NATIONAL INSTITUTE OF TECHNOLOGY CALICUT

Department of Mechanical Engineering

SEMINAR TOPIC :

MR FLUIDS AND ITS APPLICATIONS

— **Project Guide** : Dr. JAGADEESHA T , ASSOCIATE PROFESSOR , MECHANICAL DEPARTMENT , NITC

— **Presented by** : SHRISTY SHARMA , B221211ME ,NITC

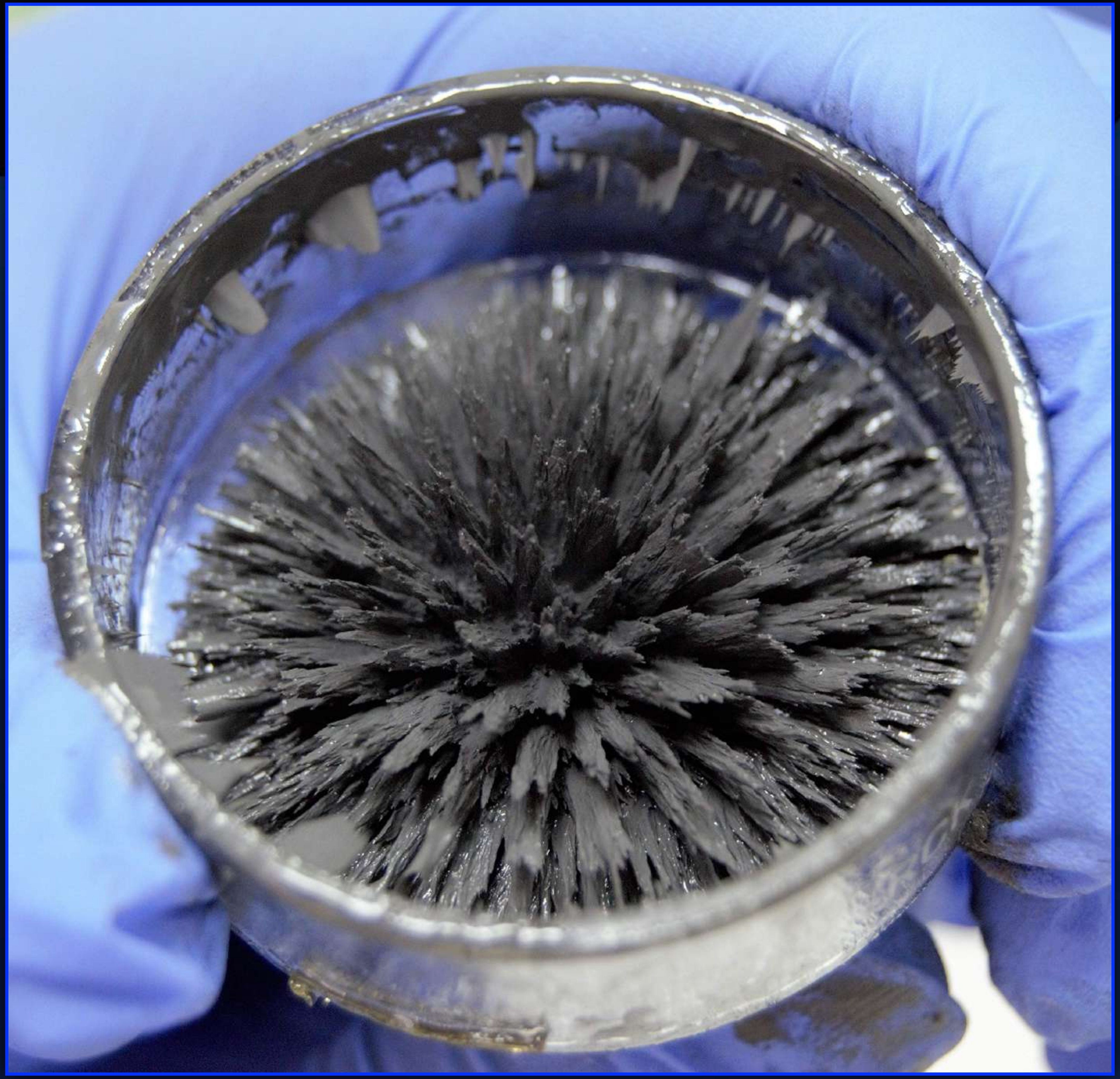
CONTENT :

Introduction

1. WHAT ARE MRF'S ?

- Magnetorheological fluids (MRFs) are smart materials with magnetic particles in a carrier fluid, whose viscosity changes under a magnetic field.

- Viscosity increases, with application of magenatic field ,and thus becomes a viscoelastic solid.It is a Newtonian fluid in off state and Non - Newtonian fluid in on state .



2. WHAT ARE THE APPLICATIONS OF MR FLUIDS ?

- Automotive Industry (MR Brakes)
- Robotics and haptics
- Aerospace and Defence
- Biomedical Engineering

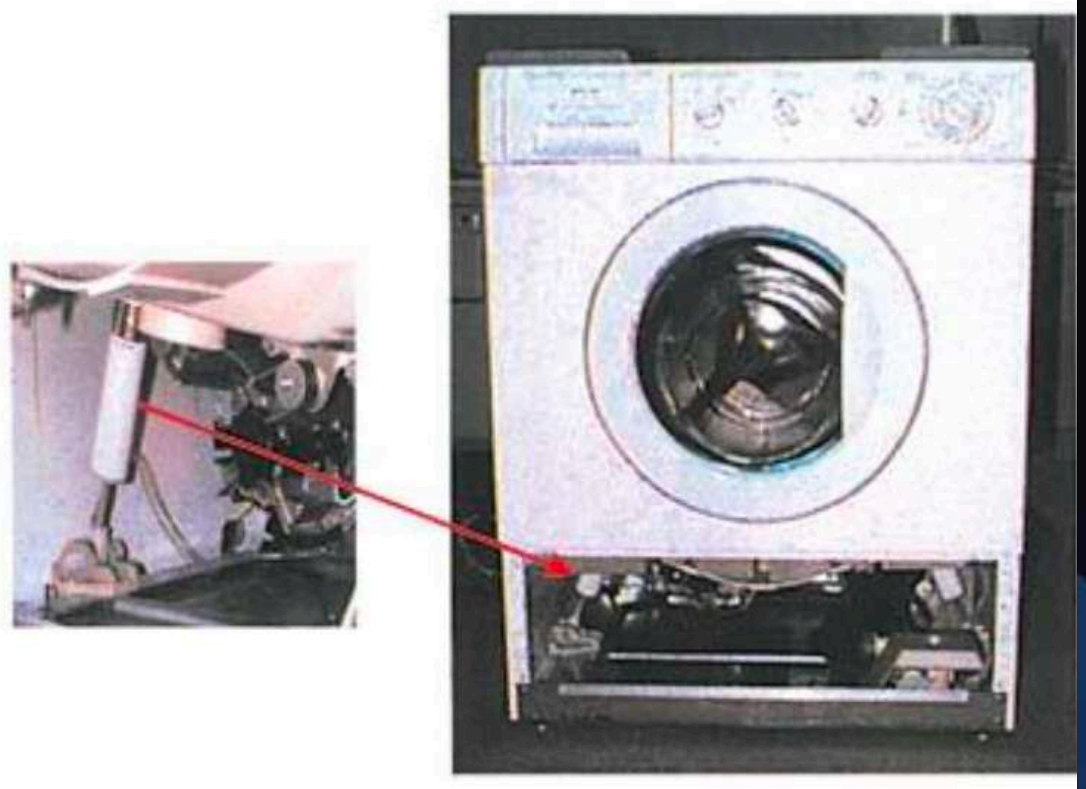


Fig.8: MR Fluid dampers in Washing Machine

MR fluids to reduce Gun recoil

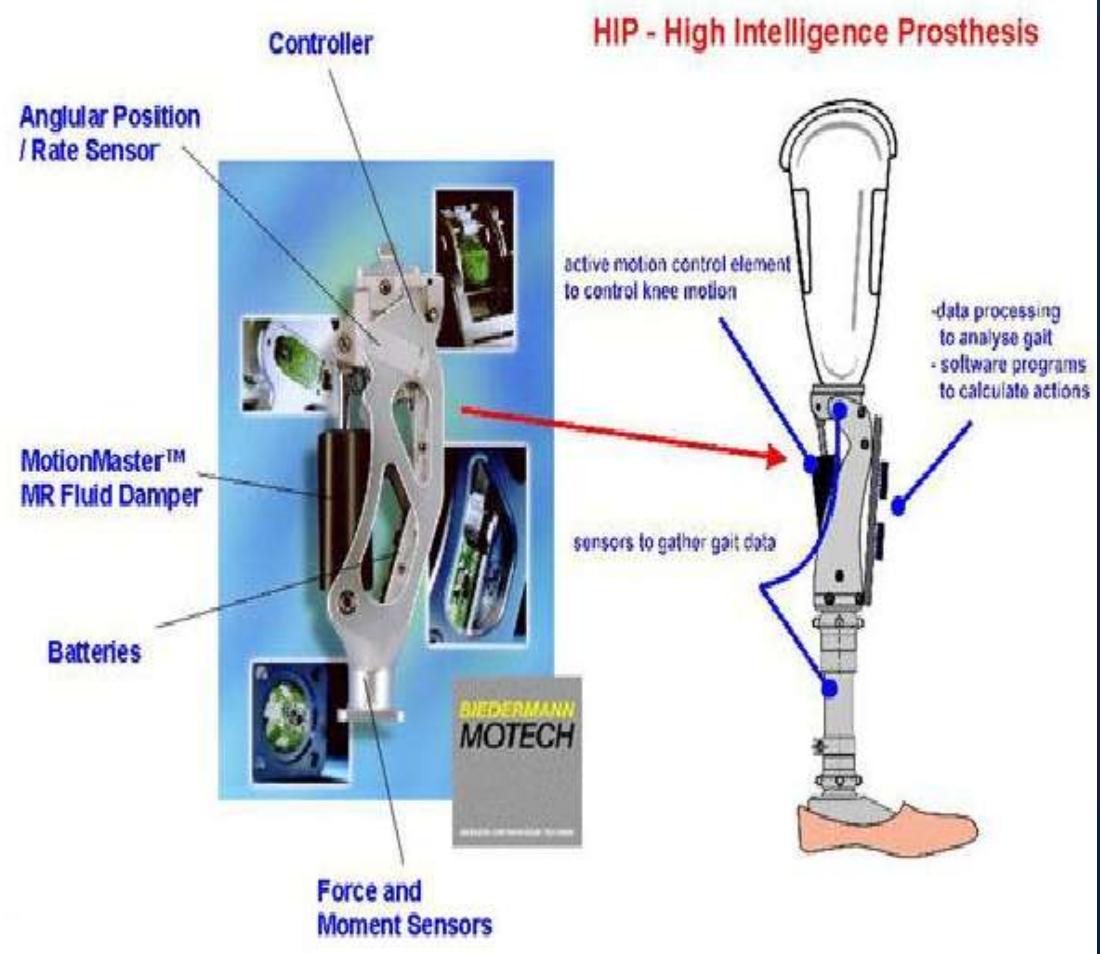


Figure 10- Application in Prosthetic Leg

MR Seisemic Damper

3. BUT WHY TO USE MR BRAKES ?

- Fast Response Time
- Variable Braking Torque
- Compact & Lightweight
- Reduce maintenance

4. CHALLENGES IN MR BRAKE DESIGN

- Torque Limitations
- Complex Manufacturing
- To address these issues, researchers proposed a new MR brake design with enhanced performance and simplified manufacturing.

MR Brakes

LITERATURE REVIEW

Main journal paper :

AUTHOR	TITTLE	REVIEW
Yousef Bazargan-Lari (2018)	**Design and shape optimization of MR brakes using Nelder–Mead optimization algorithm**	Bazargan-Lari (2019) investigates the **design and optimization of Magnetorheological (MR) brakes using the Nelder-Mead algorithm**.In the present study, FEM was employed in order to propose a new MR brake. The numerical procedure was validated by the available data in the literature. Then, different models were simulated and the most ef cient ones was selected. This model was also optimized using Nelder–Mead optimization algorithm. Increasing the number of immersed disks in the MR fluid not necessarily enhances braking effciency and the MR fluid gap dimensions should be also determined precisely.The proposed magnetic torque in the literature **(125.06 N m)** could be generated by the present configuration with half of the coil current which was used previously.

Other references :

AUTHOR	TITTLE	REVIEW
R. Siti Lydia1,*, *R.*Mokhtar1, *A.B.* Muhamad Husaini1 and *B.J.* Norhaniza1 (2017)	Design and development of coil casing MRF brake system	**Lydia et al. (2017)** studied the effect of coil casing shape on magnetic field distribution in Magnetorheological (MR) brakes.FEMM is the software is a solver to solve the governing equation for magnetic field distribution inside the domain. From the experiment above five different angle of design has been analysis using the FEMM. As the result, the good range for the electromagnet body design is between **50° to 70°.** If the design goes far than that the value of the magnetic field will be drop. As shown on graph 1. Although the supply current been manipulated, the **70° design still give the high value up to 1.31275 Tesla at 2.5 ampere.**

Other references :

AUTHOR	TITTLE	REVIEW
C Sarkar and H Hirani (2013)	**Design of a squeeze film magnetorheological brake considering compression enhanced shear yield stress of magnetorheological fluid**	**Sarkar and Hirani (2013**) propose a squeeze film Magnetorheological (MR) brake that enhances braking torque using compression-enhanced shear yield stress. Theoretical calculations estimate 600 Nm torque for a six-plate design. A **prototype single-plate MR brake was developed and tested at different currents** (0–1.25A). Results confirm higher torque generation under compression compared to shear mode alone.A squeeze film MR brake for high torque application is designed and manufactured. Performance of the prototype MR brake is studied using MRF 241ES both theoretically and experimentally. Experimental transient torque analyses show that squeeze film MR brake **generates 7 Nm torque for input current of 1.25A** which is applicable for high torque application.

Aims /Objectives /Scope

Aim : Improve braking efficiency through shape optimization.

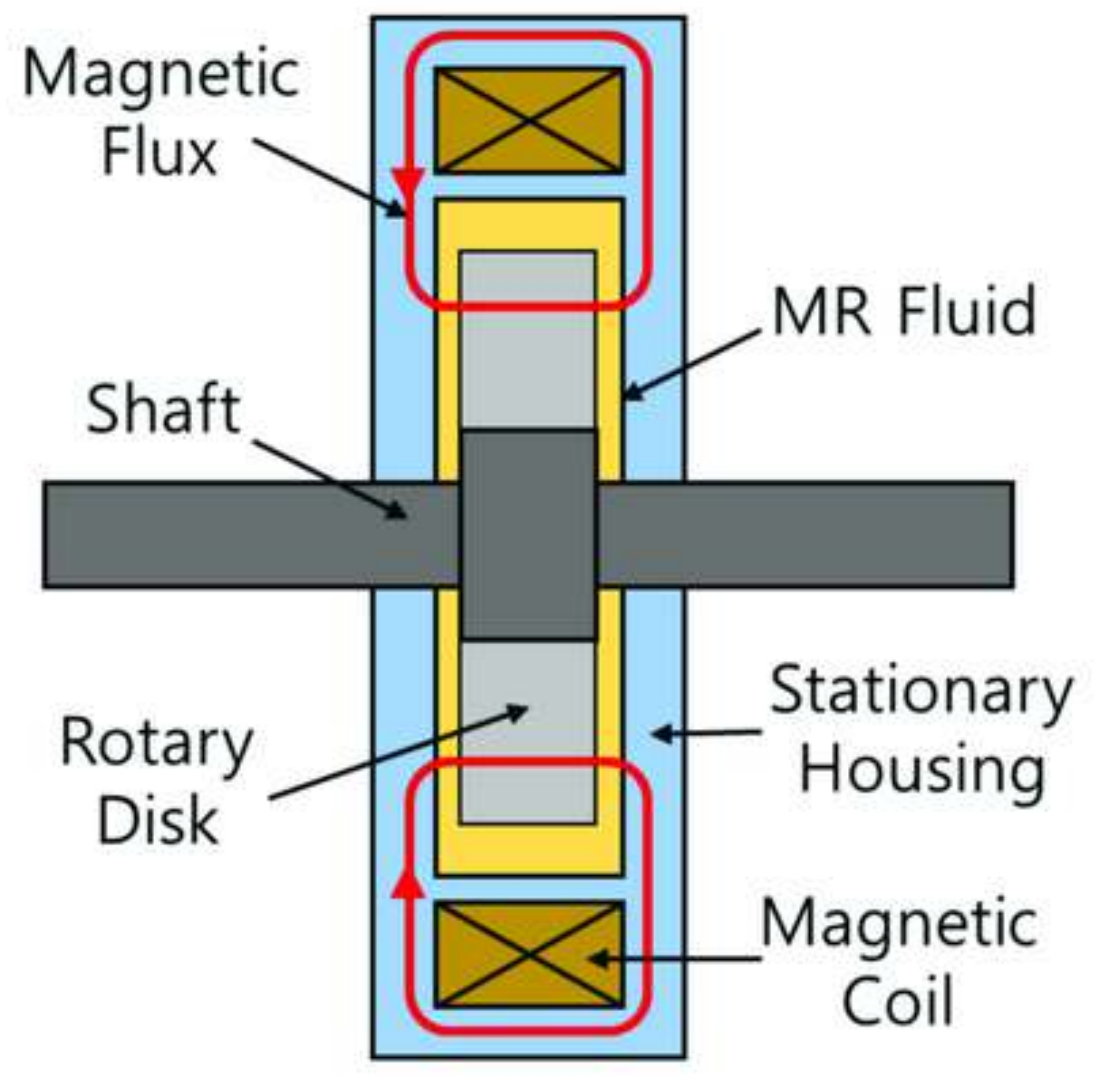
- The key variables include:
  - MR fluid gap size
  - Number of brake disks
  - Magnetic coil current
  - Brake disk geometry (thickness, diameter, and shape)

Objectives : The objective is to enhance the braking torque of MR brakes while minimizing power consumption and simplifying the design.

Scope : Focuses on improving braking torque and manufacturability

Methodology

- MR brakes consisted from an immersed disk in an MR fluid within an enclosure and the magnetic field was induced around the MR fluid by a coil.When the brake operated, the magnetic field led to changing the MR fluid to semi-solid condition. Consequently, yield stress and shear friction were increased on the disk surface and reduced the speed



(a)

- Material Selection : Stainless steel and MRF-132DG

Table 1. MRF-132DG properties [28].

Property	MRF-132DG
Base fluid	Hydrocarbon
Operating temperature	−40 to 130 °C
Density	3.09 g/cc
Viscosity	0.09 (±0.02) Pa s
k	0.269 Pa m/A
β	1

- Bingham plastic model

$$\tau = \tau_y(H) + \mu_p \dot{\gamma}$$

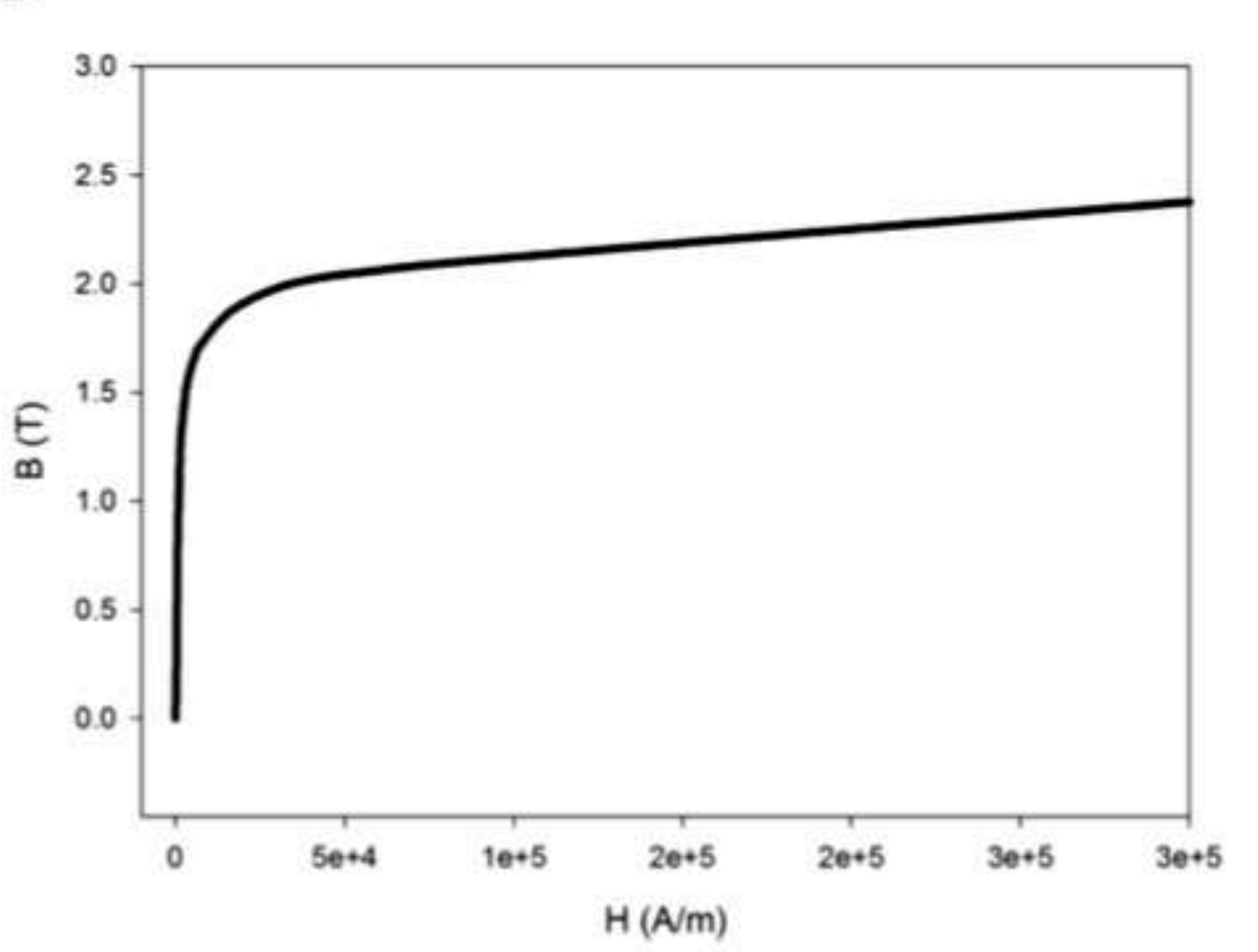
- Shear - strain rate

$$\dot{\gamma} = \frac{r\omega}{\delta}$$

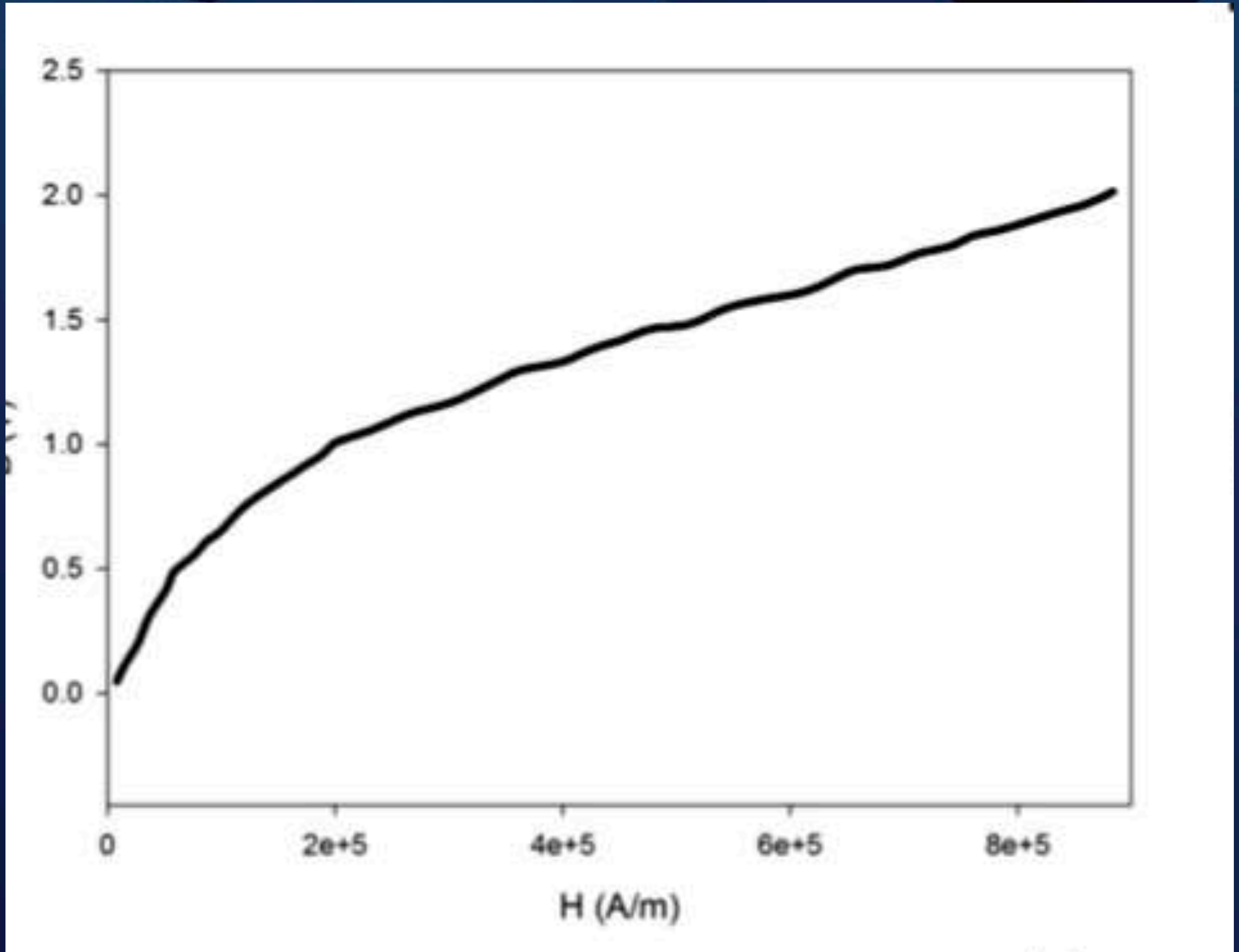
- yield stress is a function of magnetic field strength (H) and is modeled as:

$$\tau_y(H) = kH^{\beta}$$

- B-H CURVE : steel 1018



B-H CURVE : MRF-132DG



- Magnetic field:

$$\nabla \times \mathrm{H} = \mathbf{J}$$

$$\mathbf{B} = \mu_0 \mu_r \mathrm{H}$$

- MR brakes generate torque based on shear stress (τ) and yield stress (Ty) of the MR fluid.The total torque **T** is calculated using the equation:

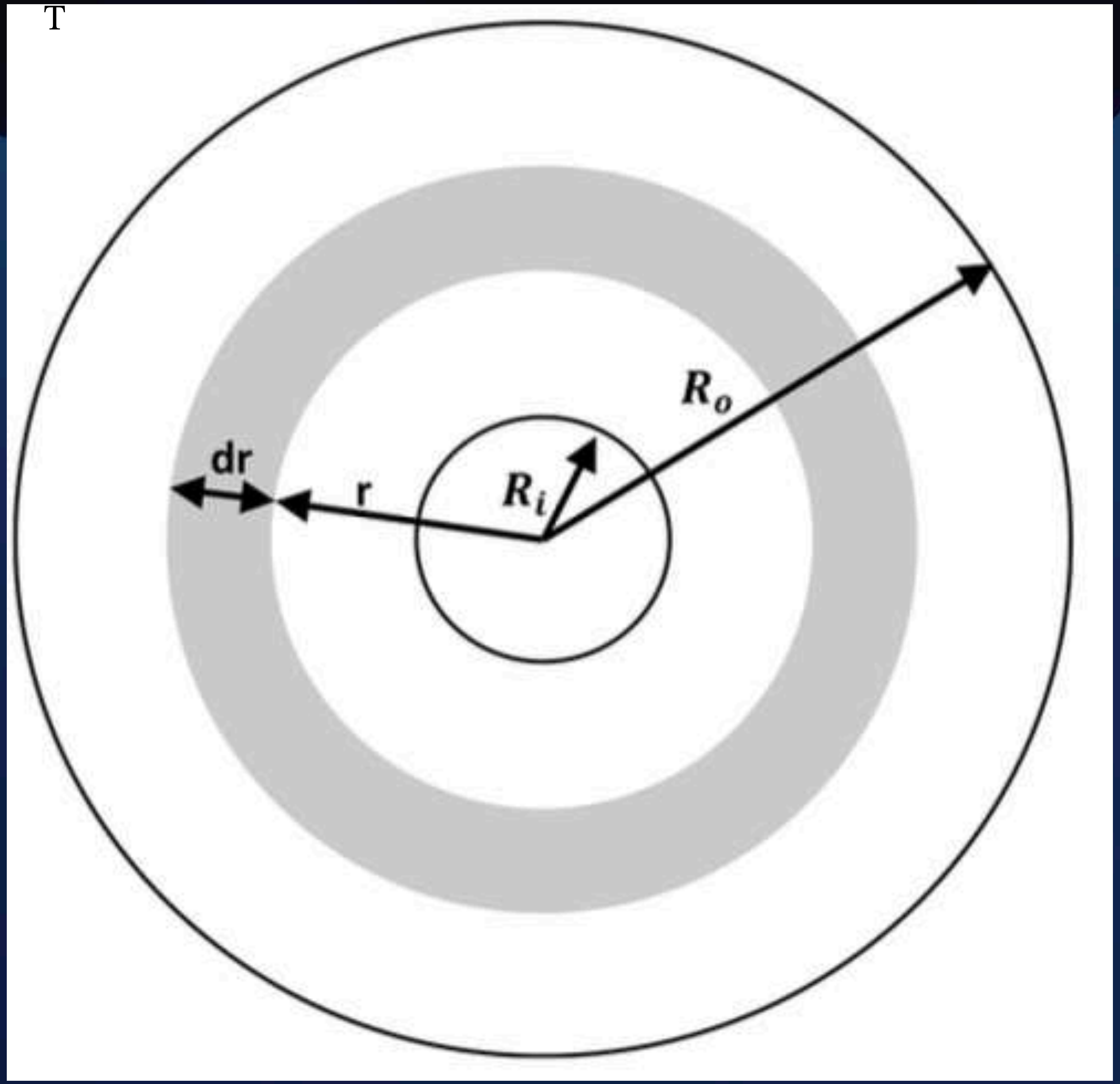
$$\mathrm{T} = \int r\tau dA = 2\pi n \int_{R_i}^{R_0} r^2 \tau dr$$

$$T_m = 2\pi n \int_{r_i}^{r_0} kH^{\beta} r^2 dr$$

$$T_\eta = \frac{\pi}{2\delta} n\mu_p \omega (R_0^4 - R_i^4) + \pi n R_0^2 \tau_\eta t.$$

MR Surface element on the disk for integration of shear stress

T



Optimization Using Nelder-Mead Algorithm :

1. Initialization:
    - Define initial brake designs (disk shape, fluid gap, coil current).

2. Sorting & Centroid Calculation:
    - Rank designs based on braking torque.
    - Compute centroid of best-performing designs.

3. Transformation (Iteration Process):
    - Reflection: Adjust worst design towards better solutions.
    - Expansion: Further improve if reflection succeeds.
    - Contraction: Reduce search area if needed.
    - Shrinkage: Refine designs for optimal parameters.

4. Convergence:
    - Iterations continue until torque is maximized.

Results & Discussions

1. Higher Braking Torque
   - Achieved 215.75 Nm, a 73% increase over the previous 125.06 Nm.

2. Lower Coil Current
   - Required half the previous current, improving energy efficiency and reducing heat.

3. Optimized MR Fluid Gap
   - Enhanced magnetic field distribution, maximizing torque output.

4. Disk Number Optimization
   - More disks did not always improve performance.
   - Two MR fluid gaps provided the best efficiency.

5. Simplified Manufacturing
   - Eliminated separator, requiring only two simple cuts, reducing fabrication time and costs.

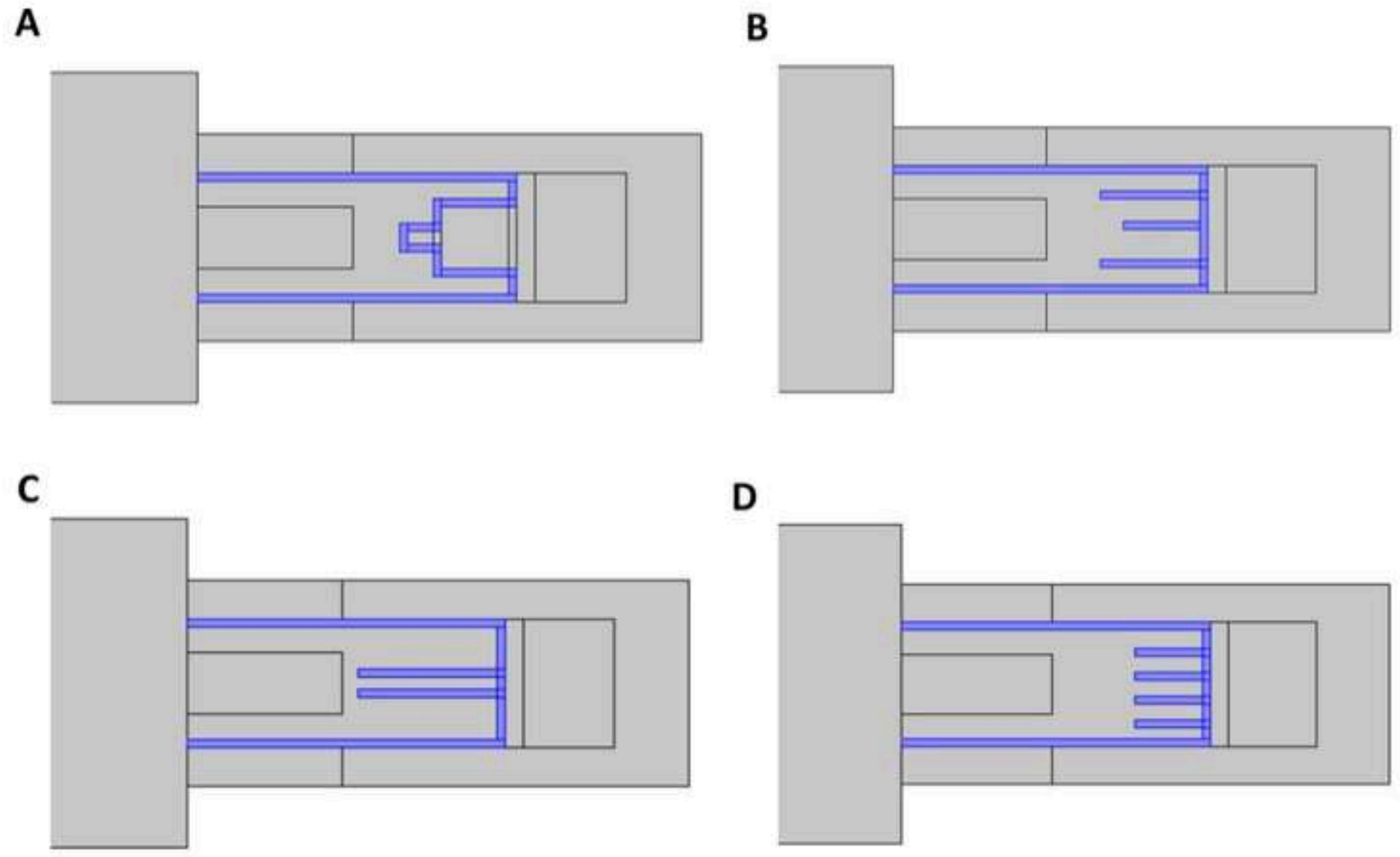


Fig. 4. Different studied layouts of the new MR brake.

- Each layout was studied to determine which configuration provides the best balance of braking torque, energy efficiency, and ease of manufacturing.

Table 3. Magnetic torque of different layouts.

Layout	Magnetic torque (N m)
Main design	125.02
a	113.68
b	147.07
c	164.38
d	126.54

Table 5. Optimization parameters.

Parameters	Optimum values
Magnetic torque	215.75 (N m)
$d1$	0.0013
$d2$	0.00334
$d3$	0.0264

Table 4. Upper and lower values for parameters.

Parameters	Bound
$d1$	0.0013–0.0031
$d2$	0.005–0.013
$d3$	0.009–0.0264

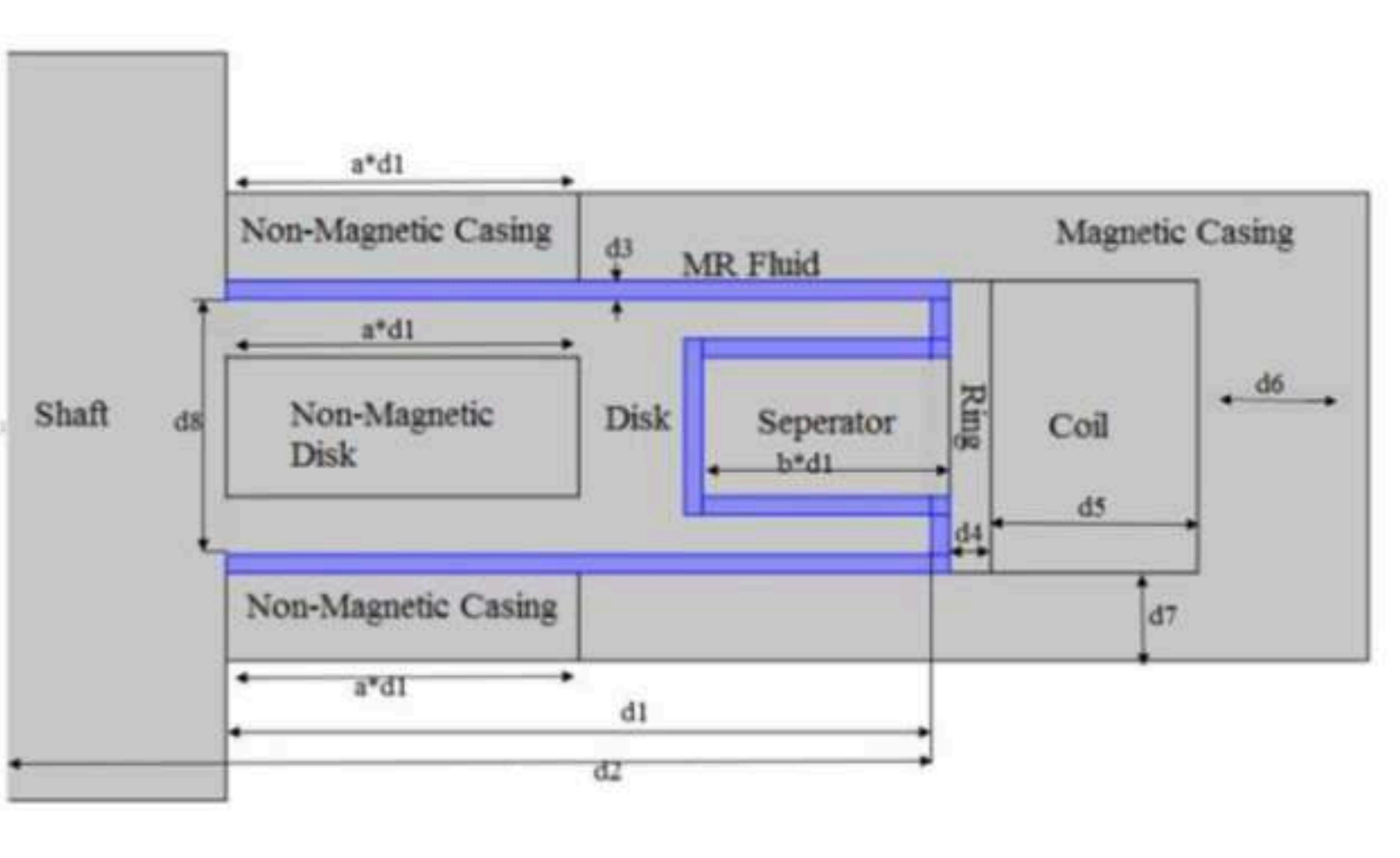
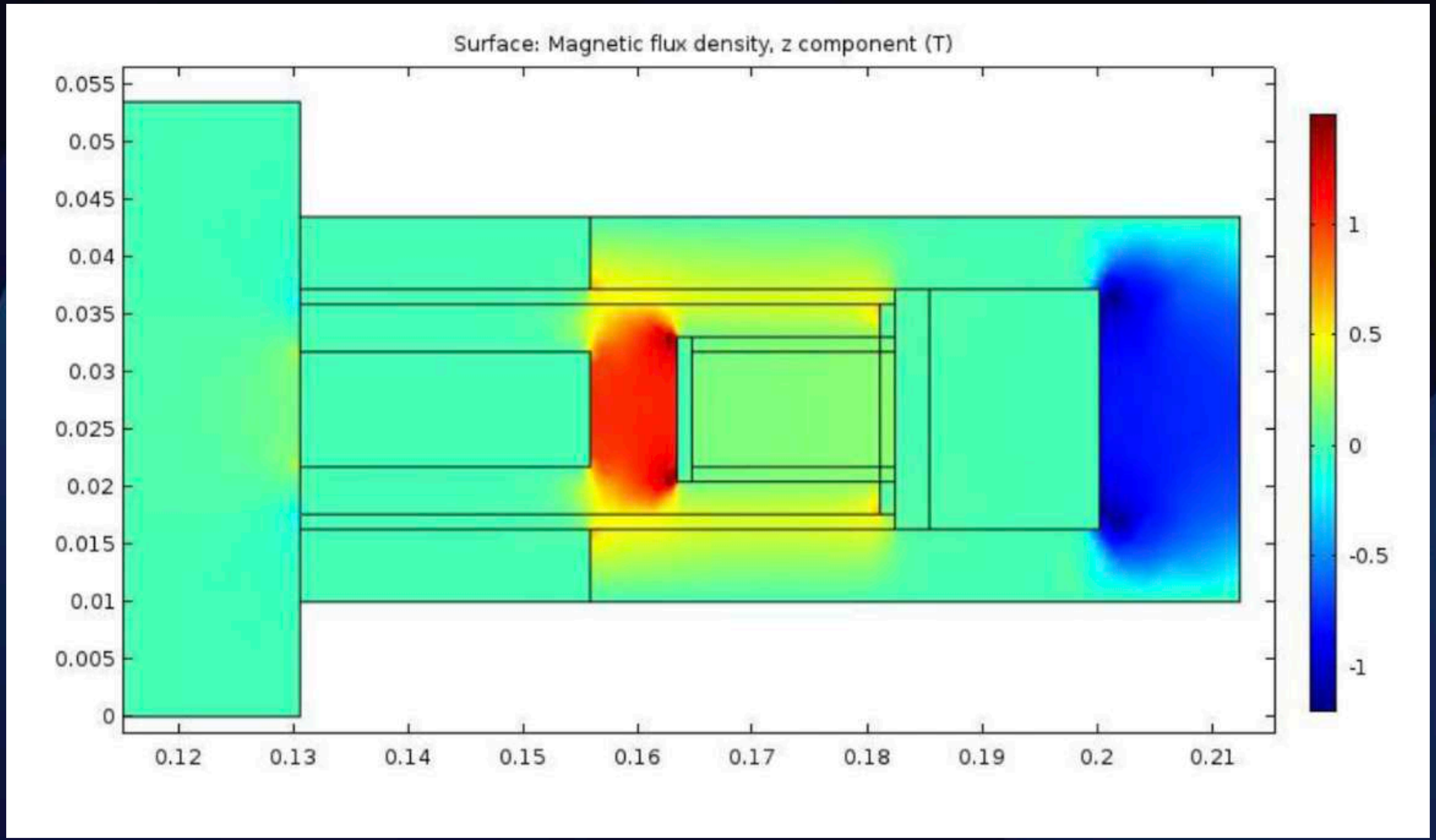
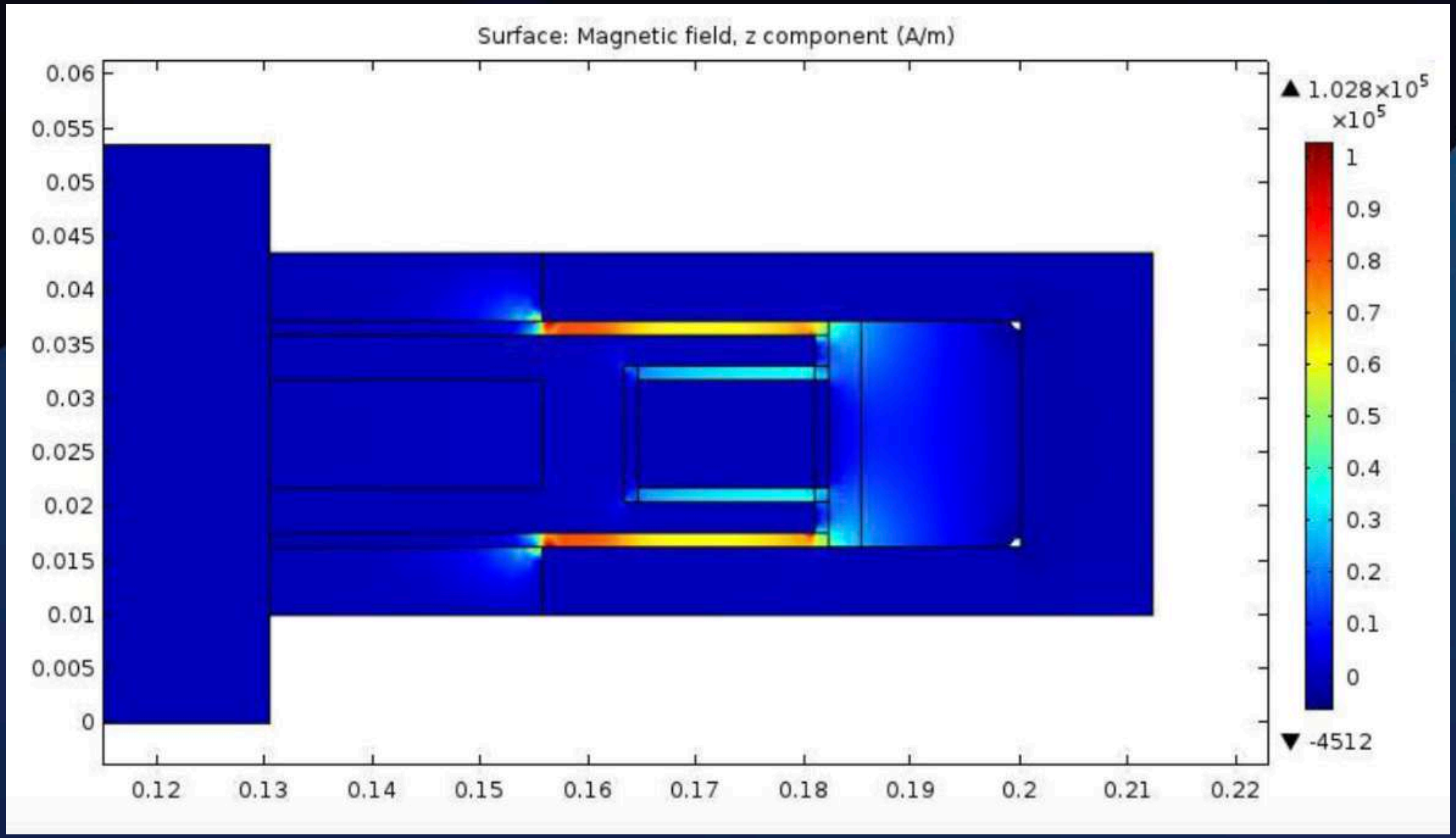


Table 2. Optimum dimensions of the MR break [21].

Variables	Values
$d1$	0.505 m
$d2$	0.1811 m
$d3$	0.0013 m
$d4$	0.003 m
$d5$	0.0148 m
$d6$	0.0122 m
$d7$	0.0063 m
$d8$	0.0183 m
a	0.5
b	0.35

- The numerical results of the present study also showed that the magnetic torque was 125.02 Nm and the viscous torque was obtained about 5.88 N m.





- shows distribution of z component of magnetic flux density (Hz) and shows distribution of z component of magnetic field intensity (Bz).Cut placement alters the magnetic field distribution, influencing torque generation.
-

Conclusions

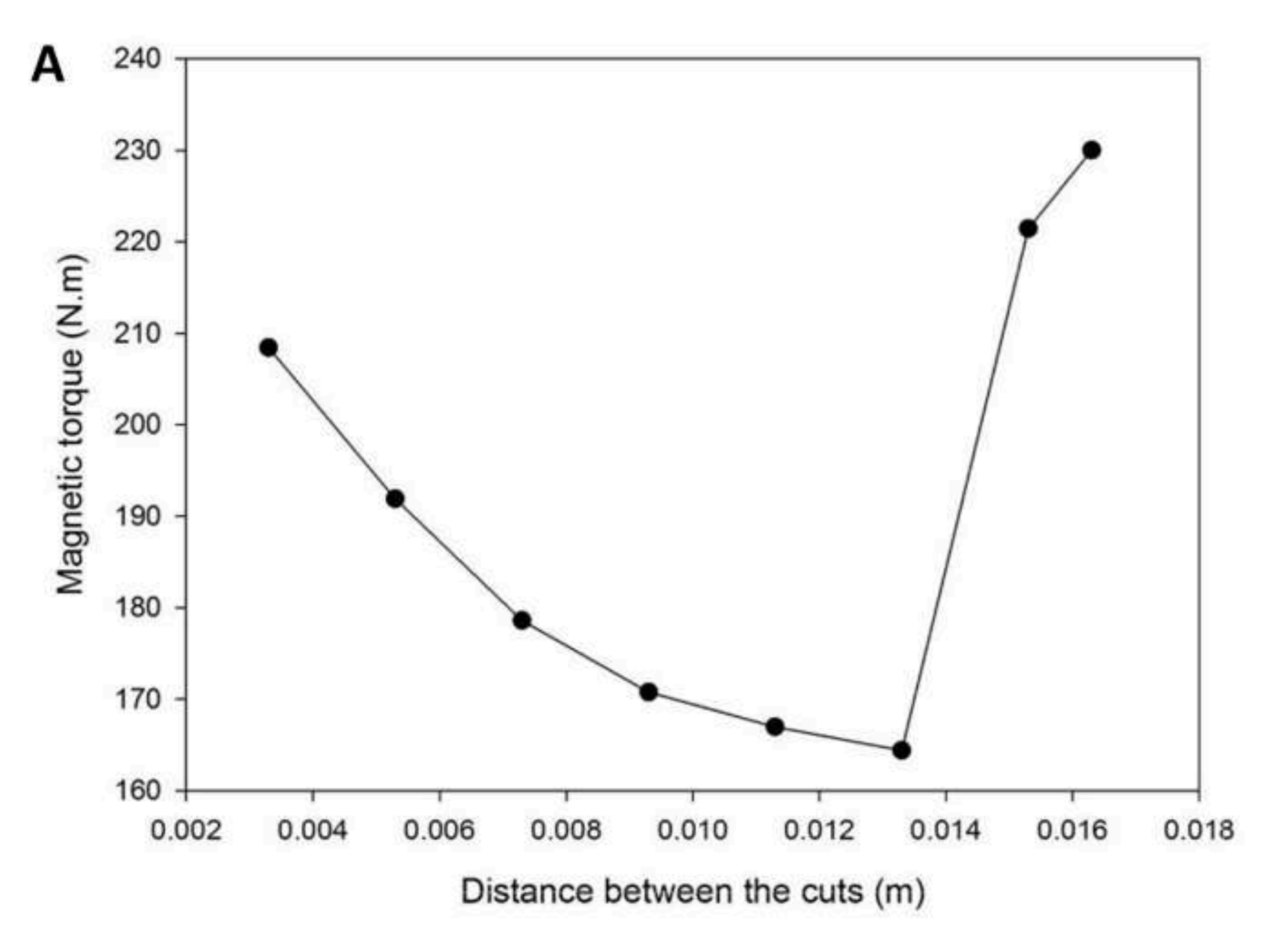
This model was also optimized using Nelder–Mead optimization algorithm. The most important outcomes of this study were:

- Increasing the number of immersed disks in the MR fluid not necessarily enhances braking effciency and the MR fluid gap dimensions should be also determined precisely.

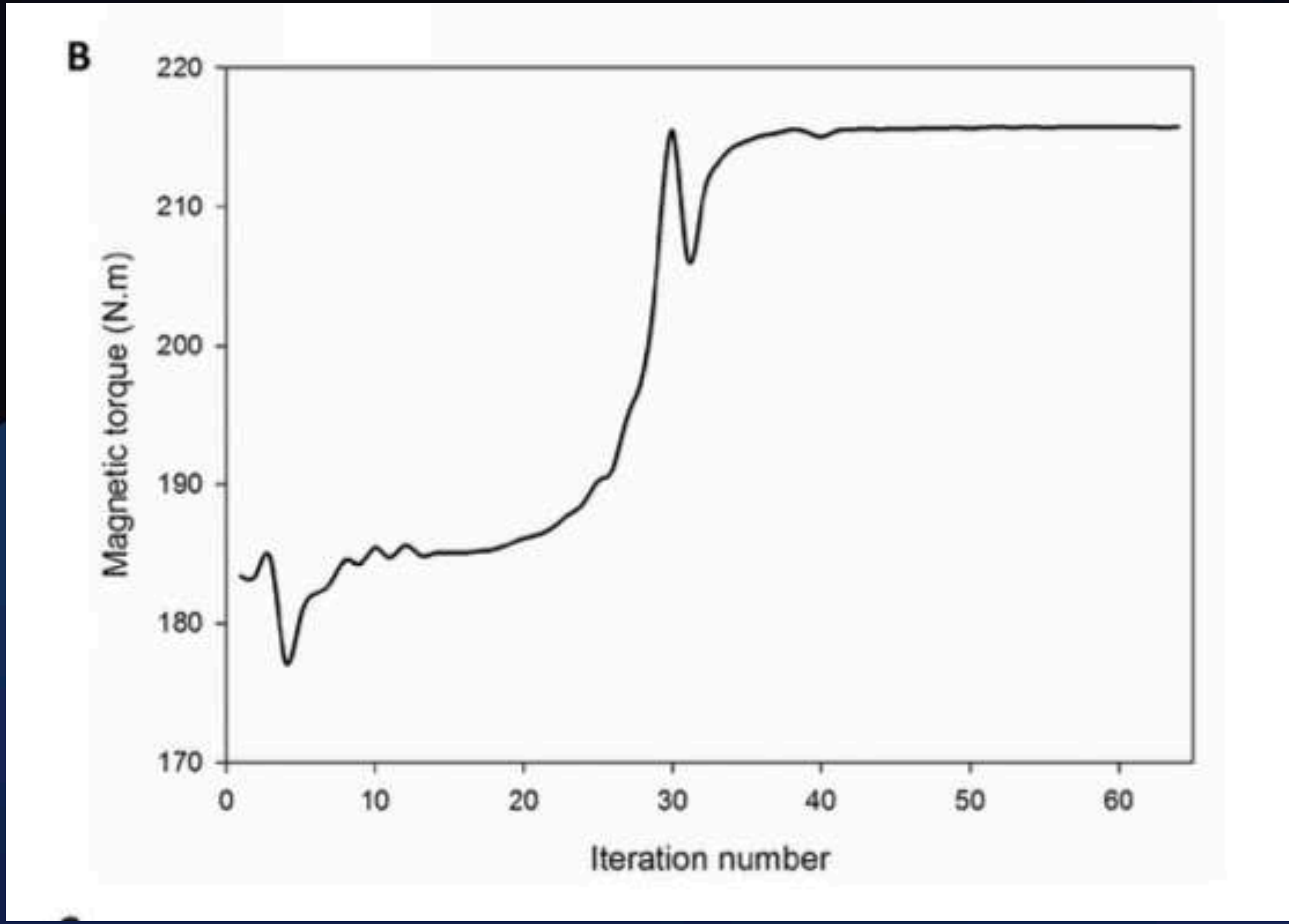
- The proposed magnetic torque in the literature (125.06 N m) could be generated by the present configuration with half of the coil current which was used previously.

- Distance between the MR fluid gaps was also one of the influential parameters on the brake effectiveness.

- Nelder–Mead optimization confirmed that when the length of the disks increases, the efficiency increases.



The ideal range for cut distance should be carefully selected to maximize braking torque. Too small or too large cut distances lead to inefficient performance.



This graph confirms the success of the optimization process, as the magnetic torque significantly improves from an initial value of ~175-180 N·m to a stable ~215 N·m.

References

- Yousef Bazargan-Lari , Design and shape optimization of MR brakes using Nelder–Mead optimization algorithm ,8 March 2019 , https://doi.org/10.1051/meca/2019017

- *R.* Siti Lydia1,*, *R.* Mokhtar1, *A.B.* Muhamad Husaini1 and *B.J.* Norhaniza ,Design and development of coil casing MRFbrake system , DOI: 10.1051/mateconf/(2017) 79001017

- C Sarkar1 and H Hirani2 , Design of a squeeze film magnetorheological brake considering compression enhanced shear yield stress of magnetorheological fluid doi:10.1088/1742-6596/412/1/012045

- M. Kciuk, R. Turczyn, Properties and application of magnetorheological uids, J. Achiev. Mater. Manuf. Eng. 18, 127–130 (2006)

- M. Ashtiani, S. Hashemabadi, A. Ghaffari, A review on the magnetorheological uid preparation and stabilization, J. Magn. Magn. Mater. 374, 716–730 (2015)

- **J. de Vicente, D.J. Klingenberg, R. Hidalgo-Alvarez,Magnetorheological uids: a review, Soft Matter 7, 3701–3710 (2011)**

- F. Gao, Y.-N. Liu, W.-H. Liao, Optimal design of a magnetorheological damper used in smart prosthetic knees,Smart Mater. Struct. 26, 035034 (2017)

THANK YOU !