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Design of a 3D Printed Line Lock With a Lever-Based Mechanism Using Neodymium Magnets

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Abstract - Line locks have been a crucial installation in vehicles in the world of motorsports. A 3D printed line lock is worked upon and the design is discussed. It comes with a lever-driven mechanism for providing manual control to block the flow of hydraulic fluid through the brake system. The open and close positions are maintained by using the magnetic power of Neodymium Magnets that have been installed in multiple of the line lock's parts. The material chosen is Nylon 12 (also called Polyamide 12) due to its superior performance in brake system applications. Multiple parts are assembled by press-fitting with appropriate tolerances considered for Nylon 12. Being the most suitable type for printing using Nylon 12, Selective Laser Sintering (SLS) is used as the printing technique. A sample printed using FDM for research is also discussed. Since hydraulic pressure distributes uniformly over the surface it acts on, the Gyroid infill pattern is used to attain isotropic print properties and counter the effect of part orientation in the distribution of the mentioned hydraulic load. The sealing has also been considered with the choice of material being EPDM, primarily due to its effectiveness in use with brake fluid.

Key Words: Isotropic, Neodymium, Gyroid, Selective Laser Sintering, EPDM, Nylon 12

1. INTRODUCTION

Drag racing has been an eminent part of the motorsport industry. Multiple cars compete on a straight stretch of road called a dragstrip. The one with the highest acceleration to eventually make it past the finish line wins. This acceleration depends on several factors like weight distribution, suspension configuration, aerodynamics, and the design of the drivetrain. Another critical metric is the traction between the driving wheels and the road. One way this traction is attained is by starting with a burnout to heat the wheels and enhance their adhesion with the road, thereby creating maximum traction. The most efficient burnout is performed only when the rear wheels can rotate freely (rear-wheel-drive vehicles) whilst having the front wheels perfectly locked up. This is done by installing a device called a line lock to the rear brake line which blocks the flow of hydraulic fluid to the respective wheel assemblies.

A line lock is basically a line shut-off valve that blocks the flow of fluid through any line that it is connected to. Pertaining to the aforementioned discussion, it is used in the braking system to block the flow of hydraulic pressure to the rear wheels of the vehicle. Hence only the front wheels lock up upon the press of the brake pedal, allowing the rear ones to rotate freely to complete the burnout.

The line lock is manufactured by 3D printing (additive manufacturing) using a polymeric material. Being an additive manufacturing method, the process has very little wastage when compared with the subtractive and formative types. Designs can be attained with as significant as a 63% lesser weight when made using 3D printing. Additionally, with the different infill patterns available today, even lighter products can be rolled-out at minimal costs and effort. The polymers used in 3D printing are chemically less reactive when compared with common metals, many of which are even required to undergo additional treatment to sustain the chemistry of brake fluids. We also have greater control over factors like surface finish, which is very important in braking system applications. There is also a plethora of different kinds of materials and printing methods available that make this technology available for use in several new and unconventional domains of application.

2. LINE LOCK

The design consists of an assembly of multiple 3D printed parts functioning in sync.

2.1 DESIGN & WORKING

The line lock functions on a lever-based mechanism and uses Neodymium magnets for keeping the line in open and closed positions respectively.

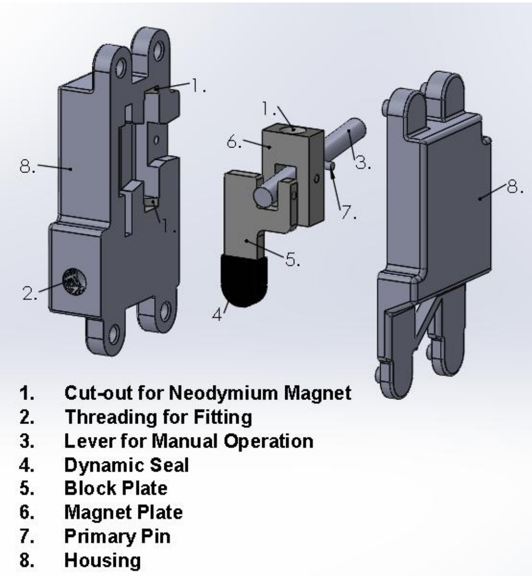

Fig. -1 :Exploded View of Assembly

The lever shown in Fig. -1 is operated manually by the driver. The threading is used for attaching hydraulic fittings to connect the valve to the brake line/ hose. Various types of fittings can be used including the common ones seen in the industry, namely the banjo fitting and the swivel fitting. In the case where the threadings do not match, male/ female adapters can easily be printed in order to create the line connection.

Along with one magnet on each of the ends of the magnet plate (shown by 1 on the magnet plate), each of the two housings contains semi-circular cutouts on the extreme positions (shown by 1 on the housing), which upon assembly provide a cylindrical space (shown by A & B in Fig. -2) for fitting the Neodymium magnets.

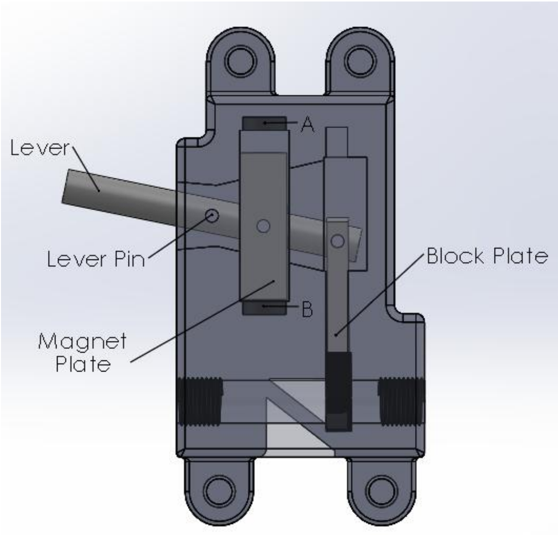

Fig. -2 : Side View

As seen in Fig. -2, the lever pivots about the lever pin and gives linear motion to the block plate to move in the vertical direction. The position of the block plate here determines the position of the line lock, open or closed. The magnet plate is also given vertical motion by the lever. The magnet plate holds Neodymium magnets on it's two ends and these mate with those in the housing and hold the magnet plate in the extreme positions (A & B) for the open and closed orientations.

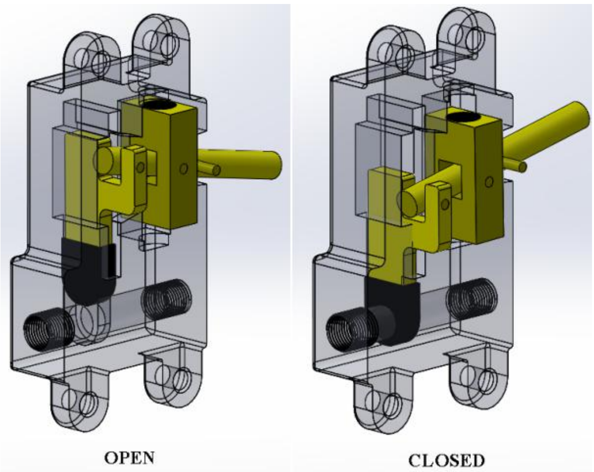

Fig. -3 : Open & Closed Orientations

The open and closed orientations with the block plate and magnet plate held in position by the Neodymium magnets have been shown in Fig. -3.

2.2 FINITE ELEMENT ANALYSIS

The line lock is analysed for a case of 100% infill density to determine the maximum operational capability of the design, as shown in Fig. -4.

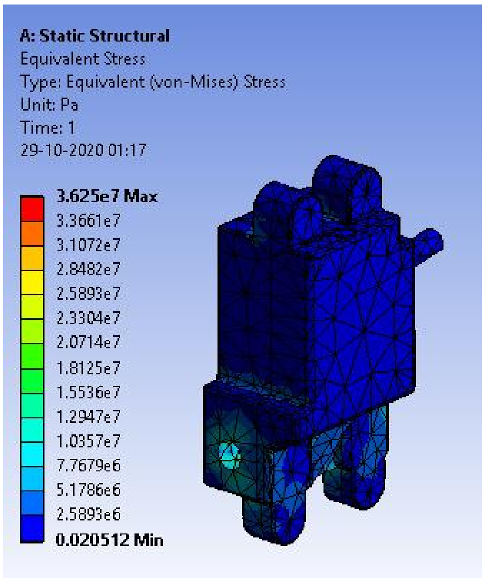

Fig. -4 : Stress Distribution Using Finite Element Analysis (FEA)

Any infill density less than this will give inferior performance results but can be used depending on the conditions of operation.

Fig. -5 : Hydraulic Pressure Gauge for Brake Line Pressure

The value of pressure used for the analysis was attained using a test-brake system installed in a vehicle. A hydraulic pressure gauge is directly attached to the inlet port of the brake caliper. The maximum value of hydraulic pressure recorded was 1800 PSI, as shown in Fig. -5.

2.3 DYNAMIC SEAL

Since the block plate and housing have a constant relative motion for the functioning of the mechanism, a dynamic seal is used to restrict the leakage of fluid. The material used for sealing is EPDM rubber (ethylene propylene diene monomer rubber), primarily due to its superior resistance to chemical attack from brake fluid.

The level of squeeze for any dynamic seal is generally recommended to be below 30% or it may undergo pinching, creating gaps in the seal for fluid to pass through. Too much of a squeeze can also create an unwanted friction between the seal and the interacting surface of the housing. Friction is observed to constantly affect the system either in the form of breakout friction (friction to be broken to establish relative motion) or running friction (friction faced during relative motion), [1]. This friction can cause significant wear & tear and ultimately reduce the life of the component. The block plate is fitted with the dynamic seal at a squeeze of 15%, a medium-level according to [2].

2.4 MATERIAL: NYLON 12

Nylon 12 (Polyamide 12), an engineering-grade material is chosen for 3D printing the line lock. The choice is backed by its chemical resistance to brake fluid, high melting point, and high durability, all of which make it useful in the long run. It also has a very low coefficient of friction, minimalizing the associated hydraulic losses.

It can be inferred from Table -1 that it has better physical properties than polyethylene and polypropylene, both of which are prevalent in the automobile as well as the 3D Printing industry. It can also be seen that one disadvantage Nylon 12 poses is that it has a greater water absorption capacity. It has a polar structure due to which it attracts the Hydrogen in the water molecule, [3]. This alteration in the molecular definition affects the structure's mechanical behavior and can make it weak. It will also affect the geometrical accuracy of the design once the water starts collecting between the lattice structure. The raw material, mostly in the filament form is required to be kept in an artificially dried place (using silica gel) or heated in an oven (to dry) before being used in the printing process.

Table -1: Physical Properties of Polymers Used in Braking System Components

	Nylon 12 (PA 12)	Low Density Polyethylene (LDPE)	High Density Polyethylene (HDPE)	Polypropylene (PP)
Tensile Strength	48 MPa	9.65 Mpa	27.5 MPa	40 MPa
Hardness (Shore D)	71	55	69	65
Water Absorption	0.2%	0.01%	0.0075%	0.003%
Melting Point	178°C	105°C	120°C	160°C

But this capacity can be reduced significantly in the rolled-out product by coating it with certain protective materials. Some of these include water-resistant chemicals like Silicones, Vinyl Acrylates, and Polyurethane. [4] considers Polyurethane to be the most appropriate coating material because Nylon can easily form Hydrogen bonds with it, thereby not needing to bond with the water molecules from outside anymore.

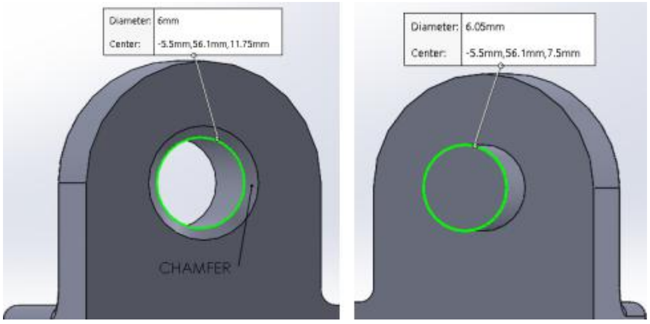

Fig. - 6 : Dimensions of Female & Male Parts After Tolerancing

Different parts are joined using press-fits and the tolerance for Nylon 12 is taken to be 0.50mm (approximately 0.002 inch). This increment is made in the diameter of the male parts, as shown in Fig. -6. All the other fits in the design are also press-fits with the same tolerance parameters. Chamfers have been provided to aid the press-fitting operation.

2.5 MANUFACTURING: SELECTIVE LASER SINTERING (SLS)

The process chosen for manufacturing this valve is Selective Laser Sintering (SLS), which according to [5] gives a stable print structure.

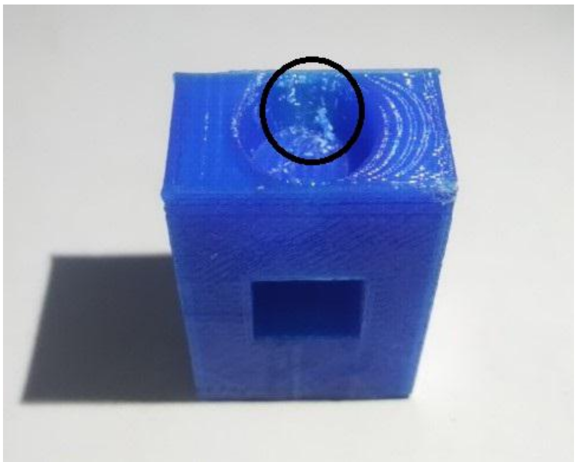

Fig. - 7 : Sample of Magnet Plate Printed Using FDM

As encircled in Fig. -7, the surface on the cut-out for the Neodymium magnet requires certain post-processing efforts to remove the irregularities present there. This unwanted material was observed to come due to the creation of support structures and such efforts can be reduced by using SLS which does not require support structures for the printing operation.

If the raw material absorbs moisture during the manufacturing operation and is processed in this wet state, [6] says that the water will cause porosity in the final structure upon being exposed to the high temperatures of operation. It is also added that the layers would also not adhere to each other properly, rendering the structure to be weak. But [7] states that SLS is performed in a closed chamber where the powder is not exposed to the external environment, eliminating the risk of water absorption. Additionally, work done by [8] also shows that SLS gives greater accuracy (by reducing shrinkage) when compared with the method of FDM. The staircase effect is also less prevalent in SLS which gives it a smoother surface finish, important in circumventing the losses that might be incurred in the transmission of hydraulic pressure.

2.6 INFILL: GYROID

As seen in Fig. -8, the hydraulic pressure (P) is seen to be uniformly acting outwards on the entire surface of the fluid line. The effect of the stress generated by the hydraulic pressure is not the same in all the directions due to the given part orientation (X Direction here), i.e., the orientation of the layers.

Concerning [9], it is observed that loads are best countered when acting in a direction parallel to that of the layers. The effect of the loading in Fig. -8 (depicted by F) along the Y-axis will be more detrimental to the structure than that along the X-axis as the layers are lying perpendicular to the direction of the generated load (along the Y-axis). This property of non-uniform behavior throughout the bulk of the material is called anisotropy.

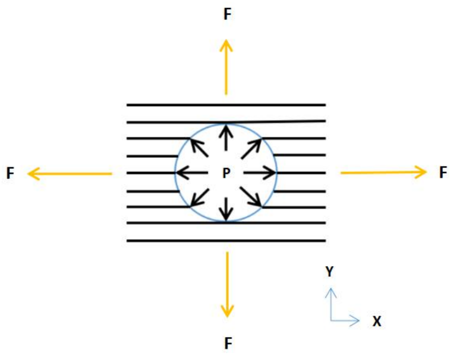

Fig. -8 : Cross-section of Fluid Line Valve With Part Orientation

The issue of anisotropy can be resolved by using the Gyroid infill pattern, which according to [10] gives isotropic properties and is used in parts with multiple directions of loading, similar to the behaviour of hydraulic pressure.

The gyroid is a bio-inspired structure, a type which is highly desired in the industry due to having better properties when compared with its bulk material counterparts, [11]. Additionally, it has superior physical properties at infill densities equal to that of any standard grid infill design, [12].

[13] discusses a study where the finite element method, namely the Arruda-Boyce finite-deformation elasto-viscoplastic model is used to analyse the pattern for tension and compression, showing it to be way ahead of the other bio-inspired structures under consideration and even the common infill types currently used in the additive manufacturing industry.

[14] presents an experiment to find the variation in ultimate tensile strength and yield strength of 13 different types of infill patterns with densities varying from 10% to 90%. The Gyroid is shown to have strength parameters greater by 15-20% than the average value observed, even after being of the same weight. Though the time to print a structure with Gyroid is also seen to be more than the average time taken by the other types.

2.7 NEODYMIUM MAGNETS

Neodymium magnet (also called neo magnet) is a permanent magnet comprising of a mix of the rare-earth metal Neodymium, Iron, and Boron (Chemical Formula: $Nd_2Fe_{14}B$). It is chosen due to having a high power-to-weight ratio. [15] calls it the most powerful magnet discovered by humans in terms of per unit size. It also has excellent magnetic characteristics like high coercivity, the density of magnetic energy, remanence, and resistance to demagnetisation, [16], [17].

Fig. -9 shows the type of Neodymium magent used in the line lock.

Fig. -9 : Neodymium Magnet (Diameter : 10 mm, Thickness: 5mm)

As shown in Fig. -10, the Neodymium magnet can be placed in the cut-out in the magnet plate. A similar cut-out is also given in the housing.

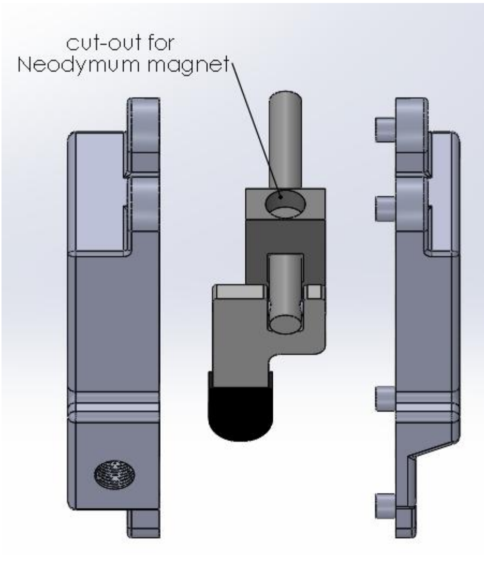

Fig. -10 : Depiction of Cut-out for Fitting Neodymium Magnet

One major disadvantage of Neodymium magnets is that they easily get corroded when being compared with the other types of magnets, mainly due to the presence of iron in their composition. This corrosivity is significantly reduced by applying a Ni-Cu-Ni coat over its surface. It comprises two layers of Nickel with one of Copper in between.

Nickel inherently shows excellent corrosion resistance and has also been used in coating metals (like Iron) and other materials in various industrial sectors, [18], [19]. Moreover, glycol and silicone-based brake fluids come with certain corrosion inhibitors (usually amines) that restrict their chemical interaction with different metals like steel, copper, and nickel. This renders Neodymium safe from any chemical attack from the external environment.

3. CONCLUSIONS

The presented line lock comes out as a lightweight alternative to the currently used metallic line locks or shut-off valves. It's neodymium magnet based mechanism eliminates the issue of wear and tear usually observed in the traditional valves after a prolonged period of use. Prints obtained by Selective Laser Sintering (SLS) may also require certain post-processing efforts due to having particular critical elements like the threadings for fittings and press-fitted parts, but the final quality of the product is at par with the desired standards. With the growing scope of 3D printing technology, it would also be easier to promote it as a commercial product out in the market. The isotropic behavior granted by the Gyroid infill pattern would also be instrumental in improving the functional life of the line lock. The Finite Element Analysis (FEA) at 100% infill density provides insight into the extreme conditions of use for the given design. For lower values of operating parameters like pressure and temperature, one can easily reduce the infill percentage in order to gain multiple benefits of minimal printing time, reduced material use, and lower per-unit costs.

FUTURE SCOPE

Further research in the field of electronics will also enhance ease of operation and would significantly improve it's functionality as well. Different actuator setups may be used to augment the existing mechanism. It also comes as a design in which changes can be made to promote use for different industrial purposes like being used as a line shut-off valve in industrial hydraulics. Work is also required to be done in improving the existing Finite Element Methods so that such designs can be optimised with the facility to analyse with different infill types and densities. Newer techniques like MultiJet printing would also be instrumental in the growth of the concept. Further study on it can give an even more accurate product and eliminate unnecessary all efforts on post-processing. As mentioned, additional research would also be needed for coating Nylon 12 in order to completely eliminate the issues faced due to water absorption. Work can even be done on the use of composites in development of this model.

REFERENCES

1. Farid Al-Bender, Federico Colombo, Dominiek Reynaerts, Rodrigo Villavicencio, Tobias Waumans, Dynamic Characterization of Rubber O-Rings: Squeeze and Size Effects, Advances in Tribology, 2017.

2. Naresh Kumar Agarwal, Craig P. Lawson, "A Practical Method to Account for Seal Friction in Aircraft Hydraulic Actuator Preliminary Design, Proceedings of the Institution of Mechanical Engineers Part G Aerospace Engineering, 2016.

3. Nanying Jia, Howard A. Fraenkel, Val A. Kagan, "Effects of Moisture Conditioning Methods on Mechanical Properties of Injection Molded Nylon 6", Journal of Reinforced Plastics and Composites, 2004, 23(7), 729-737.

4. C. Ouyang, Xiatong Ji, Qun Gao, C. Xu.; "Modification of Regeneration Polyurethane by Blend with Ternary Nylon"; Proceedings of the International Conference on Material Science and Application (ICMSA 2015) Suzhou, China.

5 Peter Maroti, Peter Varga, Hajnalka Abraham, Gyorgy Falk, Tamas Zsebe, Zoltan Meiszterics, Sandor Mano, Zoltan Csernatony, Szilard Rendeki, Miklos Nyitrai, "Printing orientation defines anisotropic mechanical properties in additive manufacturing of upper limb prosthetics", Materials Research Express, 2018, 6, 035403

6. Tuan Noraihan Azila Tuan Rahim, Abdul Manaf Abdullah, Hazizan Md Akil, Dasmawati Mohamad; "The improvement of mechanical and thermal peoperties of polyamide 12 3D printed parts by fused deposition modelling"; eXPRESS Polymer Letters; 2017, 11(12), 963-982.

7. K.R. Bakshi,A.V. Mulay, "A Review on Selective Laser Sintering: A Rapid Prototyping Technology", IOSR Journal of Mechanical & Civil Engineering (IOSRJMCE), 2016, 53-57.

8. Choudhari CM, Patil VD; "Product Development and its Comparative Analysis by SLA, SLS and FDM Rapid Prototyping Process"; IOP Conference Series: Materials Science and Engineering; 2006, 149, 012009.

9. Sung-Hoon Ahn, Michael Montero, Dan Odell, Shad Roundy, Paul K. Wright; "Anisotropic material properties of fused deposition modeling ABS"; Rapid Prototyping, 2002, 8(4), 248-257.

10. Sanket Parab, Nilay Zaveri; "Investigating the Influence of Infill Pattern on the Compressive Strength of Fused Deposition Modelled PLA Parts"; Proceedings of International Conference on Intelligent Manufacturing and Automation; 2020, 239-247.

11. Pavol Pecho, Viliam Azaltovic, Branislav Kandera, Martin Bugaj; "Introduction study of design and layout of UAVs 3D printed wings in relation to optimal lightweight and load distribution"; Transportation Research Procedia; 2019, 40, 861-868.

12. Devesh K. Yadav, Rajeev Srivastava, Saty Dev; "Design & fabrication of ABS parts by FDM for automobile application"; Materials Today: Proceedings ["Article in Press"].

13. Diab W. Abueidda, Mohamed Elhebeary, Andrew Shiang, Siyuan Pang, Rashid K. Abu Al-Rub Iwona M. Jasiuk; "Mechanical properties of 3D printed polymeric Gyroid cellular structures: Experiment and

finite element study"; Materials and Designs; 2019, 165, 107597.

14. Adi Pandzic, Damir Hodzic, Aleksa Milovanovic; "Effect of Infill Type And Density On Tensile Properties Of PLA Material For FDM Process"; 30th DAAAM International Symposium On Intelligent Manufacturing And Automation; 2019, 545-554.

15. Parag G Shewane, Abhishek Singh, Mayuri Gite, Amit Narkhede; "An Overview of Neodymium Magnets over Normal Magnets for the Generation of Energy"; International Journal on Recent and Innovation Trends in Computing and Communication; 2014, 2(12), 4056-4059.

16. Karl J. Strnat; "Modern Permanent Magnets for Applications in Electro-Technology"; Proceedings of the IEEE; 1990, 78(6); 923-946.

17. J.M.D Coey; "Permanent Magnet Applications"; Journal of Magnetism and Magnetic Materials; 2002, 248, 441-456.

18. I. Rampin, F. Bisaglia, M. Dabalà; "Corrosion Properties of NdFeB Magnets Coated by a Ni/Cu/Ni Layer in Chloride and Sulfide Environments"; Journal of Materials Engineering and Performance; 2010, 19, 970-975.

19. Olawale O. Ajibola, Peter A. Olubambi; "Comparative effects of corrosion on electroless- nickel plated A6061 alloys in DOT3 brake fluid"; International Journal of Engineering & Technology; 2018, 7(2), 927-934.