Advances in Military Technology
Vol. 21, No. 1, 2026, pp. 213-222
ISSN 1802-2308, eISSN 2533-4123
DOI 10.3849/aimt.02072

Impact of Structural Parameters on Disc-Type Magnetorheological Brake Performance

H. Quang Tuan, N. Xuan Hien, and V. Hai Quan*

School of Mechanical and Automotive Engineering, Hanoi University of Industry, Vietnam

The manuscript was received on 21 December 2025 and was accepted after revision for publication as an original research paper on 7 April 2026.

Abstract:

This study investigates the electromagnetic and braking performance of a disc-type magnetorheological brake (MRB) using MRF-140CG fluid. A 3D finite element model (Altair Flux) analyzes torque generation under varying excitation currents, fluid gaps, rotor thicknesses, and wire diameters. Results show torque increases with current, limited by saturation. An optimal design with a 0.75 mm fluid gap and 25 mm rotor thickness yields a maximum torque of 191 N·m and a peak torque-to-volume ratio of 61.6 N·m/dm³ at 3 A. Additionally, smaller coil wire diameters improve torque output. These findings provide essential quantitative guidelines for designing compact, high-efficiency MRBs.

Keywords:

magnetorheological brakes (MRBs), finite element method (FEM), torque-to-volume ratio (T/V)

1 Introduction

In recent years, magnetorheological brakes have attracted significant attention from the research community due to their flexible braking torque control, low energy consumption, and fast response time. Owing to the field-dependent variation of the yield stress of magnetorheological fluids under an applied magnetic field, MRBs enable continuous modulation of braking force through controlled electric current. This capability opens broad application prospects in mechatronic systems, robotics, military equipment, autonomous vehicles, and intelligent drivetrain systems [1–3].

Among various MRB configurations, disc-type MR brakes are highly valued for their compact structure, high torque generation capability, and ease of integration into existing mechanical systems [4, 5]. The performance of MRBs depends on multiple factors, most notably the properties of the magnetorheological fluid, the magnetic circuit structure, and the design of the excitation coil. Recent studies have

* *Corresponding author: School of Mechanical and Automotive Engineering, Hanoi University of Industry, 298 Cau Dien Street, Bac Tu Liem District, Hanoi, Vietnam. Phone: +84 09 81534266, E-mail: quanvh@haui.edu.vn*

demonstrated that improvements in magnetic particle composition, particle size, and nano-additives can enhance rheological responsiveness, improve thermal stability, and extend the service life of MRFs [6–8]. In parallel, optimizing rotor and stator geometries, along with implementing multi-disc configurations, has been demonstrated to be an effective strategy for enhancing braking torque [4, 7, 8].

Another important research direction focuses on the influence of the excitation coil on MRB performance. Previous studies have mainly investigated coil shape, the number of coils, or single- and multi-coil configurations [6, 9, 10]. The results indicate that modifying coil geometry can improve braking torque while reducing the overall mass of the device. However, parameters such as coil installation position, the distance between the coil and the MRF layer, the mean coil radius, and the conductor wire diameter have not yet been systematically investigated, despite their direct influence on magnetic field distribution and torque generation efficiency.

In this context, recent studies by the authors' research group have examined and evaluated the relationship between magnetic field distribution, the rheological behavior of MRFs, and the braking torque of disc-type MRBs through mathematical modeling combined with finite element simulations [6]. In particular, the results highlight the critical role of magnetic circuit configuration and coil parameters in enhancing braking torque as well as the torque-to-volume ratios [11]. Nevertheless, these studies have mainly focused on individual parameters and have not yet established a comprehensive evaluation framework that balances braking performance with mass and size requirements – factors that are especially important for practical applications.

Motivated by the aforementioned limitations, the present study directly builds upon the recently published magnetic field and braking torque simulation results of MRBs reported by the authors' research group [6, 12]. In addition, the analysis is further extended toward the simultaneous optimization of coil and structural parameters based on the torque-to-volume ratio under a selected excitation current level. Using finite element simulations conducted in Altair Flux, combined with the Bingham rheological model of MRF-140CG, this study systematically investigates the effects of excitation current intensity, the coil-to-fluid gap (d), rotor thickness (b), and conductor wire diameter (D) on the braking performance.

From an application perspective, the obtained results not only contribute to strengthening the scientific foundation for the design of high-performance MRBs but also provide a basis for the development of compact, energy-efficient, and intelligent braking systems in the future, particularly in defense applications, electric vehicles, industrial robotics, and precision-controlled drivetrain systems. Moreover, the proposed research methodology can be extended to multi-disc MRB configurations or integrated with thermal analyses and advanced control strategies, thereby facilitating practical implementation at the industrial scale.

2 Methodology and Materials

2.1 Electromagnetic Simulation Model of the MRB

The electromagnetic model of the magnetorheological brake is developed in Altair Flux based on the FEM. The problem is formulated in a three-dimensional domain under the assumption of a magnetostatic field, in which the excitation current supplied to the coil is maintained constant for each investigated operating condition. This modeling approach is consistent with the previous studies conducted by the authors' research group [6, 12] and enables accurate evaluation of the magnetic field distribution, magnetic field intensity *H*, and magnetic flux density *B* within the magnetorheological fluid gap – the region that directly governs the generated braking torque.

The computational domain consists of the rotor, stator, excitation coil, fluid gap, and the surrounding air region. To minimize the influence of artificial boundary conditions, the air domain is extended using an Infinite Box, ensuring natural closure of magnetic flux lines. The rotor and stator components are modeled using 1010XC10 soft magnetic steel, with their *B*–*H* magnetization characteristics defined according to material data, following the same modeling approach reported in [6, 12].

2.2 Mesh Generation

As shown in Fig. 1, a uniform tetrahedral mesh is employed to accommodate the complex geometry of the MRB. The average element size is set to 0.5 mm, while mesh refinement is applied in regions with high magnetic field gradients, such as the fluid gap and the vicinity of the excitation coil, in order to enhance solution accuracy. Mesh quality is assessed based on the proportion of elements classified as "good" and "very good" which accounts for more than 85 % of the total elements, thereby ensuring the numerical stability and convergence of the FEM solution.

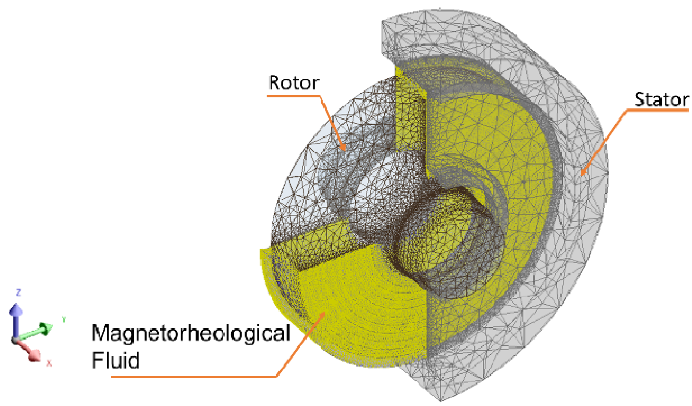

Fig. 1 Mesh Model of the Disc-Type MRB

A specific mesh control strategy was applied to the magnetorheological fluid gap to capture the steep magnetic field gradients across this thin layer. Regardless of the fluid gap thickness variation (*d* ranging from 0.5 mm to 1.5 mm), the mesh density was regulated to ensure a minimum of 3 finite element layers along the gap direction. This corresponds to a local element size significantly smaller than the global average, ranging approximately from 0.15 mm to 0.25 mm in the gap region. This level of discretization is essential to strictly satisfy the mesh convergence criteria and to avoid numerical errors caused by magnetic flux leakage or insufficient interpolation points within the active fluid volume, thereby ensuring the accuracy of the calculated braking torque.

2.3 Material and Boundary Conditions

The magnetorheological fluid employed in this study is MRF-140CG, manufactured by Lord Corporation, has been shown in previous MRB studies to exhibit high yield stress and generate substantial braking torque [6, 13]. The main physical properties of the fluid, including density, viscosity, and operating temperature range, are defined according to the manufacturer's datasheet.

The excitation coil is modeled as a toroidal winding made of copper wire with an electrical resistivity of 1.74×10^{-8} Ω·m. As shown in Fig. 2, the geometric parameters of the coil – including the number of turns, wire diameter, coil height, and coil width – are selected to ensure a high fill factor and compatibility with the available space in the stator. The excitation current supplied to the coil varied from 0 to 3 A with an increment of 0.25 A, in order to systematically investigate the relationship between excitation current, magnetic field, and braking torque, following an approach similar to that adopted in previous studies [6].

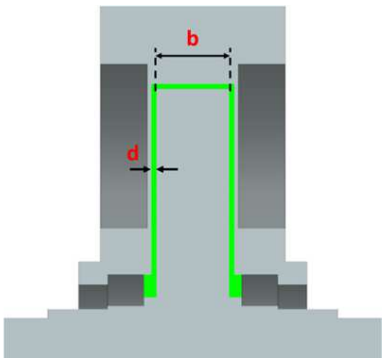

Fig. 2 Geometric Parameters of the Coil Structure

During the simulations, the system temperature is assumed to remain constant; therefore, the effects of temperature on the magnetic properties of the materials and the viscosity of the magnetorheological fluid are neglected. The magnetorheological fluid is considered homogeneous, and sedimentation effects as well as turbulent flow phenomena are not considered. The viscous torque generated in the absence of a magnetic field is evaluated separately and used as a reference, while the torque induced by the applied magnetic field is regarded as the dominant component of the total braking torque. This assumption is consistent with the Bingham rheological model and previously reported results [6].

3 Results

Based on the simulation results obtained from the preliminary MRB configuration using Altair Flux and the mathematical model derived from the theoretical framework, the braking torque of the device employing MRF-140CG with superior performance characteristics was determined [6, 14, 15]. After selecting appropriate baseline parameters, structural modifications were subsequently implemented to optimize the operational performance of the device. The primary parameters considered include the coil-to-fluid gap (d), rotor thickness (b), and conductor wire diameter (D). In particular, when varying the rotor thickness, the torque-to-volume ratio was analyzed to evaluate material utilization efficiency and spatial effectiveness. In addition, the influence of the excitation coil was investigated by varying the conductor wire diameter to clarify the role of electromagnetic factors and to further validate the underlying theoretical assumptions. The results of these parametric studies enable the identification of an optimal configuration that achieves a balanced trade-off between braking torque and device volume.

3.1 Coil-to-Fluid Gap (d)

Following the preliminary investigation and evaluation, two key physical parameters that significantly affect the device performance were identified as the applied excitation current and the rotational speed of the rotor. On this basis, the study further focuses on the investigation of the structural parameters of the brake, with the excitation current varied in the range of 0 to 3 A to comprehensively evaluate the torque generation characteristics of the system. In particular, the rotor rotational speed is kept constant throughout the entire simulation process so as to fully exploit the characteristics of the Bingham rheological model [16].

Fig. 3 illustrates the variation of braking torque with excitation current, investigated for different fluid gap sizes ranging from 0.5 mm to 1.5 mm, at a constant angular speed of Ω = 15.26 rad/s. The magnetorheological fluid used in the simulations is MRF-140CG.

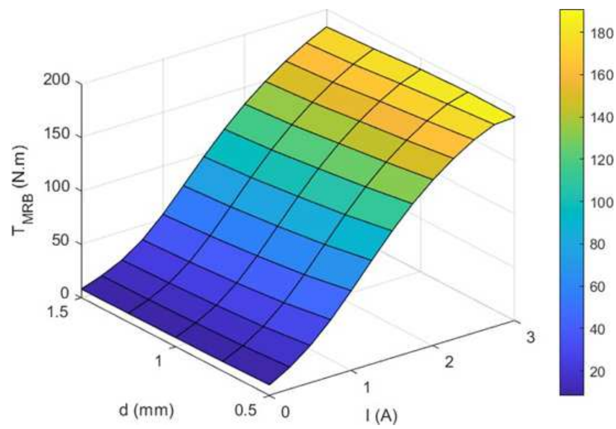

Fig. 3 Variation of braking torque as a function of fluid gap thickness (d) and excitation current (I)

The results indicate that the fluid gap size plays a crucial role in controlling the braking torque. As the gap increases, the braking torque decreases significantly due to the weakening of the interaction forces among magnetic particle chains, which leads to a reduction in the shear stiffness of the fluid medium. Specifically, at an excitation current of 3 A, the braking torque reaches a maximum value of 191 N·m for a gap of d = 0.75 mm, which is slightly higher than the 190 N·m obtained for d = 0.5 mm. This slight reduction at the smaller gap is attributed to magnetic saturation effects at high current levels, which limit further enhancement of magnetic flux density in the d = 0.5 mm case.

In contrast, the braking torque further decreases to 189 N·m, 185 N·m, and 183 N·m for gap sizes of 1.0 mm, 1.25 mm, and 1.5 mm, respectively, as shown in Fig. 4. This behavior arises because a larger fluid gap provides more space for fluid motion, thereby reducing the shear force within the magnetorheological fluid. This trend is also well described by the Bingham model, in which the shear stress is inversely proportional to the gap thickness, resulting in a pronounced reduction in braking torque as the gap increases.

Overall, the simulation results demonstrate that the braking torque is simultaneously influenced by both the excitation current and the fluid gap size. Increasing the current enhances the braking torque by increasing the apparent viscosity of the magnetorheological fluid, whereas increasing the gap size reduces the torque due to weakened shear forces. Therefore, an appropriate trade-off between excitation current and fluid gap size must be selected in order to optimize the performance of the magnetorheological braking system.

3.2 Rotor Thickness (b)

As previously analyzed, the simulation results of the magnetic field intensity *H* and magnetic flux density *B* distributions within the fluid gap indicate that the rotor tip region is the area where the magnetic vectors are most strongly concentrated, exhibiting significantly higher values than those at other locations [6, 12]. This region also contributes the largest portion of the braking torque, accounting for a substantial fraction of the device's total braking force (Fig. 2). On this basis, the influence of rotor thickness (*b*) is investigated, since this parameter directly affects the effective length of the fluid gap in the working region of the MRB.

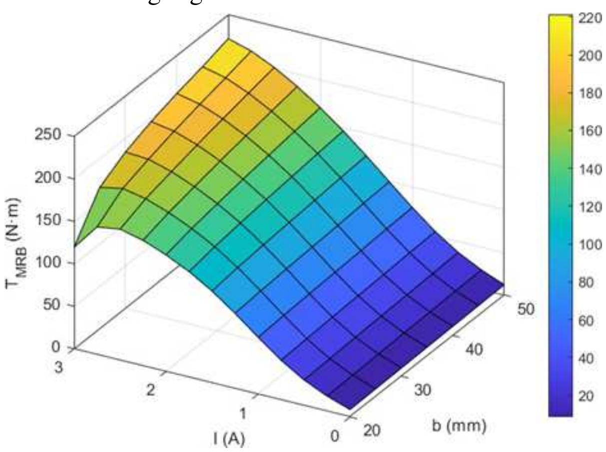

Fig. 4 Effect of Rotor Thickness on the Braking Torque of the MRB at Different Excitation Current Levels

Fig. 4 presents the variation of braking torque as a function of excitation current for different rotor thicknesses ranging from 20 mm to 50 mm. The results demonstrate that an increase in rotor thickness leads to a corresponding increase in braking torque. The maximum torque reaches approximately 221.38 N·m when the rotor thickness is *b* = 50 mm. This behavior can be attributed to the increase in the active volume of the magnetorheological fluid as the rotor thickness becomes larger, which allows greater shear forces to be generated during operation, thereby enhancing torque transmission capability. However, increasing the rotor thickness also results in higher mass and larger overall dimensions of the MRB, which may adversely affect compactness and applicability in systems with strict space or weight constraints. Therefore, to assess the overall effectiveness, the T/V ratio must be considered. This performance index is essential for selecting an optimal rotor configuration that achieves a balance between torque performance and size-weight requirements of the device.

Fig. 5 illustrates the nonlinear variation of the T/V ratio as a function of rotor thickness. The results show that the T/V ratio reaches a maximum value of 61.6210 N·m/dm³ at a rotor thickness of *b* = 25 mm, after which it gradually decreases, attaining a minimum value of 57.9459 N·m/dm³ at *b* = 50 mm. This trend indicates that a rotor thickness of 25 mm represents the optimal value, as it ensures both a high braking torque and the maximum T/V ratio, thereby optimizing braking performance while maintaining reasonable mass and overall dimensions of the MRB. These results further confirm that the brake disc configuration with *b* = 25 mm provides superior performance in terms of both generated torque and T/V ratio at an excitation current of 3 A.

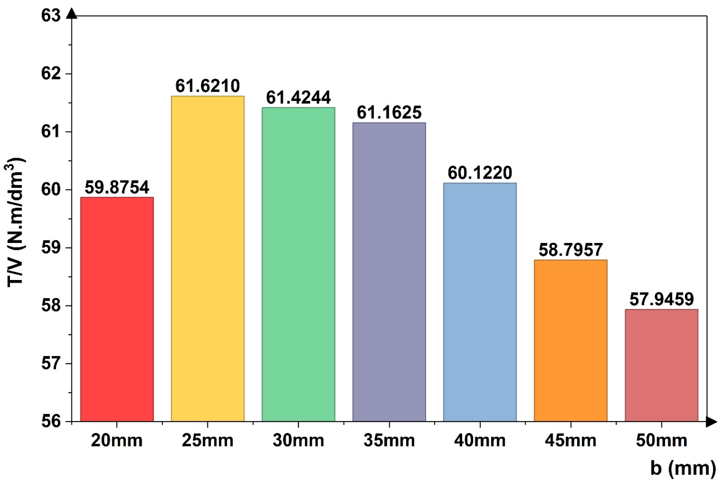

Fig. 5 T/V Ratio at 3 A

3.3 Conductor Wire Diameter (D)

After investigating the key physical and structural parameters, the study further examines how the coil dimensions influence the operational performance of the device. Specifically, in this analysis, the conductor wire diameter (*D*) is selected as the variable to evaluate its impact on the performance characteristics of the braking system.

Fig. 6 presents the braking torque results obtained by varying the excitation current for different investigated values of the conductor wire diameter (*D*), while maintaining a constant coil fill factor. The simulation conditions include a constant angular speed of Ω = 15.26 rad/s, a fluid gap of *d* = 1 mm, and the use of MRF-140CG as the magnetorheological fluid. The results indicate that the braking torque decreases significantly as the wire diameter increases. Specifically, the maximum torque of 189.48 N·m is achieved at an excitation current of 3 A with a wire diameter of *D* = 0.5 mm.

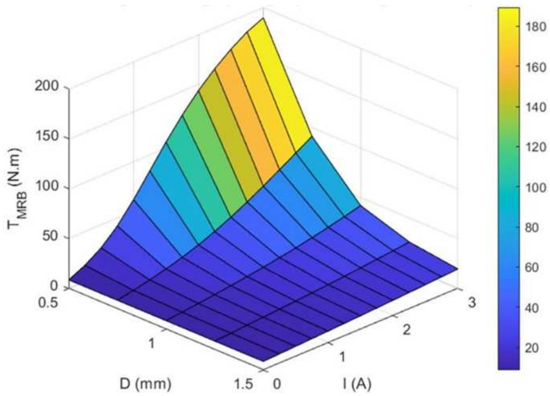

Fig. 6 Effect of Conductor Wire Diameter on Braking Torque at Different Excitation Current Levels

This decreasing trend in torque can be explained by Ampère's law and the relationship between the number of turns *N* and the magnetic field intensity *H*. When the coil fill factor is kept constant, increasing the wire diameter reduces the number of turns that can be wound within the same coil volume, leading to a lower total ampere-turns (*N*-*I*) and, consequently, a reduced magnetic field intensity. As a result, the braking torque decreases due to the weakened magnetic force acting on the magnetorheological fluid. This clearly demonstrates the significant influence of coil structural parameters on the overall performance of the braking device.

4 Conclusion

In this study, a three-dimensional electromagnetic simulation model of a disc-type magnetorheological brake was developed and analyzed using the finite element method in Altair Flux. Based on the established model, the effects of key operational and structural parameters on the braking torque generation capability of the device were systematically investigated. The simulation results indicate that the braking torque increases significantly with excitation current and rotor rotational speed, with the torque component induced by the magnetic field playing a dominant role compared to the viscous torque under zero-field conditions. However, when the excitation current exceeds an optimal threshold, magnetic saturation occurs, which reduces the effectiveness of torque enhancement and leads to energy inefficiency. This finding highlights the necessity of appropriately selecting the control current range during the design and operation of MRBs.

The structural parametric studies reveal that the fluid gap size has a direct influence on torque generation characteristics, with a gap of approximately 0.75 mm yielding the maximum braking torque under the investigated conditions. Increasing the rotor thickness increases braking torque because it enlarges the active volume of the magnetorheological fluid. However, when performance is assessed using the torque-to-volume (T/V) ratio, a rotor thickness of 25 mm emerges as the optimal configuration, providing the best compromise between braking capability and overall device compactness. In addition, the results demonstrate that increasing the conductor wire diameter, while maintaining a constant coil fill factor, leads to a reduction in braking torque due to a decrease in the total ampere-turns, thereby weakening the generated magnetic field intensity.

Overall, this study clarifies the relationship between magnetic field distribution, the rheological behavior of magnetorheological fluids, and the torque generation capability of MRBs, and proposes optimal design parameters with high practical relevance. In future work, several research directions will be pursued to address these limitations and enhance the practical applicability of the device. First, a physical prototype will be manufactured to experimentally validate the simulation results regarding braking torque and magnetic field distribution. Second, coupled thermal-electromagnetic analyses will be integrated to evaluate the thermal stability of the brake. Preliminary investigations by the authors into the thermal analysis of MRBs during downhill braking [11] have laid the foundation for this expansion, and further studies will incorporate these thermal models into the multi-objective optimization framework. Finally, the research scope will be broadened to compare the performance of different commercial magnetorheological fluids and to assess the brake's dynamic response under transient regimes and variable rotational speeds, ensuring its reliability in modern mechatronic and automotive systems.

References

[1] ROSSA, C., A. JAEGY, J. LOZADA and A. MICAELLI. Design Considerations for Magnetorheological Brakes. *IEEE/ASME Transactions on Mechatronics*, 2013, **19**(5), pp. 1669-1680. DOI 10.1109/TMECH.2013.2291966.

[2] NGUYEN, Q.H and S.B. CHOI. Optimal Design of an Automotive Magnetorheological Brake Considering Geometric Dimensions and Zero-field Friction Heat. *Smart Materials and Structures*, 2010, **19**(11), 115024. DOI 10.1088/0964-1726/19/11/115024.

[3] HU, G., L. WU and L. LI. Torque Characteristics Analysis of a Magnetorheological Brake with Double Brake Disc. *Actuators*, 2021, **10**(2), 23. DOI 10.3390/act10020023.

[4] HUNG, N.Q., N.N. DIEP and N.S. DZUNG. Development of Magnetorheological Brake with Two Coils Placed on Each Side of the Brake Housing. *Vietnam Journal of Mechanics*, 2015, **37**(4), pp. 263-273. DOI 10.15625/0866-7136/37/4/5918.

[5] CAO, Z., X. YANG, X. ZHU and Y. XIA. Optimal Design and Experimental Study of Comb-Type Disc Magnetorheological Brake. *Measurement*, 2024, **229**, 114458. DOI 10.1016/j.measurement.2024.114458.

[6] NGOC, N.A., N.M. DUC, N.M. TIEN and H.Q. TUAN. Research on Coil Design to Improve Performance of Disc-Shaped Magnetorheological Brakes. *Advances in Military Technology*, 2025, **20**(2), pp. 361-373. DOI 10.3849/aimt.01977.

[7] TURABIMANA, P. and J.W. SOHN. Optimal Design and Control Performance Evaluation of a Magnetorheological Fluid Brake Featuring a T-shape Grooved Disc. *Actuators*, 2023, **12**(8), 315. DOI 10.3390/act12080315.

[8] ACHARYA, S., T. SAINI and H. KUMAR. Optimal Design and Analyses of T-shaped Rotor Magnetorheological Brake. In: *Proceedings of the IOP Conference Series: Materials Science and Engineering*. Chennai: IOP Publishing, 2019, **624**, 012024. DOI 10.1088/1757-899X/624/1/012024.

[9] BIEN, N.V., L.H.Z. ZY, Q.H. NGUYEN, N.D. NGUYEN and D.Q. DUYEN. Design of a Tooth-Shaped Magnetorheological Brake with Multiple Coils. *Vietnam Journal of Mechanics*, 2024, **46**(4), pp. 331-342. DOI 10.15625/0866-7136/21128.

[10] WU, J., W. KONG, Y. HUANG and H. HUANG. Design and Experimental Evaluation of a Multi-Drum Magnetorheological Brake with Side-Set Dual-Coil. *Alexandria Engineering Journal*, 2024, **108**, pp. 549-560. DOI 10.1016/j.aej.2024.07.114.

[11] TUAN, H.Q. Thermal Analysis of the MRB During Downhill Braking. *International Journal of Mechanical Engineering and Robotics Research*, 2025, **14**(3), pp. 245-251. DOI 10.18178/ijmerr.14.3.245-251.

[12] TUAN, H.Q., T.M. HOANG and N.T. TUNG. Simulation of Auxiliary Magnetorheological Brake on Vehicles. *Journal of Transportation Technologies*, 2025, **15**(1), pp. 122-134. DOI 10.4236/jtts.2025.151007.

[13] *MRF-140CG Magneto-Rheological Fluid – 1 Liter* [online]. [viewed 2025-05-05]. Available from: https://www.shoplordmr.com/mr-products/mrf-140cg-magneto-rheological-fluid-1-liter

[14] SHIAO, Y. and M. BOLLEPELLY. Effect of Pole Head Profile on Torque Performance of a Disc-Type Multipole Magnetorheological Brake. *Applied Sciences*, 2023, **13**(14), 8327. DOI 10.3390/app13148327.

[15] WELLBORN, P., J. MITCHELL and R. WEBSTER III. Magnetorheological Brake with High Torque and Fast Response [online]. 2023 [viewed 2025-05-05]. Available from: https://patentimages.storage.googleapis.com/28/3c/93/0e6f9b8a39c486/US11815142.pdf

[16] CHEN, S., R. LI, P. DU, H. ZHENG and D. LI. Parametric Modeling of a Magnetorheological Engine Mount Based on a Modified Polynomial Bingham Model. *Frontiers in Materials*, 2019, **6**, 68. DOI 10.3389/fmats.2019.00068.