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A STUDY OF THE EFFECT OF KEY PARAMETERS ON THE MAGNETO-RHEOLOGICAL BRAKE TORQUE BASED ON THE SIMULATION METHOD

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ABSTRACT

This paper presents the design and simulation of a magnetorheological brake (MRB) model that supports a van truck downhill without interfering with the traditional brake system available on this vehicle. A research brake model using rheological magnetic fluid, an intelligent material. The operation of MR fluid-based brakes has inherent advantages such as continuously changing dynamic range and fast response. The research presents the process of calculating and simulating the braking torque generated by this brake model. This research helps to open up a new direction for the traditional brake system in cars. Consequently, the safety of the movement of cars, in particular, and vehicles in general during downhill is compromised. Based on the simulation model, the effect of key parameters (operation conditions, MRB tooth tilt angle, MRB rotor thickness, and number of MRB teeth) on the brake torque was completely presented.

Keywords: magnetorheological fluid, magnetorheological brake, MRB tooth tilt angle, MRB rotor thickness, braking torque.

Manuscript Received 28 December 2022; Revised 29 August 2023; Published 13 September 2023

1. INTRODUCTION

Small van trucks are a popular vehicle in the Vietnamese market; moving in Vietnam's traffic terrain often has to go downhill. When a small van truck goes downhill, it is subjected to a force of Gsinα, thereby generating an acceleration of a1, increasing the vehicle's speed, and causing danger to the movement. Usually, the driver will use the traditional brake to brake and reduce speed. The problem is that if a van goes downhill for a long time, the long braking time will generate a lot of heat, causing wear of the brake pads and damage to the brake quickly. Then there will be costs for repairing or replacing new brakes for the vehicle. Considering the car is going downhill, we need to calculate the downhill torque caused by the acceleration. The Magneto-Rheological (MR) oil disc brake is a device that transmits torque using the shear force of the MR fluid. A liquid is introduced between the rotating and stationary discs, and a magnetic field is applied to the liquid. In the study of E.M. Attia *et al*. [1], a complete test rig for MR fluid disc brakes is introduced. The experiments were performed to measure the braking torque and shaft speed during braking, and the results were performed at different voltage inputs to the brake.

In addition, theoretical analysis for both the MR brake and the mechanical system was developed and numerically solved using the finite difference method and MATLAB software. The influence of input current on MR braking, fluid viscosity, and design parameters is considered. Confirm the theoretical results with the introduced CFD model. The experimental results were performed to show that both angular velocity and braking torque are obtained as responses during braking. The comparison between the braking torque obtained from theoretical and experimental work shows consensus when the voltage is 2 V at 150 rpm and is favorable when the voltage is 2 and 3 V at 250 rpm. The research team's goal was to design and simulate a high-performance MR brake with high transmission torque, long-term stability, and simple construction. The ability to generate MR brake torque is heavily dependent on the properties of MR oil, specifically the rheological properties of both MR oil when the magnetic field is changed. The transmission torque equation for disc brakes is derived based on the Bingham fluid models. Also, in the study of author N.Q. Hung and his team, presented a new configuration of the dynamic magnetic fluid-based brake with multiple coils placed on each side of the brake housing (magnetic fluid-based brakes). Proposed, best-designed, and evaluated [2]. With this configuration, multi-coil side-coil dynamic magnetic fluid-based brakes are expected to provide higher braking torque and a more compact size than traditional magnetic fluid-based brakes. The proposed dynamic magnetic fluid-based brake torque is then analyzed based on the Bingham plastic rheological model of the dynamic magnetic fluid. Optimization of the proposed multi-coil magnetic fluid-based brake, magnetic fluid-based brake with one coil located on each side of the brake housing (single coil magnetic fluid-based brake), and conventional magnetic fluid-based braking is then performed, considering the maximum braking torque and the mass of the brake. Based on the optimal results, enhanced performance characteristics of the proposed magnetic fluid-based brake are found. In addition, tests are conducted to confirm the performance of the proposed multi-branch magnetic fluid-based brake. Research by Seiyed Hamid Mousavi et al. [3] with a new configuration of the MR hybrid brake consisting of a T-shaped drum with an arc surface. The author has experimentally determined the braking torque when changing the amperage, through which the maximum braking torque is

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38.5 Nm when the maximum current in each coil is 1.2A. Another study by V. K. Sukhwani and H. Hirani [4] determined the torque characteristics of the MRB when changing the current from 0 A to 1.2 A, and the number of revolutions of the motor from 200 to 1200 rpm. Another synthetic study was carried out with the analysis on the test bench of the moments generated with different structures of MR brakes such as drum, multilayer magnetic, and disc types [5] and showed some braking torque characteristics with current and structure. Research by Dr. Ngoc Nguyen Anh [6] has proposed a new type of MR brake with the features of modeling, structure optimization, testing, and prototype analysis. The main contribution of this work is the optimal design of the new configuration of the MR brake to improve the braking torque. However, for magnetic brakes, to evaluate the effectiveness of specific objects, the output braking torque characteristics need to be taken into account along with the mass and volume of the structure. Therefore, with the specific MRB structure chosen by the authors, the goal is to use the experimental method on the brake test platform with high stability and accuracy to determine the characteristics of the braking torque generated on the MRB when changing the input current value is necessary.

It can be seen that many research groups have focused on exploiting the potential applications of MR magnetic oil, wishing to create MR brake devices on the test platform with a compact structure, achieving effective braking. The resulting braking torque value is large... However, very few studies have delved into the application of a specific moving object. Therefore, in this paper, the authors focus on the application of an MR brake design with a toothed disc structure installed on a small truck to support the vehicle when going downhill. This device works completely independent of the main brake system to actively generate braking torque when there is a change in the slope of the road, ensure a stable speed of the vehicle, and increase the service life of traditional brake systems.

2. METHODOLOGY

2.1 Calculation Method to Estimate the Value of Braking Torque Generated by MRB

2.1.1 Magnetic brake structure

As analyzed the advantages and disadvantages of the above installation options, to match the installation space under the vehicle and the rotation of the components in the powertrain, the selected structure is in the form of plates, and round discs put together. Figure 4 shows the structure of a magnetic brake. The magnetic brake is coupled between the cardan and the active bridge housing at the mounting position with flanges. The additional bolt holder includes an active bridge cover and a magnetic brake to keep the magnetic brake stable while the vehicle is operating and braking. The main structure of the MRB kit includes:

+ Rotor caught with cardan shaft, active bridge shell, trapezoidal disc profile, and trapezoidal angles of magnitude 30 degrees.

+ The brake outer shell is assembled by steel plates, which have round holes drilled to catch bolts and have holes to install coils.

The magnetic oil is introduced into the area between the rotor and the housing. The outside of the housing has an oil pump hole and is covered by the oil pump breast. The brake housing and the rotating disc are held together by ball bearings and oil seals. SKF bearings and SKF oil seals are both selected as standard, capable of withstanding a large number of revolutions and torques in operation, and comfortable in working conditions.

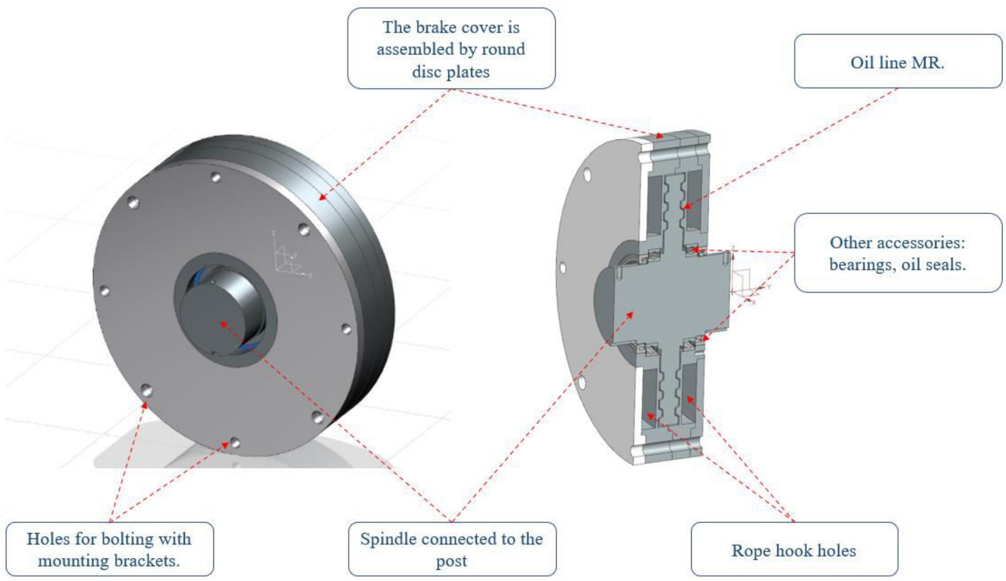

Figure-1. Magnetic brake construction.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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2.2 Theoretical Basis for Calculating Brake Torque

Calculation basis based on Bingham fluid model equation [7]:

$$\tau = \tau_y + \eta\dot{\gamma} \quad (7)$$

Calculation of torques: To calculate the torque for this structure, the study calculates the torque generated by the brake at the position of the contact surface perpendicular to the axis of rotation (E regions), the inclined plane to the axis of rotation (A regions), the torque generated at the housing inner annular contact, the rotor outer surface (C region), and the bearing contact with the rotor shaft (sf regions).

The torque generated by area E has a linear method to the rotor rotation, area A has a linear method to the rotor rotation at an angle of 30 degrees, and area has a linear method perpendicular to the rotor's rotation. The brake structure and areas (A, E, and C) are presented in Figure-2.

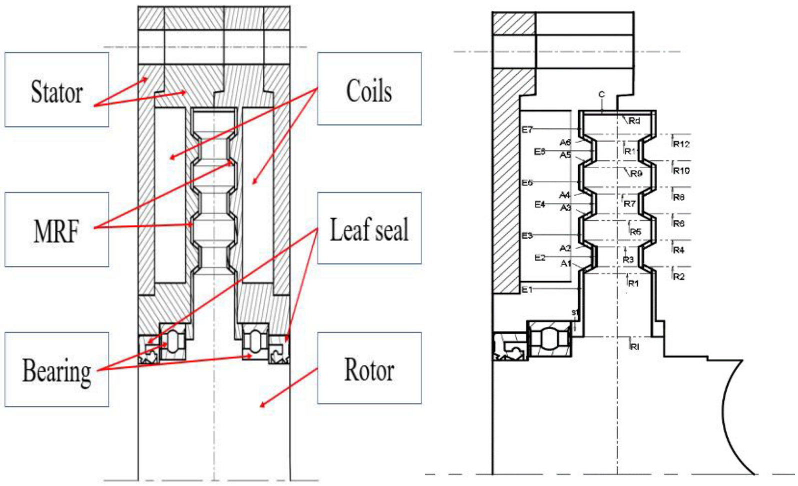

Figure-2. Description of brake structure with MRF.

2.3 MRF 140-CG Oil

LORD Corporation has been working with controllable fluids since the 1980s and is presently the largest global supplier of commercial MR Fluids. Lord currently offers several oils:

- MRF-140CG
- MRF-132DG
- MRF-122EG
- MRF-126LF
- MRF-140BC

Each type of oil has a different type of characteristics, working parameters, and state of operation. In this study, the team used the oil code MRF-140 CG to simulate the results. According to the documentation from LORD, we have the following material parameter value table and its properties (Table-1):

Table-1. MRF 140-CG oil properties.

Typical Properties	
Appearance	**Dark Gray Liquid**
Viscosity, Pa-s @ 40°C (104°F)	0,280 ± 0.070
Density (g/cm^3)	3,54-3,74
Solids Content by Weight, %	85,44
Operating Temperature, °C	-40 to +130

2.4 Simulation Models

In the world, many scholars approach the research problem of optimizing topology and materials using specialized software such as: CATIA, ANSYS Workbench, Hyperworks, AVL [8-9]. In this study, MRB was first built as a CAD model with SIEMENS NX CAD software, then a finite element model with the HYPERMESH tool, and the stability was tested using the Flux solver of Altair Engineering.

C45 steel is the simulation material.

Place two copper coils in the MRB cavity and control the current flowing through the copper wire with a given value.

The finite element model is built with a mesh size of 4 mm, with 337050 nodes and 1496943 elements (9).

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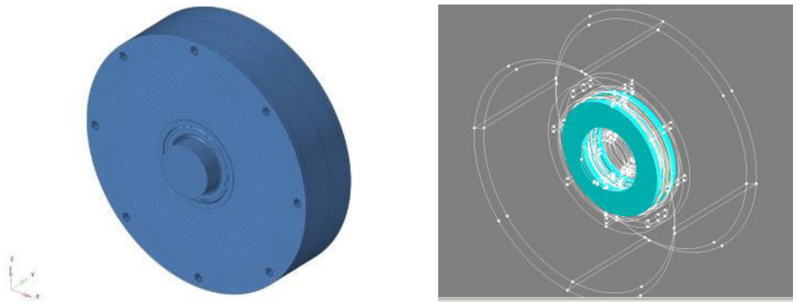

Figure-3. Finite element model of MRB.

The materials used in the MRB model are C45 steel and MRF-140CG oil.

Simulated boundary conditions: Put in 2 coils of brake unit, and apply a DC to 2 coils.

Apply current to the coil, with the corresponding number of turns and amperage applied after referring to some research results:

Table-2 shows the simulation case study:

Table-2. Simulation cases.

	Case 1	Case 2	Case 3
Coil diameter (mm)	0,5	0,6	0,7
Number of turns	1600	1100	800
Current (A)	3,5	5,5	7,5

3. RESULTS AND DISCUSSIONS

Using the Altair Flux solver, the calculated torque output at each area is shown in the table 3:

Table-3. The torque output of the three cases.

Method	Case 1	Case 2	Case 3
Oput torque (Nm)	135,30	144,73	143,74

Applying the formula, one obtains the result of the overall torque produced by the MRB at the operating conditions.

The total torque generated by the MRB with the structure and some working conditions gives a value of about 145 Nm, in which the local torque generated in the Tc region gives the largest value. In general, this value satisfies the initial conditions of the problem when overcoming the torque generated when the vehicle goes downhill.

To create a brake model installed on the van truck, overcoming the problem posed at the beginning of the problem, the research team's results selected the option of 0.6 mm wire, the number of turns: 1100, and the current: 5,5 A to obtain. As a result, the magnetic braking torque generated by the MRB is 144, 73 Nm, which can overcome the torque generated when the vehicle goes downhill.

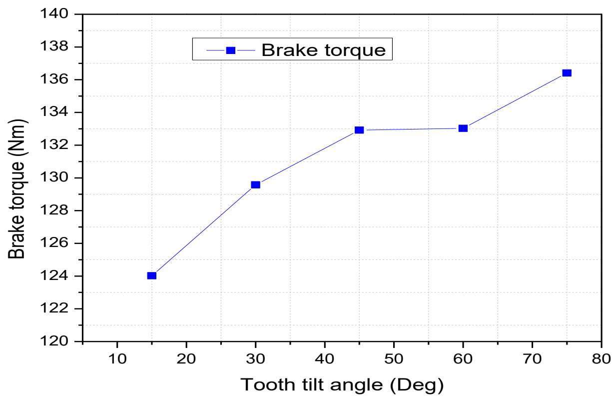

Figure-4. The effect of MRB tooth tilt angle on the brake torque.

Figure-4 shows the influence of the tooth pitch angle on the brake torque. When the pitch angle of the teeth increases from 15 to 75 degrees, the brake torque increases from 124 Nm to 136 Nm. This can be explained by the fact that increasing the angle of inclination will increase the area of influence of the magnetic field strength H on the oil layer. At this time, the oil layer in the inclined tooth area will tend to be parallel to the rotation axis of the rotor disc (horizontal), which is the direction receiving the greatest impact of the H magnetic field vectors.

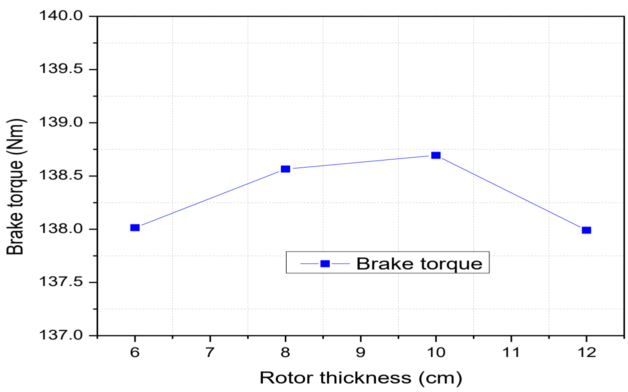

Figure-5. The effect of MRB rotor thickness on the brake torque.

Figure-5 shows that the thickness of the rotor shaft has a negligible effect on the brake torque. When the thickness of the rotor increases from 6 cm to 12 cm, the brake torque increases from 138 Nm to the maximum value and then gradually decreases even though the thickness of the rotor continues to increase. The maximum value of the braking torque achieved is 138.7 Nm at a rotor thickness value of 10 cm. This is because increasing the rotor shaft thickness has little effect on the total working length of the oil layer, as well as the azimuth of the oil layer affected by the magnetic field strength vectors H. Therefore, there is almost no significant change in braking torque in this case.

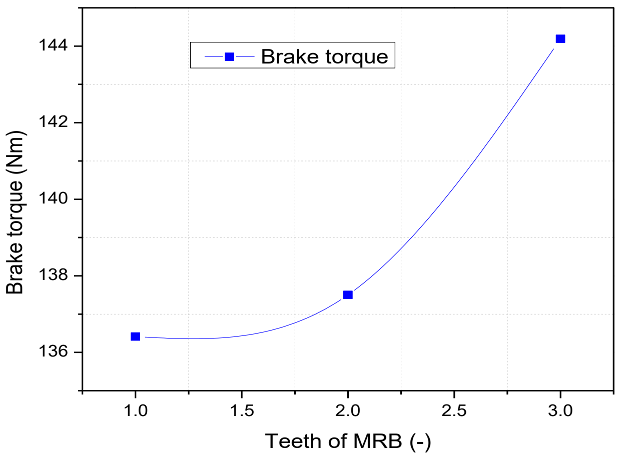

Figure-6. The effect of MRB teeth on the brake torque.

Figure-6 shows the influence of the number of teeth on the brake torque. The brake torque value increases as the number of teeth on the MRB increases. When the number of teeth increases from 1 to 2, the braking torque increases from 136Nm to 137Nm. When the number of teeth increased to 3, the braking torque value reached 144 Nm, an increase of nearly 6%. It is explained that increasing the number of teeth of the MRB will increase the total working length of the MR oil layer. Therefore, the braking torque value will be improved significantly. However, it is also necessary to be careful about increasing the number of teeth in the allowable conditions of actual processing and manufacturing.

4. CONCLUSIONS

In this research, an MRB simulation model was completely established. From the simulation results, the MRB's performance at various operation conditions was investigated. The maximum brake torque value is about 136.41 Nm at the inclination angle of the tooth disk at 75 degrees. The MRB rotor thickness does have not much effect on the brake torque. The maximum brake torque (138.7Nm) can be achieved at 10 cm of rotor thickness. The brake torque increases following the increase in the number of MRB teeth. The brake torque increases by 6% when the number of teeth increases from 1 to 3. The main limitation of the new study is that it only simulates the estimation of the MRB braking torque generated when changing the tooth tilt angle, which has not been experimentally verified. However, it is also the basis for the selection of a ladder-shaped toothed disc structure to be considered in the next research directions of the authors.

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