Design and Analysis of Electromagnetic Braking System.

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ABSTRACT

Electro-magnetic Braking is a method that uses principle of electro-magnetic induction to generate braking force. Electro-magnetic braking works on creating a resistance force that opposes the motion of the object thereby slowing it down. In this paper we have designed and analysed one such electro-magnetic braking system. The conventional braking system is bulky and its power to weight ratio is low. Electro-magnetic braking system overcomes this disadvantage. The effectiveness of the braking system remains constant and heat dissipation becomes optimal according to surrounding conditions. Minimal maintenance and minimal wear and tear with progressive technological advancement in the system, providing better response time and increased lifecycle of the system. This designing and analysing being done for small commercial vehicles will prove to be a significant change in the braking and automobile sectors. The commercial braking system can be replaced by this electromagnetic braking system providing advantages such as improved and efficient braking, increased lifespan.

Keywords: - Electro-magnetic Braking, Design, Analysis, Dissipation, Technological Advancement, Commercial, Efficient.

I. INTRODUCTION

In the world of automotive engineering, the challenge of improved vehicle safety and efficiency has been a driving force behind the development of innovative braking technologies. One such technology that has gained limelight in recent years is the "Electromagnetic Braking System." This system represents a change from traditional friction-based braking methods, delivering a promising alternative that aims to revolutionize the automotive industry. The conventional braking system, which completely rely on mechanical components to generate braking force, have been used for over a century. However, they come with inherent limitations, including wear and tear, heat generation, and reduced braking efficiency in adverse conditions. These limitations have led researchers and engineers to explore alternative braking solutions that are not only more reliable but also environment friendly. The Electromagnetic Braking System is one such solution that employs the principles of electromagnetism to slow down and stop a vehicle. By harnessing the magnetic fields generated by powerful magnets and electric currents, this technology offers numerous advantages over conventional braking systems. The benefits include improved safety, reduced maintenance requirements, and the ability to recuperate energy through regenerative braking, thereby enhancing overall efficiency. As the automobile industry shifts towards sustainability, safety, and efficiency, this Electromagnetic Braking System stands as a compelling solution with the potential to replace conventional braking in the future of braking technology. This paper aims to provide a comprehensive understanding of this system, its applications, and its role in light weight commercial vehicles.

This paper focuses on the design and analysis of electromagnetic braking system that can be used in light commercial vehicles in replacement of commercial brakes. The process starts with designing of the setup to be installed with reference to dimensions from commercial light weight vehicles, following the analysis of different parameters of the component such as deformation, temperature, stress, magnetostatic.

II. LITERATURE REVIEW

Y. Shindo and O. Noro, "Simple Circuit Simulation Models for Eddy Current in Magnetic Sheets and Wires," The transactions of the Institute of Electrical Engineers of Japan. A, vol. 134, no. 4.[1] M. N. Kailash, S. Daniel.J, and N. .H, "Fabrication of Electromagnetic Braking System," International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol. 9, no. 12, Dec. 2021.[2] Karakoc, K., Park, E.J. and Suleman, A. (2012) 'Improved braking torque generation capacity of an eddy current brake with time varying magnetic fields: A numerical study', Finite Elements in Analysis and Design, 59.[3] He, R., Liu, X. and Liu, C. (2013) 'Brake Performance Analysis of ABS for eddy current and electrohydraulic hybrid brake system', Mathematical Problems in Engineering, 2013.[4] Shivashankar. R et al., Shivashankar.R. and Naveen, Dr.P.G.V. (2019) 'An analysis of permanent magnet eddy current braking system', International Journal of Mechanical and Production Engineering Research and Development, 9(4).[5] Chakraborty, P. et al. (2021) 'Application of electromagnetic braking torque and different braking modes programmed with ATmega328p microcontroller in Electromagnetic Braking System', Reason-A Technical Journal, 20(0).[6] Chowdhury,

R.U. et al. (2021) 'Design and fabrication of efficient electromagnetic braking system for Bangladesh Railway: A prototype approach', Proceedings of the International Conference on Industrial Engineering and Operations Management [Preprint].[7] Hoo, D.S. et al. (2023) Comparison of regenerative braking energy recovery of a DC third rail system under various operating conditions [Preprint]. doi:10.2139/ssrn.4379981 [8] Joseph Godfrey, A. and Sankaranarayanan, V. (2018) 'A new electric braking system with energy regeneration for a BLDC Motor Driven Electric Vehicle', Engineering Science and Technology, an International Journal, 21(4). [9] Karakoc, K., Suleman, A. and Park, E.J. (2016) 'Analytical modeling of eddy current brakes with the application of time varying magnetic fields', Applied Mathematical Modelling, 40(2).[10] Li, L., Yang, G. and Wang, L. (2023) 'Dynamic mechanical characteristics of NDFEB in electromagnetic brake', Defence Technology, 19.[11] Li, W. et al. (2024) 'Regenerative Braking Control Strategy for pure electric vehicles based on Fuzzy Neural Network', Ain Shams Engineering Journal, 15(2).[12] Shindo, Y. and Noro, O. (2014) 'Simple circuit simulation models for eddy current in magnetic sheets and wires', IEEJ Transactions on Fundamentals and Materials, 134(4) [13] Silva, L.I., de la Barrera, P.M. and De Angelo, C.H. (2012) 'Multi-domain modeling of electric vehicles including lead-acid battery dynamics', IFAC Proceedings Volumes, 45(21), pp. 447–453. doi:10.3182/20120902-4-fr-2032.00079.[14] Szántó, A. et al. (2022) 'Simultaneous measurement of the moment of inertia and braking torque of electric motors applying additional inertia', Measurement, 204, p. 112135.[15] Kailash, M.N., Daniel.J, S. and .H, N. (2021) 'Fabrication of Electromagnetic Braking System', IJIREEICE, 9(12). doi:10.17148/ijireeice.2021.91204. [16] Talib, I. et al. (2022) 'Brake power and load analysis of electromagnetic braking system', Pakistan Journal of Engineering and Technology, 5(2) [17] Günay, M., Korkmaz, M.E. and Özmen, R. (2020) 'An investigation on braking systems used in Railway Vehicles', Engineering Science and Technology, an International Journal, 23 [18] Szántó, A. et al. (2022) 'Simultaneous measurement of the moment of inertia and braking torque of electric motors applying additional inertia', Measurement, 204, [19]

III. PRINCIPLE AND OBJECTIVES

Principle of electro-magnetism is employed in this system. When a current is skilled around a conductor then it produces a magnetic flux which is uniform around the conductor. The strength of the flux depends upon numerous factors such as no. of coil windings, amount of current and properties of material used.

Objectives – The main objective is to design and analyse the system model. Besides the main objective, sub objectives are as follows:

1. Understand design considerations and execution.
2. Understand analyzation techniques.
3. Optimise the model.

IV. SETUP & MODELLING

Setup of experimentation/ Analysis is completed taken as the current version of Ansys Application.

Ansys Inc. Ansys 2024 R1 UI/UX

The System model is designed by considering the references of a small light weight public commercial vehicle. These dimensions have been modelled in such a way that this system fits inside the Rim of the tyre.

Tyre specification – 135/70 R12

Material used in windings is taken as CUPRUM(Cu-29) commonly known as copper which has the highest electrical conductivity rating of 16.78 nΩ.m at room temperature. It also generates a magnetic field of intensity 1500Am-1 carrying a current of 2.0A.

Dimensions:

Outer Ring	Outer Diameter	270 mm
Outer Ring	Inner Diameter	190 mm
Outer Ring	Thickness	75 mm
Inner Ring	Outer Diameter	180 mm
Inner Ring	Inner Diameter	100 mm
Inner Ring	Thickness	75 mm

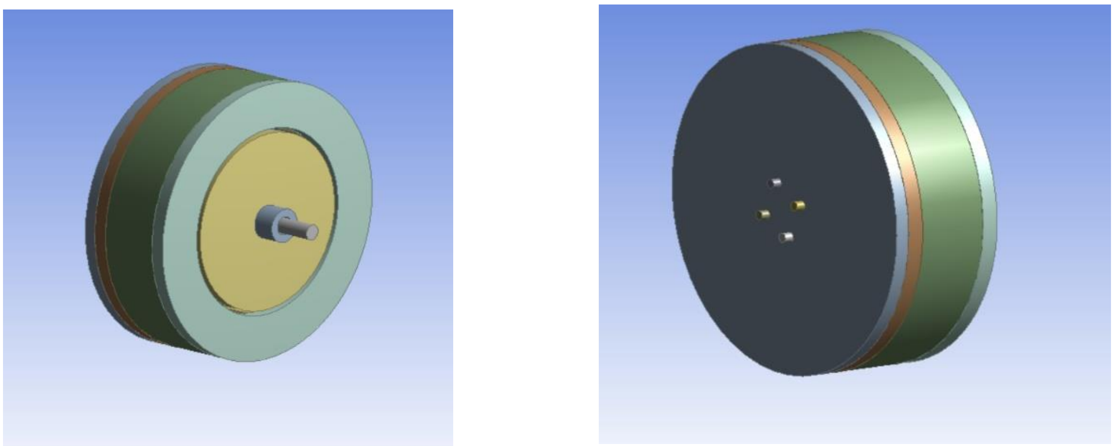


Fig. 01 Isometric view of assembly.

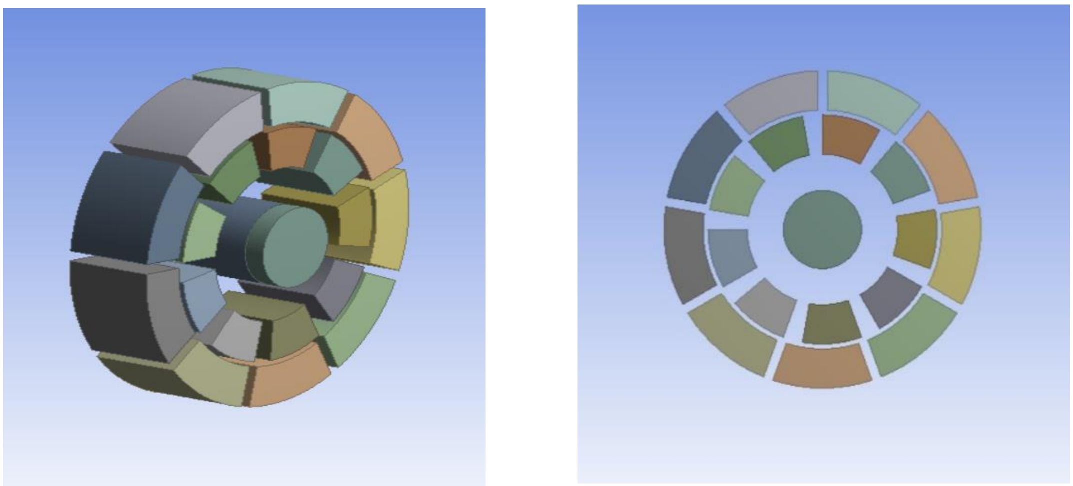


Fig. 02 Electro-magnets Assembly.

The inner ring holds the inner set of electro-magnets on its outer surface and is positioned such that it coincides with the axis of the outer ring. But unlike the outer ring the inner ring is stationary and is mounted on a hub. The complete assembly with magnets included is done after both sections are mounted over the Driving shaft.

V. EXPERIMENTAL DETAILS

The required magnetic field strength can be calculated using the formula,

$B = \mu * N * I * L$

Where,

I – current in solenoid. (A)

N – Number of Turns solenoid has.

L – Length of the solenoid.

μ - Permeability of free space. ($4\pi * 10^{-7}$ T.m/A)

The number of turns can be calculated using the formula,

$N = (\mu o * \mu r * A * n * l) / I$

Where,

μo – Permeability of free space.

μr – Relative permeability of material.

A – Cross section area of the core.

n – Number of layers.

l – Length of coil.

I – Desired current in coil.

The generated electro-magnetic force by coils can be calculated using formula,

$F = (q * v) * B$

Where,

q – Electric charge. (Coulomb)

B– Magnetic field. (Tesla or µT)

v – Velocity of particle.

The process started with sketching a 2D model of the required component in Auto CAD 2022. The 2D sketch was then converted to3D by the extrusion method. Similarly, all the other components were also modelled using Auto CAD. The whole assembly was then converted and transferred to the Ansys application i.e., Ansys 2024 R1 UI/UX. The whole assembly was then subjected to the required force and the required components were tested according to the decided parameters and the results were obtained. These results were then validated with the help of published and verified data through comparison. The validations were considered as they were published in various research papers mentioned in the Literature Review and the results obtained were nearby to the results in the research papers.

VI. RESULTS AND VALIDATION

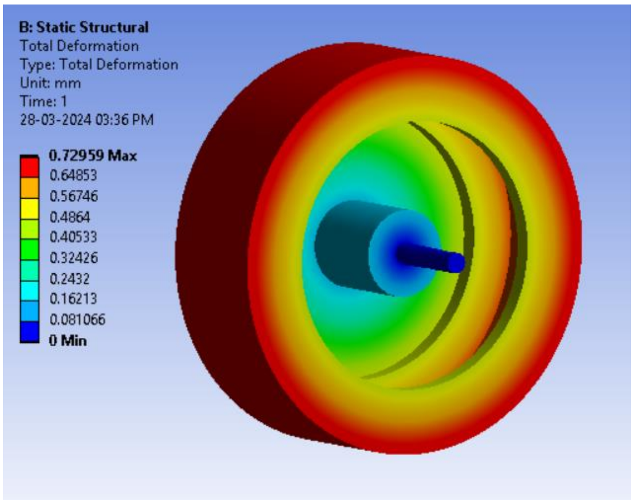
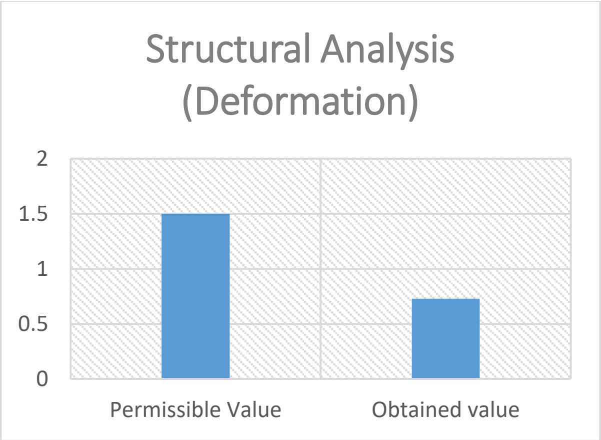


Fig.1 Structural Analysis (Total Deformation)

The component was subjected to a moment force of 51 kN-mm. These images depict total deformation occurred during the structural analysis.

Permissible deformation value in mm – 1 mm considering factor of safety ~ 1.5 mm maximum.

Obtained deformation value in mm – 0 mm minimum ~ 0.72959 mm maximum.



Graph.1 Structural Analysis (Total Deformation)

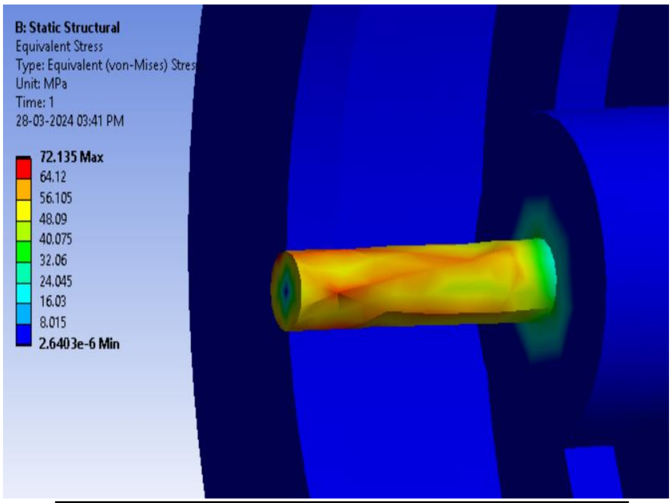
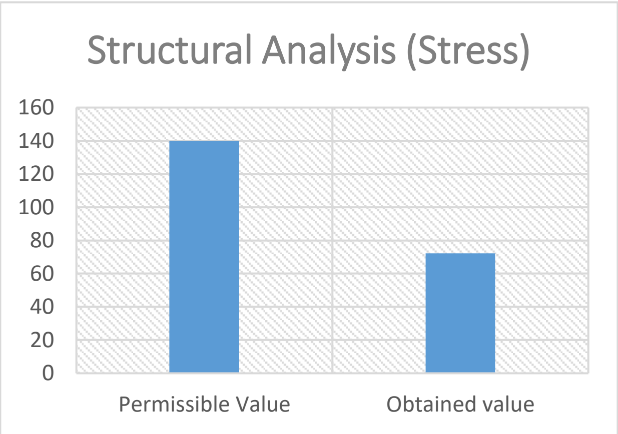


Fig.2 Structural Analysis (Equivalent Stress)

Upon subjected to the mentioned torque, the stress generated in the shaft was obtained as such.

Permissible stress value – 140 MPa ~ Till Failure.

Obtained stress value – 2.640 3e-6 minimum ~ 72.135 maximum.



Graph .2 Structural Analysis (Equivalent Stress)

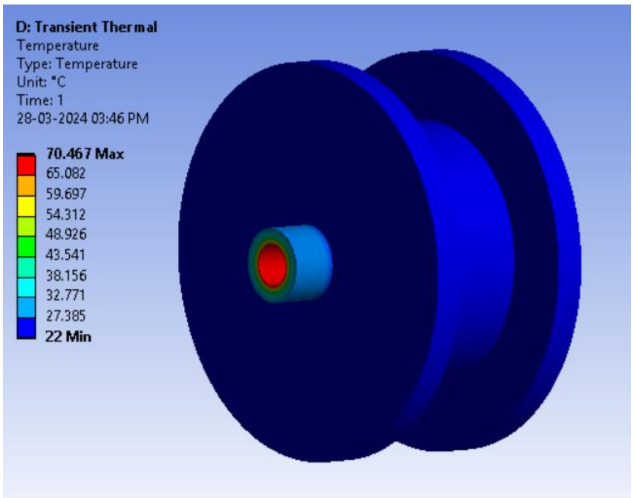


Fig.3 Temperature Analysis (Thermal)

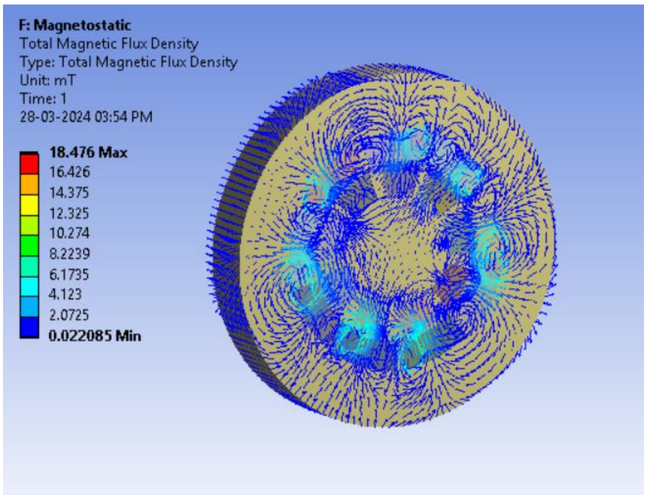


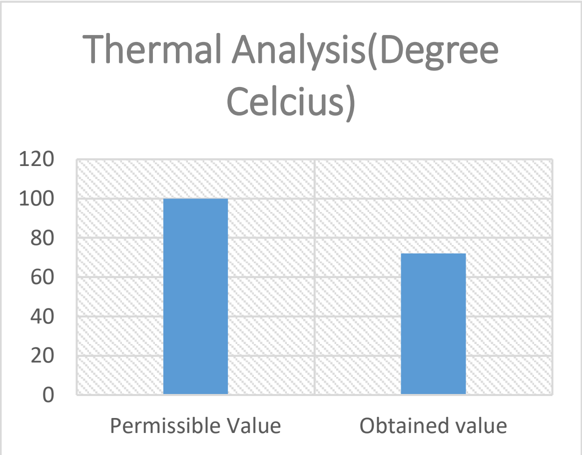
Fig.4 Magneto static (Total Magnetic Flux Density)

Permissible temperature value - 65° minimum ~ 100° maximum.

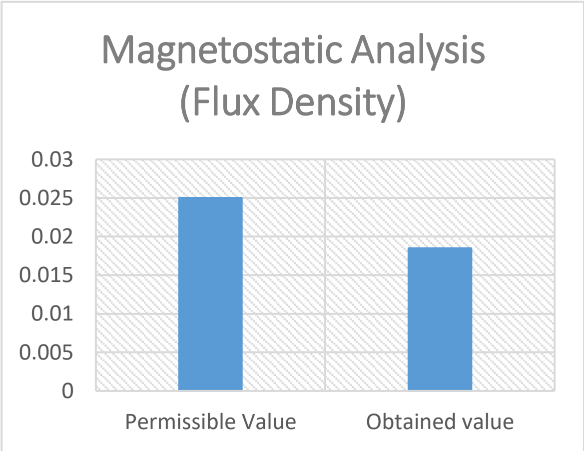
Obtained temperature value – 22 °C minimum ~ 70.467 °C maximum.

Permissible magnetic flux density – 0.025 mT maximum for CUPRIM (CU-29).

Obtained magnetic flux density – 0.00022085 mT minimum ~ 0.018476 mT maximum.



Graph.3 Temperature Analysis



Graph.4 Magnetostatic Analysis

CONCLUSION

Electro-magnetic braking system not only helps in effective braking but also in avoiding accidents caused due to slipping and reduces maintenance costs by a significant amount. Furthermore, the electro-magnetic brakes prevent the danger that can arise due to prolonged use of brakes with minimal heat dissipation. Electro-magnetic braking system are found to be more reliable than others.

In conclusion, the Electromagnetic Braking System represents a change or innovation in the automotive and industrial sectors. Its advantages, such as regenerative braking, reduced maintenance, and enhanced safety, and sustainable and efficient transportation.

So, the outcomes we achieved during this were that the usage of Electro-magnetic Brakes over Drum Brakes was proven to be more efficient and reliable, the electromagnetic brakes provided a more accurate and precise output of brake power with minimal wear and tear. The frictional losses that were recorded were reduced to a minimum according to the results obtained. As a result of which the overall braking efficiency and reliability of Electromagnetic Braking System was observed to be more in comparison of traditional friction brakes.

FUTURE SCOPE

Electro-magnetic braking system not only helps in effective braking but also in avoiding accidents caused due to slipping and reduces maintenance costs by a significant amount. Furthermore, the electro-magnetic brakes prevent the danger that may arise due to prolonged use of brakes with minimal heat dissipation. The scope of electro-magnetic braking system encompasses various applications across multiple industries where controlled deceleration or stopping of moving objects is required.

ACKNOWLEDGMENT

We would like to express our heartfelt and sincere appreciation to all those who provided us guidance to complete this Project.

Special thanks to our Project Guide Hon. HOD & Prof. Dr. Nitin Sherje whose guidance, stimulating suggestions and motivation helped us to reach this milestone. Also, our sincere appreciation for all the valuable time he and Prof. Prateek Malwe spent proofreading and correcting many of our mistakes.

We would also like to express our sincere appreciation for all faculty of Mechanical Department for guiding us during the duration of this Project Stage.

REFERENCES

[1] Y. Shindo and O. Noro, “Simple Circuit Simulation Models for Eddy Current in Magnetic Sheets and Wires,” The transactions of the Institute of Electrical Engineers of Japan. A, vol. 134, no. 4, pp. 173–181, 2014, doi: 10.1541/ieejfms.134.173.

[2] M. N. Kailash, S. Daniel.J, and N. .H, “Fabrication of Electromagnetic Braking System,” International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol. 9, no. 12, Dec. 2021, doi: 10.17148/IJIREEICE.2021.91204.

[3] Karakoc, K., Park, E.J. and Suleman, A. (2012) ‘Improved braking torque generation capacity of an eddy current brake with time varying magnetic fields: A numerical study’, Finite Elements in Analysis and Design, 59, pp. 66–75. doi:10.1016/j.finel.2012.05.005.

[4] He, R., Liu, X. and Liu, C. (2013) ‘Brake Performance Analysis of ABS for eddy current and electrohydraulic hybrid brake system’, Mathematical Problems in Engineering, 2013, pp. 1–11. doi:10.1155/2013/979384.

[5] Shivashankar. R et al., Shivashankar.R. and Naveen, Dr.P.G.V. (2019) ‘An analysis of permanent magnet eddy current braking system’, International Journal of Mechanical and Production Engineering Research and Development, 9(4), pp. 23–38. doi:10.24247/ijmperdaug20193.

[6] Chakraborty, P. et al. (2021) ‘Application of electromagnetic braking torque and different braking modes programmed with ATmega328p microcontroller in Electromagnetic Braking System’, Reason-A Technical Journal, 20(0), p. 34. doi:10.21843/reas/2021/34-45/212372.

[7] Chowdhury, R.U. et al. (2021) ‘Design and fabrication of efficient electromagnetic braking system for Bangladesh Railway: A prototype approach’, Proceedings of the International Conference on Industrial Engineering and Operations Management [Preprint]. doi:10.46254/an11.20210934.

[8] Hoo, D.S. et al. (2023) Comparison of regenerative braking energy recovery of a DC third rail system under various operating conditions [Preprint]. doi:10.2139/ssrn.4379981.

[9] Joseph Godfrey, A. and Sankaranarayanan, V. (2018) ‘A new electric braking system with energy regeneration for a BLDC Motor Driven Electric Vehicle’, Engineering Science and Technology, an International Journal, 21(4), pp. 704–713. doi:10.1016/j.jestch.2018.05.003.

[10] Karakoc, K., Suleman, A. and Park, E.J. (2016) ‘Analytical modeling of eddy current brakes with the application of time varying magnetic fields’, Applied Mathematical Modelling, 40(2), pp. 1168–1179. doi:10.1016/j.apm.2015.07.006.

[11] Li, L., Yang, G. and Wang, L. (2023) ‘Dynamic mechanical characteristics of NDFEB in electromagnetic brake’, Defence Technology, 19, pp. 111–125. doi:10.1016/j.dt.2021.11.002.

[12] Li, W. et al. (2024) ‘Regenerative Braking Control Strategy for pure electric vehicles based on Fuzzy Neural Network’, Ain Shams Engineering Journal, 15(2), p. 102430. doi:10.1016/j.asej.2023.102430.

[13] Shindo, Y. and Noro, O. (2014) ‘Simple circuit simulation models for eddy current in magnetic sheets and wires’, IEEJ Transactions on Fundamentals and Materials, 134(4), pp. 173–181. doi:10.1541/ieejfms.134.173.

[14] Silva, L.I., de la Barrera, P.M. and De Angelo, C.H. (2012) ‘Multi-domain modeling of electric vehicles including lead-acid battery dynamics’, IFAC Proceedings Volumes, 45(21), pp. 447–453. doi:10.3182/20120902-4-fr-2032.00079.

[15] Szántó, A. et al. (2022) ‘Simultaneous measurement of the moment of inertia and braking torque of electric motors applying additional inertia’, Measurement, 204, p. 112135. doi:10.1016/j.measurement.2022.112135.

[16] Kailash, M.N., Daniel.J, S. and .H, N. (2021) ‘Fabrication of Electromagnetic Braking System’, IJIREEICE, 9(12). doi:10.17148/ijireeice.2021.91204.

[17] Talib, I. et al. (2022) ‘Brake power and load analysis of electromagnetic braking system’, Pakistan Journal of Engineering and Technology, 5(2), pp. 140–145. doi:10.51846/vol5iss2pp140-145.

[18] Günay, M., Korkmaz, M.E. and Özmen, R. (2020) ‘An investigation on braking systems used in Railway Vehicles’, Engineering Science and Technology, an International Journal, 23(2), pp. 421–431. doi:10.1016/j.jestch.2020.01.009.

[19] Szántó, A. et al. (2022) ‘Simultaneous measurement of the moment of inertia and braking torque of electric motors applying additional inertia’, Measurement, 204, p. 112135. doi:10.1016/j.measurement.2022.112135.