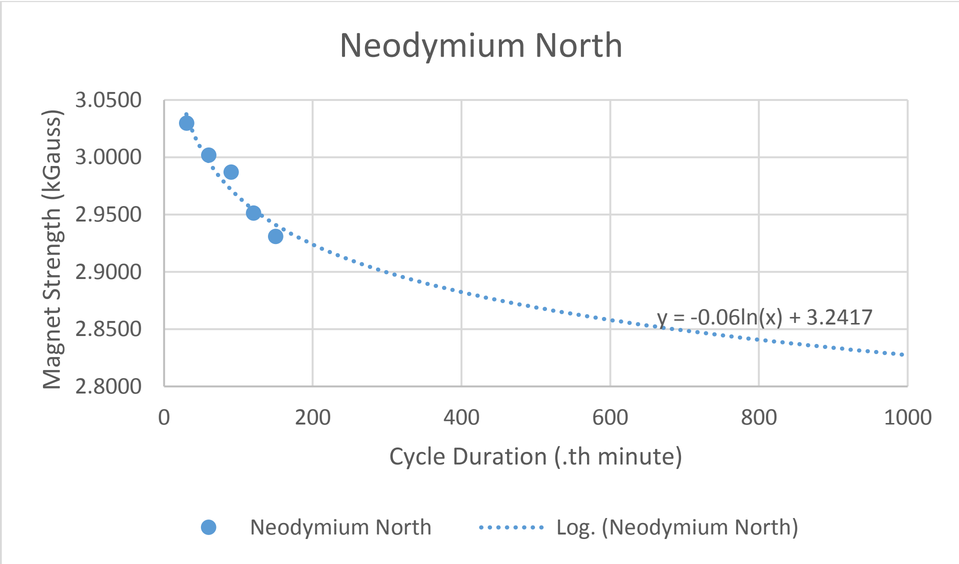


Figure 24: Neodymium Forecast Magnet Strength vs. Extended Cycles (N)

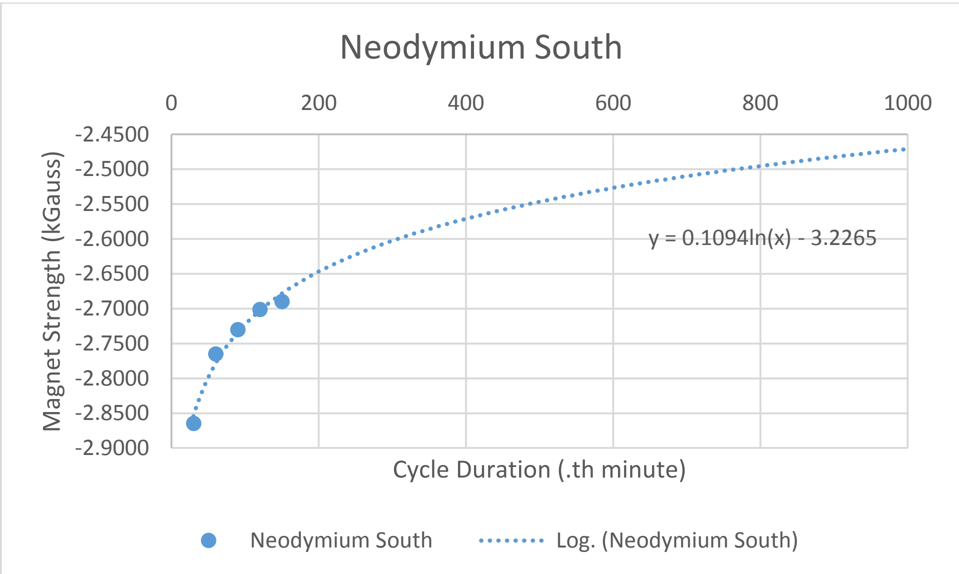


Figure 25: Neodymium Forecast Magnet Strength vs. Extended Cycles (S)

2. Alnico Magnet

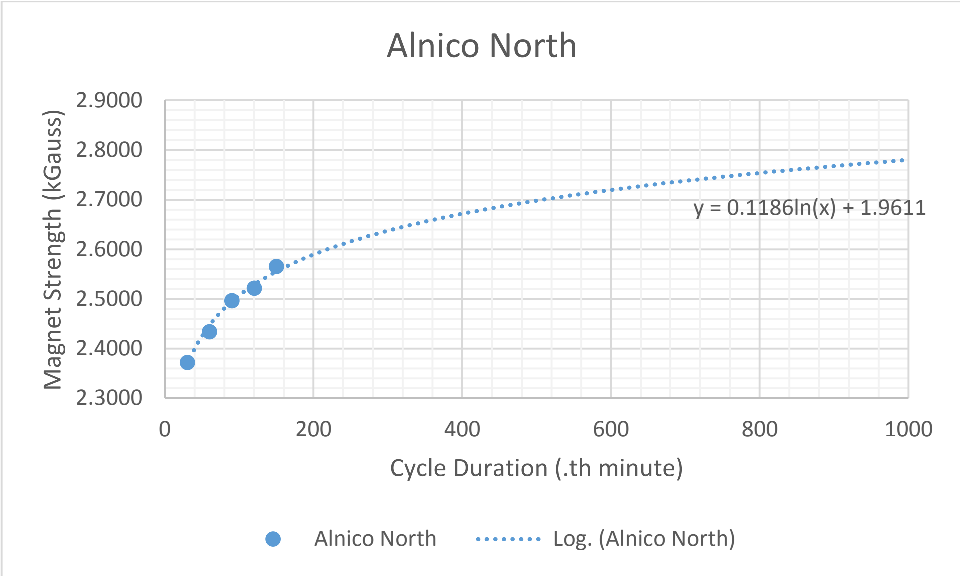


Figure 26: Alnico Forecast Magnet Strength vs. Extended Cycles (N)

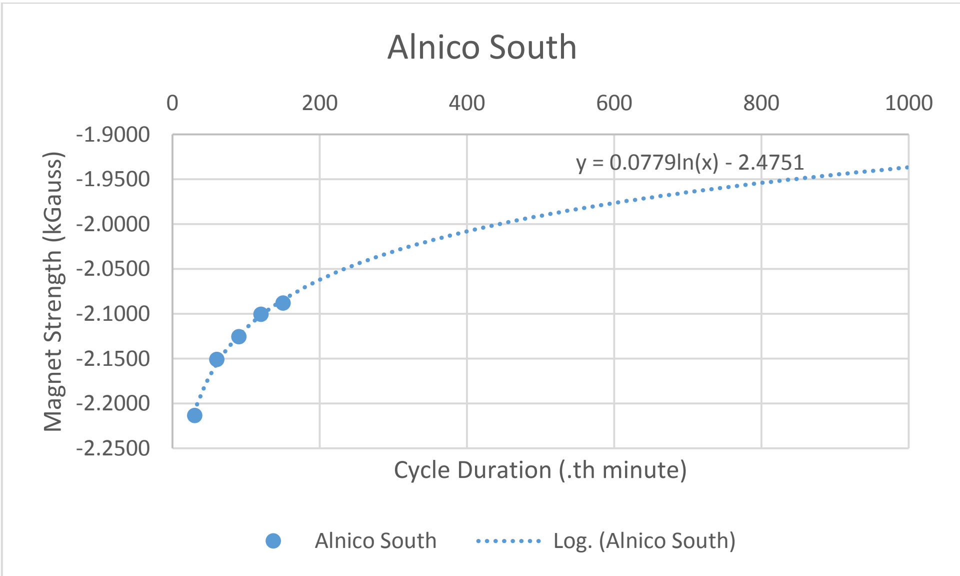


Figure 27: Alnico Forecast Magnet Strength vs. Extended Cycles (S)

3. Ferrite Magnet

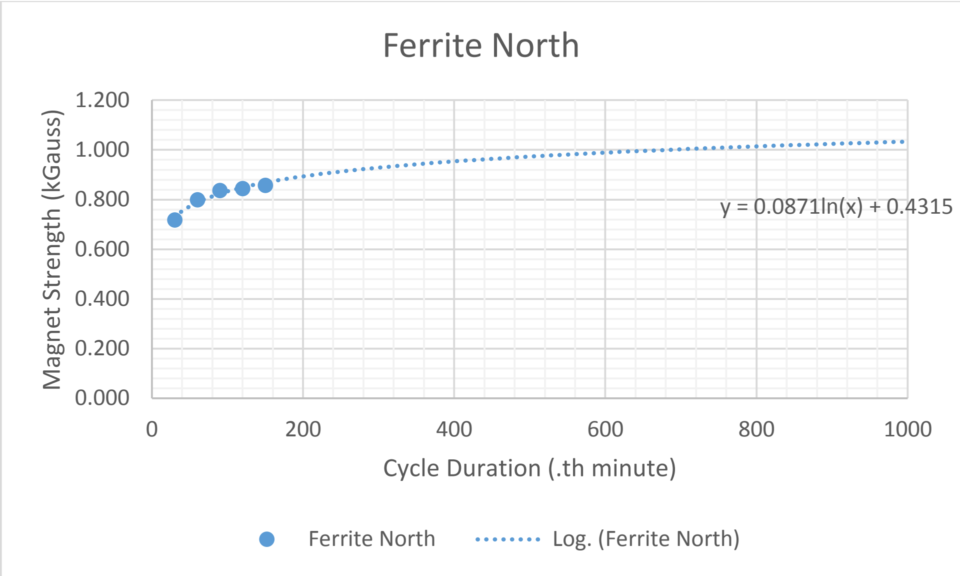


Figure 28: Ferrite Forecast Magnet Strength vs. Extended Cycles (N)

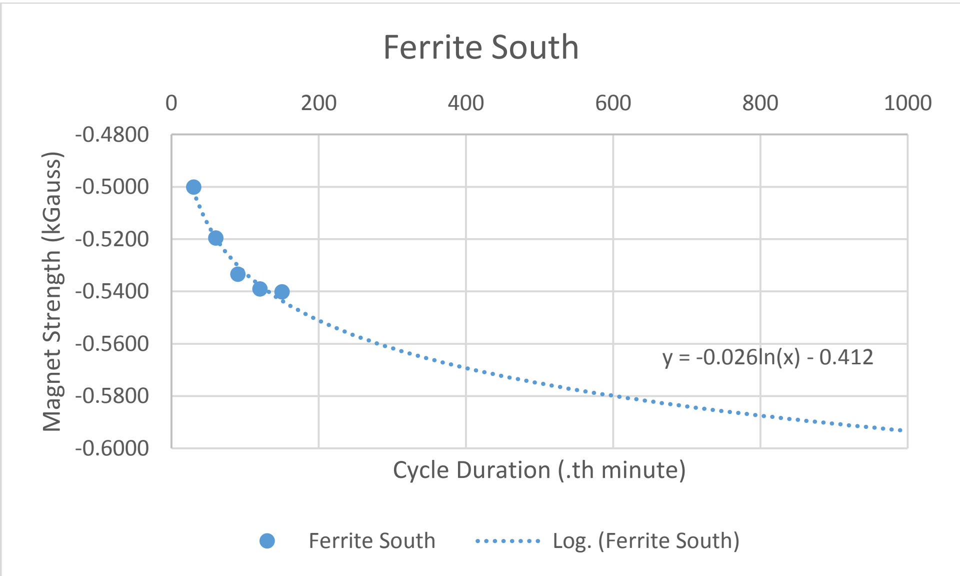


Figure 29: Ferrite Forecast Magnet Strength vs. Extended Cycles (S)

Discussion

1. Magnet strength degradation relationship with magnet's coercivity

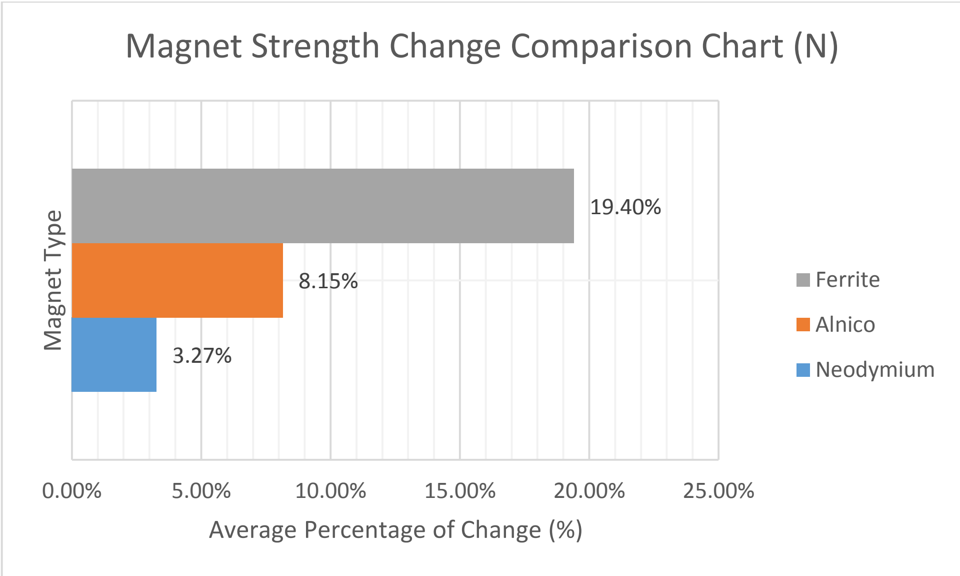


Figure 30: Comparison of each magnet respective changes on North pole

Data obtained from early experiment as above is presented altogether with difference calculation were presented. Material that being used in this paper's experiment, was categorized based on the change in percentage in magnet strength.

Neodymium material has shown its superior features in maintaining high coercivity in resisting demagnetization and retaining its own field even under destructive condition.

3.27 percent of change is considerably small especially neodymium which excels also in heavy industry engineering. While alnico as the second highest in coercivity rank, 8.15% of its magnitude changes was calculated.

Throughout this experiment, the relationship between individual magnets' coercivity and changes of magnet strength by PM cyclic motion, can be successfully established by relating this data obtained.

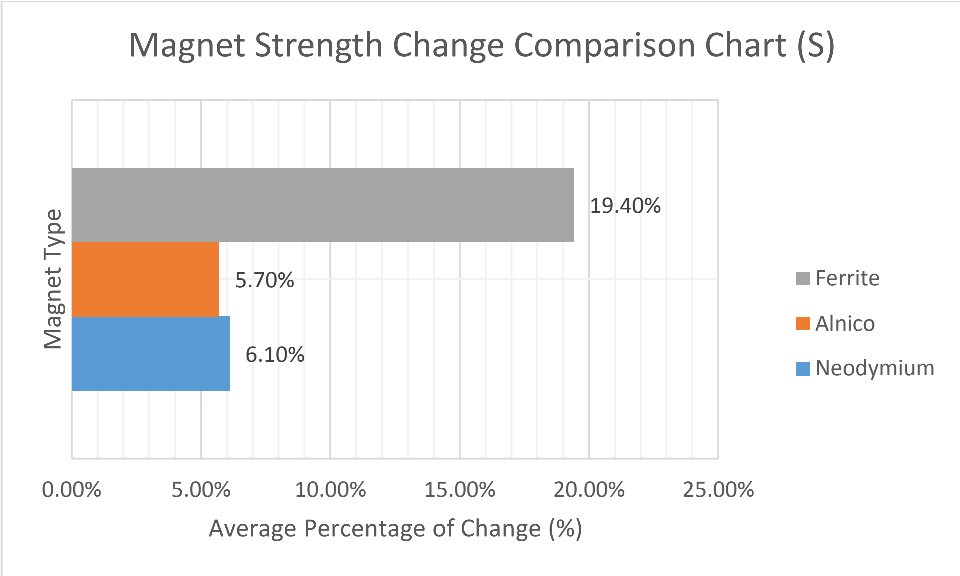


Figure 31: Comparison of each magnet respective changes on South pole

By comparing all changes in each respective magnet, the percentage of changes can be tabulated as shown in above figure. Alnico magnet has shown least changes with 5.70 % overall. Whereby neodymium slightly above alnico with 6.10 % of change. Ferrite magnet however since it is very soft material in term of coercivity, shown the biggest changes of all, with up to 19.4 % of changes from the initial value.

2. Anomaly of increasing strength of PMs under repulsive condition.

Theoretically, magnetic strength will decrease on both sides of poles if being put in opposite direction of field. However, in Figure 19 and Figure 21 for Alnico and Ferrite respectively, shows that increase in magnet strength has increased.

Expected results of this predicts that both magnet would experience losses in magnetic strength at least for few Gauss since opposite direction of field would force the weaker type of magnet's domain to follow each other, hence resulting in decrease in strength (Magnet Blog: Factors Which Cause Permanent Magnets to Lose Strength or to Demagnetize, 2012). Most of the cases,

CHAPTER 5: RECOMMENDATION & CONCLUSION

Recommendations

Throughout this experiment and analysis of this paper, there were few issues that should have been put into considerations for recommended work in the future.

Firstly, regarding the anomaly in the experiment, where magnetic strength should decrease instead of being increased. This problem rose from uncertain direction of domains in each individual magnet. Based on electromagnet Fleming's Right Hand Law, repulsive poles or adverse field does not mean giving decreasing effect of magnet strength. In fact, the effect can be constructive despite of destructive depending on the orientation of the magnet that being tested in every experiment. This consideration must not be taken lightly to avoid anomaly or uncertainties and confusion in future work in succession of this paper.

Secondly, from all the tabulated data shown, only the pattern of change of magnetic strength can be obtained experimentally. All the changes that happen on each individual magnet is reversible, hence the magnetization or demagnetization lines should be in linear form. However, the point where the forecast trend line should deviated and perform an upward or downward curve must be further investigated. This step is important since the cut-off line of usage in real application is still unknown. The cycles of the experiment could be done in more extensive ways in term of duration, speed and chosen material variables.

Another recommendation of this paper suggests to perform re-evaluation of concept that being investigated of. For example, permanent magnet – permanent magnet interaction in real life situation is scarcely in small numbers. However, this paper can be improved in its usability by investigating permanent magnet – electromagnet interaction instead of both by permanent magnet. This recommendation only apply if and only the case study involved changes of magnetic strength in motor or generator.

Conclusion

As for the conclusion, permanent magnets strength under cyclic magnetic field of other permanent magnet indeed changes whether it is increasing or decreasing in magnitude. The changes that occurred are in small magnitudes or scale except for ferrite magnet. The hardest magnet, neodymium has shown minor changes in its strength, followed by alnico and ferrite consecutively. Ferrite magnet, since it is a material that have low coercivity value which is material dependent, has shown major changes in its magnetic strength which explains why soft ferrite being used in digital memory-writing where magnetization and demagnetization occurs more frequently than any material else.

Plus, all the data obtained has been used to do prediction of how these magnets would react if the cycles were being extended for extra period. This is indeed very important to forecast how each individual magnet would behave especially in real-time application such as industrial, manufacturing, etc. However, the trajectories of the changes not yet to be determined due to few circumstances and limitations.

Next, the main objective of this paper is successfully accomplished by carrying out experimental work and further analysis on degradation of permanent magnet force under cyclic magnetic field of permanent magnet. All the experiment has been carefully carried out. On analysis, all clinical and critical reasoning has been done based on authorised, legitimate, and valid form of source.

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