

Modelling and Simulation of Compression Plate for Magnetorheological Brake

(Model dan Simulasi Plat Mampatan untuk Brek Reologi Magnet)

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Abstract

Magnetorheological (MR) rotary brakes have a high potential to operate and deal with other forms of brakes in the automotive industry. MR brake used an external squeeze mode as an additional device to the traditional mode. Whether for heavy or light vehicles, brakes were no longer a small issue whereas it became a crucial problem to maintain safety and to avoid unpredictable cases especially on roads. The conventional hydraulic brake system had a limitation on certain issues including delayed response time, bulky size, heavyweight, brake pad wear and low performance at high speed. This project aims to fabricate the compression plate for the MR brake and to increase the force at the compression plate of Magnetorheological Brake between 10%-20%. Hence, alloy steel 1010 was used to simulate the prototype of a compression plate. Cutting process, drilling and grinding processes were applied in this project. The optimal results were obtained by implementing the Finite Element Method (FEM) and Solidworks 2020 software into the parameter analysis. For conclusion, our initiative met its primary goal of increasing the pressure on the compression plate by 10% to 20%. The additional pressure on the compression plate will aid in improving braking performance.

Keywords: Magnetorheological brake, Design, Compression plate

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INTRODUCTION

The braking system is one of the most important active safety systems for reducing injuries and property damage in a vehicle. The earliest systems to slow a vehicle's momentum and prohibit motion were tested in the 1800s. After more than a century, the braking system has evolved into a complicated technology that can respond to various road conditions. Brake system innovation has enhanced safety and lowered the danger of car crashes across Canada and the world, from early drum brakes to modern disc brakes. It's difficult to pinpoint the designer of the first braking system because there have been so many variations throughout the years; yet, those who created these systems all had the same purpose in mind: to allow people to manage a motor vehicle. To create safer conditions, innovators over the years have brought new technologies to the braking system, improving upon this original idea (Did You Know Cards (n.d.)). The advancement of brake systems began in the nineteenth century and continues now. The wooden block brake seen in Figure 1 is one of the many types of braking systems that have been employed over the years.

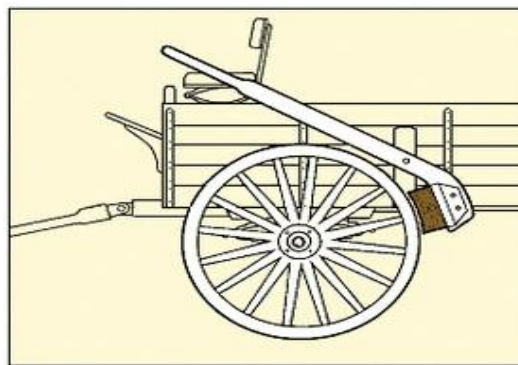


Figure 1. Wooden block brake Did You Know Cards (n.d.)

The first braking system used the same physical concepts that are used today to construct brakes, but it only consisted of wooden blocks and a single lever that the driver used to apply the brake. Vehicles with steel-rimmed wheels, such as horse-drawn carriages and steam-powered autos, were fitted with this design. The mechanical drum brake was conceived by Gottlieb Daimler and refined by French manufacturer Louis Renault in 1902. It is considered the foundation of the contemporary braking system. Daimler proposed that anchoring a cable-wrapped drum to a vehicle's chassis could be used to stop the momentum, resulting in the first drum brake concept such as in Figure 2 (Park, Da Luz, Suleman, 2008).

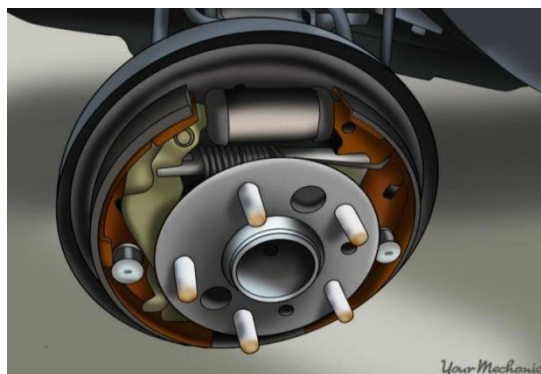


Figure 2. Mechanical drum brake (Park et al., 2008).

Malcolm Loughead first presented the idea of a four-wheel hydraulic brake system in 1918. When a pedal was pressed, fluids were employed to deliver force to the brake shoe. By

the late 1920s, practically every automobile had incorporated this braking mechanism (Park, et al., 2008).

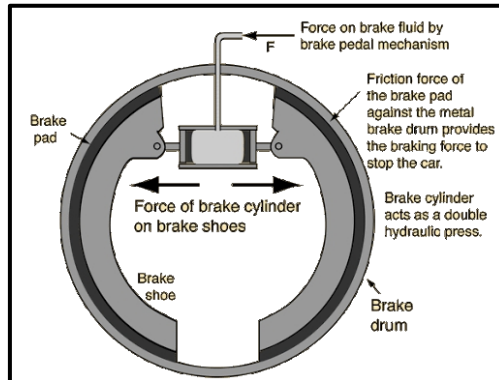


Figure 3. Hydraulic brake (Park, et al., 2008)

In 1902, the disc brake was created. The rise of disc brakes as a popular alternative can be related to the weight and speed capabilities of cars, which led hydraulic brakes to lose efficiency in transferring heat. The Chrysler Imperial was the first vehicle to use disc brakes, and it included both disc and hydraulic features as shown in Figure 4.



Figure 4. Disc brake (Amazon, 2021; Park, et al., 2008)

The anti-lock brake system (ABS) was developed to help previous braking systems prevent the brakes from locking up while in use. ABS detects when a lock is going to happen and activates a series of hydraulic valves to lessen the pressure of a single wheel's brake. The technique has altered the way brakes work and allows modern drivers to have more control (Did You Know Cards, n.d.; Park, et al., 2008).

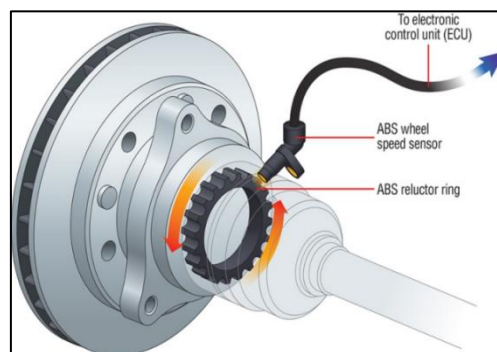


Figure 5. Anti-lock brake (Did You Know Cards, n.d.; Park, et al., 2008)

Brakes, whether on large or light vehicles, are no more a minor issue; they have evolved into a critical issue for maintaining safety and avoiding unanticipated situations,

particularly on roadways. Certain limitations of traditional hydraulic brake systems include delayed response time, bulky dimensions, heavyweight, brake pad degradation, and low performance at high speeds (Gred & Partnets, 2021; Ismail, Mazlan, Zamzuri & Olabi, 2012).

Latest, with the use of magnetic simulation, the Magnetorheological (MR) brake was built with a novel notion of braking mechanism in consideration. When a magnetic field is applied, Magnetorheological (MR) fluid transforms from fluid to semi solid continuously and reversibly in a matter of milliseconds. When electricity is applied to the braking system, the fluid transforms a lot of particles into strong parallel chains (fibrils) made up of thick clusters, resulting in a semi solid fluid. Because the current technology is easy to integrate, there are various advantages of employing MR brake. Based on these advantages, MR brakes appear to be the optimal braking system option. Commonly shear mode is used in designing the MR brakes but combining the shear and squeeze mode are recently studied. In this paper, our objective is to design a new compression plate for magnetorheological brake by using Autodesk Inventor 2021 Software and conduct an analysis on the compression plate to study the pressure increase by using Solidworks 2020 Software (Ismail et al., 2012).

METHODOLOGY

The development of the prototype for the compression plate undergoes a few steps. The most crucial step was a discussion session with our supervisor about the design of the compression plate. After the design had been decided, the next step was to design the compression plate by using Autodesk Inventor Professional 2021. The next step was obtaining the materials for the fabrication of the prototype. Next, we conducted the simulation by using Solidworks Software 2020 to obtain the result. After the optimum result had been obtained, we proceed with constructing the report based on the result that has been obtained. This development of the prototype of the compression plate is based on the flowchart in Figure 2.

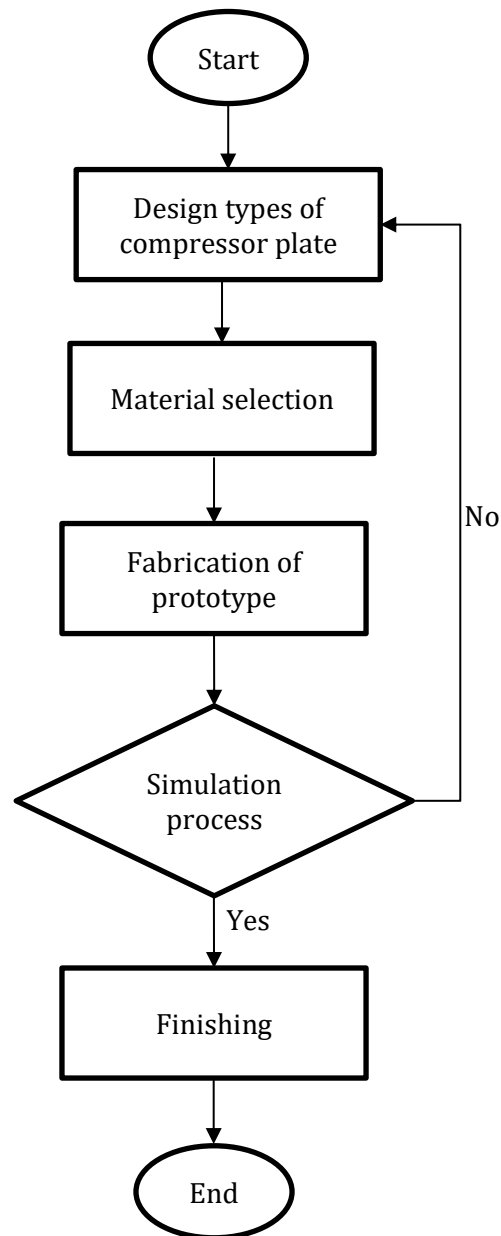


Figure 6. Flow chart for fabrication of compression plate

DESIGNED OF COMPRESSION PLATE

The design of the compression plate is a critical process due to ensuring that the fluid coming out and could optimize the magnetic flux path. High pressure in the MR area gave a high compression to the particle to increase the flux intensity, which is introduced to the MR fluid by minimizing the flux path length. Therefore, various sketches had been developed and the final design was selected based on the simulation result as shown in Figure 7, 8 and 9.

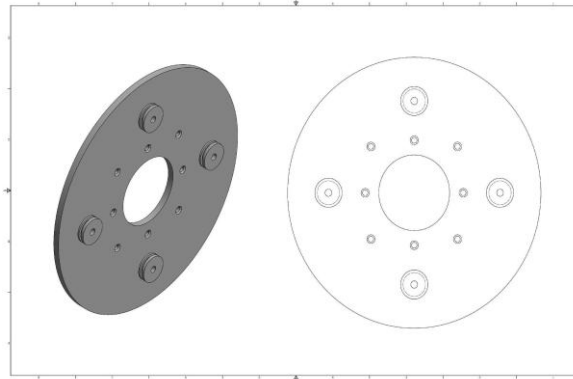


Figure 7. Design of compression plate 1

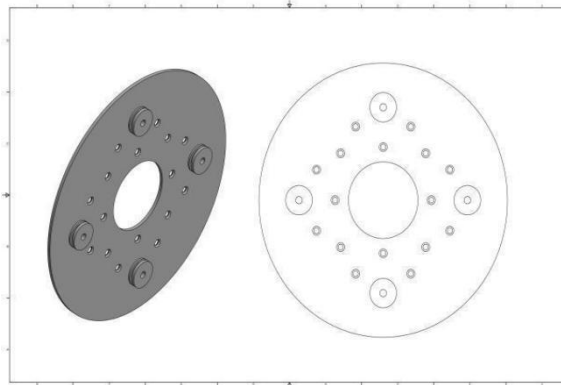


Figure 8. Design of compression plate 2

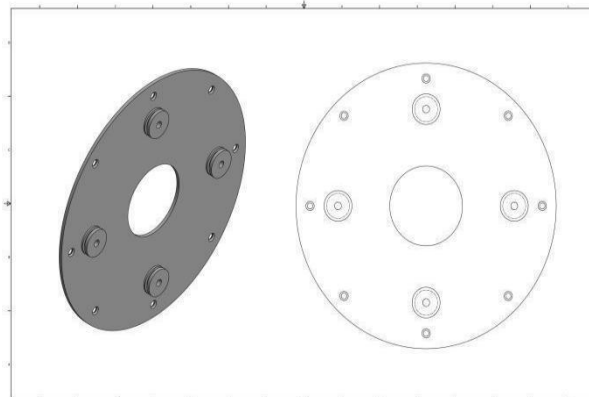


Figure 9. Design of compression plate 3

The process in designing the compression plate for Magnetorheological brake was by using Autodesk Inventor 2021 software as Figure 10. Overview of the exact position of the compression plate is in a red colour in the figure below.

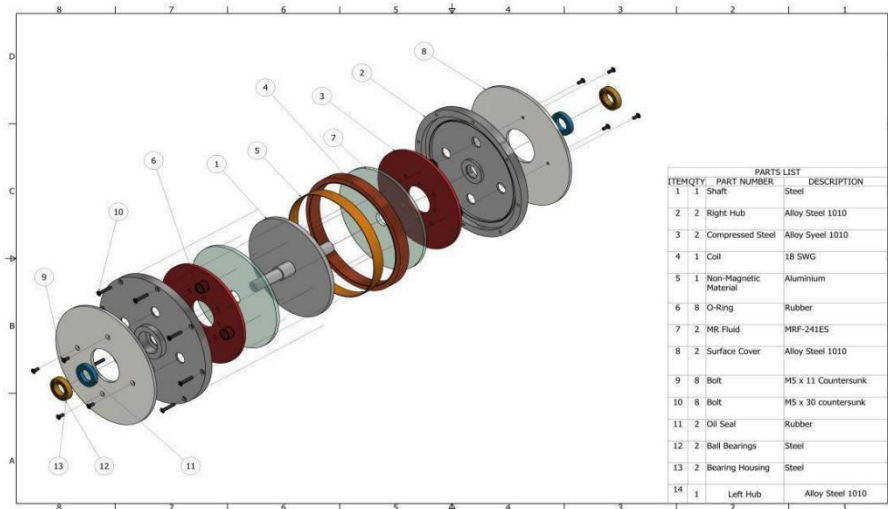


Figure 10. Exploded view of Magnetorheological brake

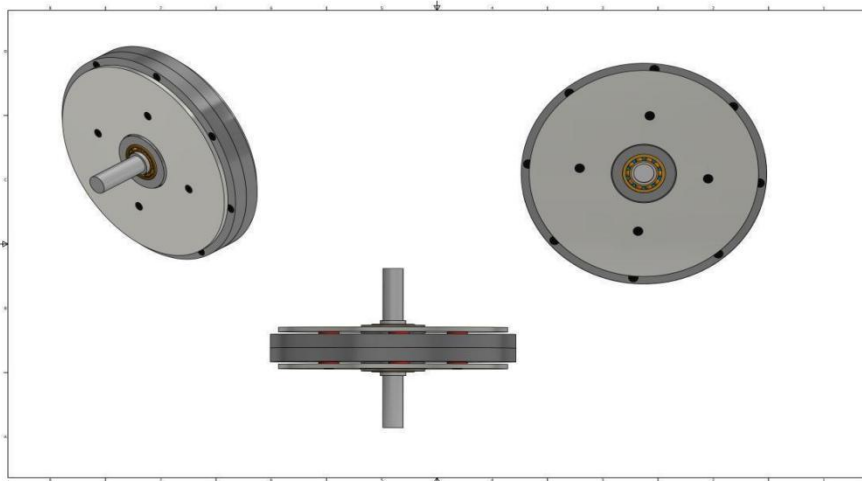


Figure 11. Final design for Magnetorheological brake

FABRICATION OF PROTOTYPE

Subsequently, the fabrication for the prototype of the compression plate involved three fabrication processes. The first process is the cutting process. A metal sheet is cut into a few pieces according to the desired measurement by using a hydraulic sheet cutting machine (Figure 12).



Figure 12. Cutting metal sheet

The drilling process was done after the cutting process was completed. The cut metal sheet was marked according to the position of the hole based on the compression plate that had been designed by using Autodesk Inventor 2021 software. A hole was made on the metal sheet and 4mm drill bit was used to drill the metal sheet by using a drilling machine (Figure 13).



Figure 13. Drilling process

After the drilling process was completed, the next process was the grinding process. The purpose of the grinding process was to remove access materials from the workpiece. The final step was to level out the rough edges of the workpiece via grinding wheels (Figure 14).



Figure 14. Grinding the workpiece

RESULT & DISCUSSION

MAGNETORHEOLOGICAL FLUID

MR fluids were suspensions of micron-sized magnetizable particles in a non-magnetic carrier fluid such as oil or water and smart material. Jacob Rabinow of the US National Bureau of Standards developed the MR fluid effect in the 1940s. As indicated by Imaduddin et al., the capacity to transition from a fluid flowing condition to a solid like state in the presence of a magnetic field boosted this fluid's stability and lifespan for commercial applications (Gred & Partnets, 2021; Ismail, Mazlan, Zamzuri & Olabi. 2012). The capacity of a fluid to transition from a flowing condition to a solid-like state in the presence of a magnetic field, which improved this fluid's stability and durability for commercial applications. The selection of MR fluid is an important factor to obtain the largest magnetic field strength and ensure that the design of the MR brake obtained the highest torque to act as braking components. Different types of MR fluid which are MRF-140CG, MRF-241ES

and MRF-132DG have been analyzed to get the highest magnetic flux density (Figure 15) (Hamdan, Mazlan, Sarip, & Zamzuri, 2014; Hamdan, Mazlan, Sarip, Zamzuri, & Rahman, 2014; Hung Nguyen, Diep Nguyen, & Bok Choi, 2015).

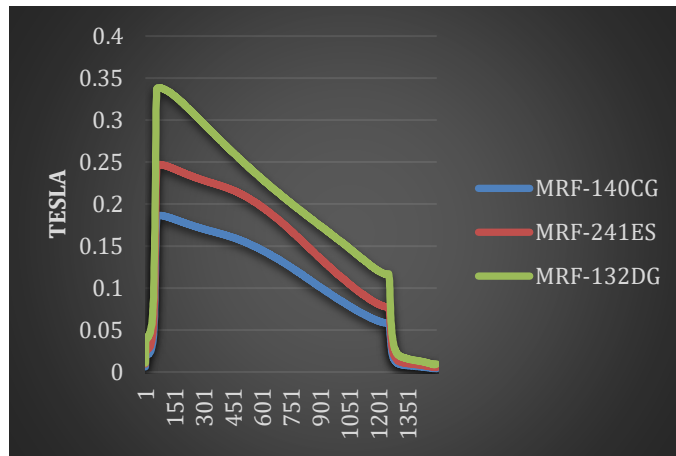


Figure 15. Different types of MR fluid

The MR brake rotary disc's design necessitates a high viscosity MR fluid to react with the rotor and respond to the high rotating speed differential. Table 1 compares the parameters of the three major types of magnetic resonance fluids. The MRF-140CG had high viscosity and meet the requirements to be used on the brake, as shown in the table.

Table 1. The comparison of properties for MR fluid

Properties	MRF-140CG	MRF-241ES	MRF-132DG
Type of fluid	Hydrocarbon-based	Water-based	Hydrocarbon-based
Viscosity (Pa-s)	0.280 ± 0.070	10.8 ± 1.5	0.112 ± 0.02
Density (g/cm ³)	3.54 - 3.74	3.80 - 3.92	2.95 - 3.15
Solid content by weight (%)	85.44	85.00	80.98
Operating temperature (°C)	-40 to +130	-10 to +70	-40 to +130

COIL CONFIGURATION

Depending on the coil's position, size, diameter, and the number of turns, coil wire selection is one of the elements to consider. In this study, 30 AWG coils produce the maximum magnetic flux density when compared to other coil types (Figure 16) (Hamdan et al., 2014; Hamdan et al., 2014; Hung Nguyen et al., 2015; Sarkar & Hirani, 2013; Satyajit & Suresh, 2018).

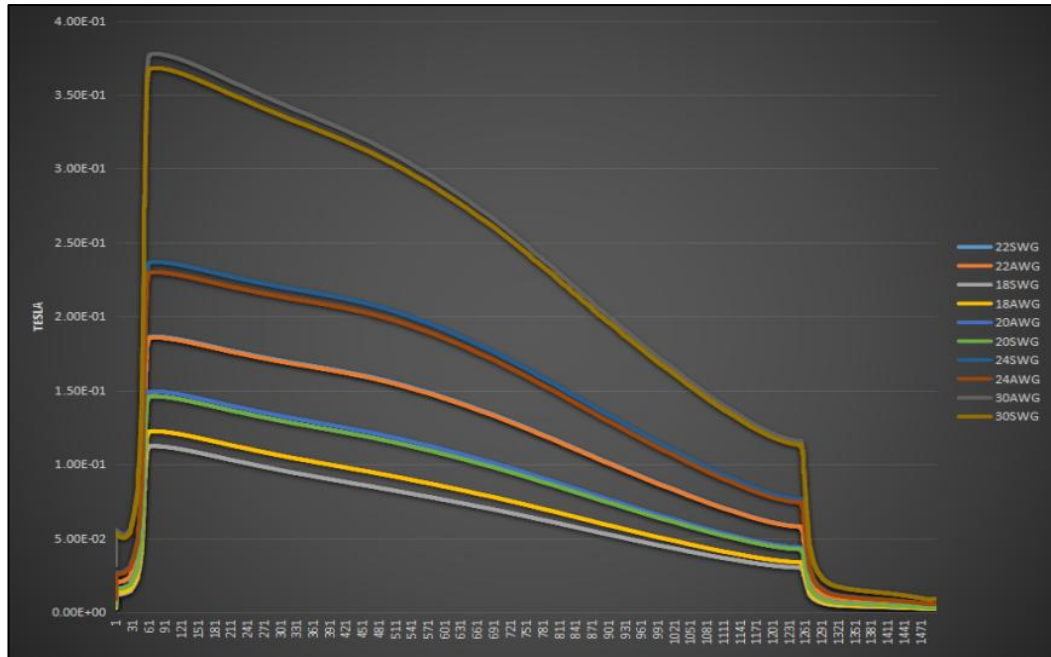


Figure 16. Different types of coil

COMPRESSION PLATE

A compression plate was a component in Magnetorheological that functions as a squeeze plate. This compression plate will compress the MR fluid that had changed its state from liquid to semi solid against the rotating rotor to produce a braking torque (Hung Nguyen et al., 2015). An analysis using Solidworks 2020 had been conducted on the new design of the compression plate in order to obtain the highest pressure produced by the compression plate. In this analysis, the same normal braking pressure that is 50 bar, was applied on all designs of the compression plate.

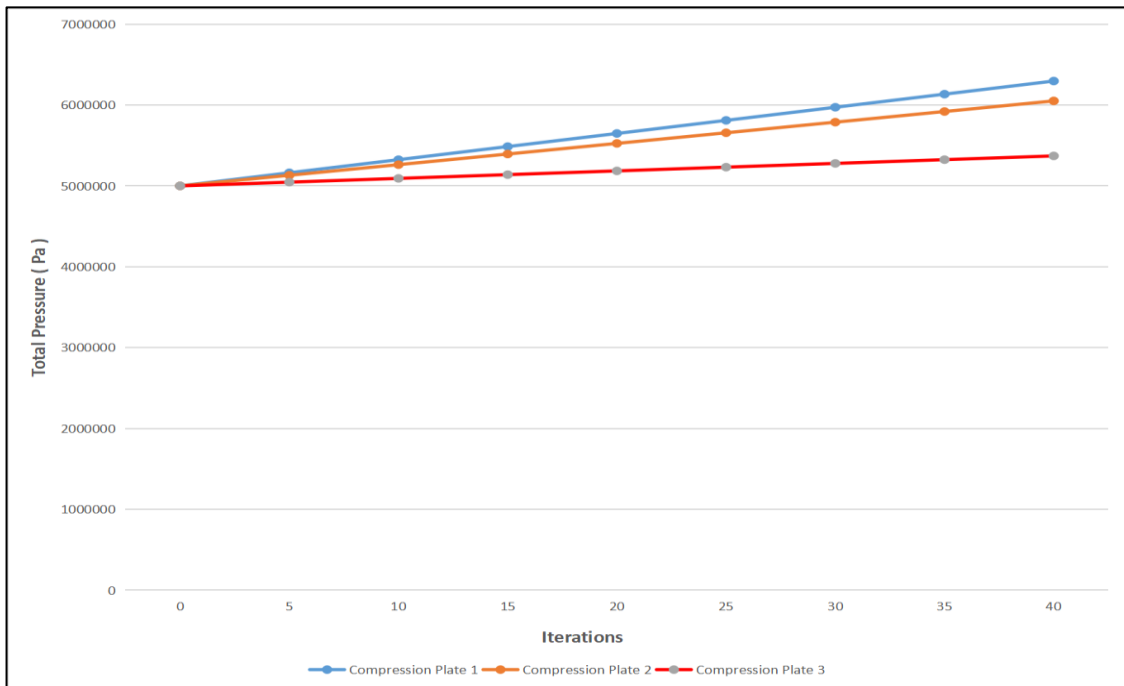


Figure 17. Total pressure for different types of compression plate

Based on the analysis that had been conducted, compression plate 1 (Figure 18) produced the highest pressure that is 6296750 Pa, and compression plate 3 produced the lowest pressure with 5370800 Pa. Compression plate 1 produced 17.240% more pressure compared to compression plate 3.

$$6296750 \text{ Pa} - 5370800 \text{ Pa} = 925950 \text{ Pa}$$

$$(925950 \div 5370800) \times 100\% = 17.240\%$$

Therefore, compression plate 1 as Figure 18 was chosen for the final design of compression plate for Magnetorheological (MR) brake that would help to improve the braking performance.

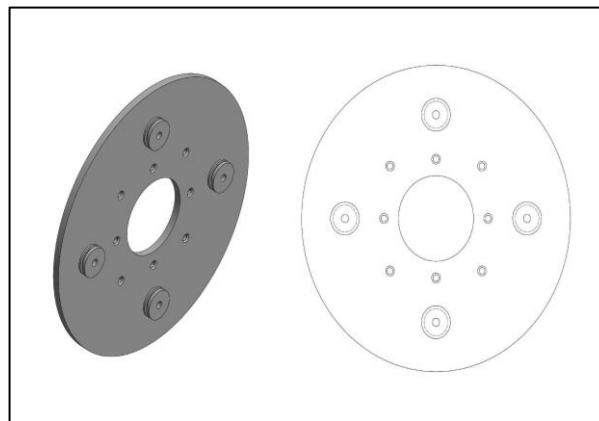


Figure 18. Final Compression plate (Design 1)

CONCLUSION

In conclusion, our project had achieved our main objective was to increase the pressure on the compression plate between 10% to 20%. The increment pressure on the compression plate would contribute to the improvement of brake performance. Therefore, this will contribute to automotive industries to create more efficient and high performance braking systems in the future.

Our recommendation for this project is to fabricate the actual Magnetorheological brake with the new compression plate design. By fabricating the actual Magnetorheological brake with a new compression plate design, we can run a study on the compression plate and compare the results that have been obtained by using SOLIDWORKS 2020 software. By doing this kind of study, we can see the actual result and make a test in the Magnetorheological brake to see how it performs in a real situation when the brake is applied.

REFERENCES

- Did You Know Cards (n.d.). The History of Brakes. Retrieved from <https://didyouknowcars.com/the-history-of-brakes/>.
- Park, E. J., Da Luz, L.F., & Suleman, A. (2008). Multidisciplinary design optimization of an automotive magnetorheological brake design, *Computer Structure*, 86, 207-216.
- Gred, M. & Partners (2021). Evolution Brake Systems. Retrieved May 02, 2021, from <https://www.gregmonforton.com/windsor/car-accident-lawyer/car-safety-evolution/evolution-brake-systems.html>.

- Ismail, I., Mazlan, S. A., Zamzuri, H., & Olabi, A-G. (2012). Fluid-Particle Separation of Magnetorheological Fluid in Squeeze Mode. *Japanese Journal of Applied Physics*, 51(6R), [067301].
- Hamdan, L. H., Mazlan, S. A., Sarip, S., & Zamzuri, H. (2014). A New Concept of Multimode Magnetorheological Brake Design. *Key Engineering Materials*, 605, 271-274.
- Hamdan, L. H., Mazlan, S. A., Sarip, S., Zamzuri, H., & Rahman, M. A. A. (2014). Selection of Materials in Designing Magnetorheological Brake. *In Applied Mechanics and Materials*, 663, 700-704.
- Hung Nguyen, Q., Diep Nguyen, N., & Bok Choi, S. (2015). Design and evaluation of a novel magnetorheological brake with coils placed on the side housings. *Smart Materials and Structures*, 24(4), 047001.
- Sarkar, C., & Hirani, H. (2013). Design of a squeeze film magnetorheological brake considering compression enhanced shear yield stress of magnetorheological fluid. *Journal of Physics Conference Series*, 412(1):2045-2057
- Satyajit R. P. & Suresh M. S. (2018). Experimental Studies on Magnetorheological Brake for Automotive Application. *International Journal of Automotive and Mechanical Engineering*, 15(1). 4893-4908.