Finite Element Analysis of Eddy Current Braking System

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***Abstract*—Most braking systems today convert kinetic energy into heat energy which is lost to the surroundings. This method of braking has its drawbacks and must be replaced by a more efficient and effective braking system. In this paper, the design and performance of an eddy current braking system is studied using finite element analysis and compared to a normal disc brake.**

Keywords-Brakes; Eddy Current; Finite Element Analysis; Electromagnet;

I. Introduction

The design of a basic braking system involves the conversion of kinetic energy into heat energy which is then dissipated. This is accomplished by the rubbing of the brake pads with the wheel surface and the generation of friction. This method of braking poses several problems however. There is wear and tear of brake pads, requires assisted braking systems, glazing, complexity of system, increased fuel consumption and poor heat dissipation. To solve these problems, a contactless braking system has been developed. This system involves a metal disc on which eddy currents will be generated.

The eddy current braking system can prove to be an optimal solution for frictionless braking. It can reduce friction loss and help in improving the overall efficiency of the automobile. In an eddy current brake, an electromagnetic force between a magnet and a nearby conductive object in relative motion induces eddy current in the conductor through electromagnetic induction which opposes the relative motion causing the change in magnetic field. This helps to stop the wheel and hence braking action is accomplished. This brake is wear-free, less sensitive to temperature, has a faster and simpler actuation and wheel lock sensitivity is reduced considerably. This braking system has various applications like in automobiles, locomotives, roller coasters etc. The wide range applications of these brakes imply their effectiveness and efficiency.

II. Objective

The purpose of the project is to propose a much better and efficient braking system then mechanical braking by use of electromagnetic braking.

Finite element models of the eddy current braking system (ECB) and the disc braking system (DB) were created using SolidWorks and simulated in COMSOL Multiphysics and ANSYS Workbench respectively. 3D modelling and meshing using the simulation program ANSYS and COMSOL were successfully implemented in this project, allowing for greater flexibility and accuracy in the results achieved.

Further analysis based on the following factors is carried out–

1) Variation of brake torque with respect to air gap between electromagnets
2) Variation of brake torque with respect to thickness of the disc.

III. Literature Review

[1] “Eddy Current Braking Study for Brake Disc of Aluminium, Copper and Zink” - M.Z.Baharom, M.Z.Nuawi, G.Priyandoko, S.M.Harris, L.M. Siow - In this paper, the most suitable material among Aluminium, Copper and Zinc for use in an eddy current brake is investigated.

[2] “Experiments with eddy currents: the eddy current brake” - Manuel I Gonzalez- This paper investigates the qualitative and quantitative results using an experimental setup to measure the eddy current losses.

[3] “Analysis of Eddy-Current and Magnetic Rail Brakes for High-Speed Trains” - Sergey Kitanov et al - The investigation of eddy-current and magnetic rail brake structures is described. It is demonstrated that a brake built up from permanent magnet pieces that combines both magnetic rail brake and eddy-current brake permits of the most profitable braking action through the whole range of acceptable speeds – from zero (a parking brake) to 350 km/hr. etc.

[4] “The Design of Eddy-Current Magnet brakes” - Der-Ming Ma, Jaw-Kuen Shiau - In this paper, concentrating only the constant magnetic field is the simplest and easiest design to implement an experimental braking system using constant magnetic field is built to demonstrate the design procedure.

[5] “Innovative Electro Magnetic Braking System”- Sevvel P, Nirmal Kannan V and Mars Mukesh S - In this paper the advantage of using the electromagnetic braking system in automobile is studied. These brakes can be incorporated in heavy vehicles as an auxiliary brake. The electromagnetic brakes can be used in commercial vehicles by controlling the current

IV. METHODOLOGY

A. *Literature Survey*

Recent trends in the automobile industry with respect to electromagnetic brakes and related technologies are studied. Material to be used for fabrication of parts is studied in journals and research papers.

B. *Material/Component Selection*

After conducting the literature survey the following materials are selected –

- Aluminium 6061 is the best material for the rotor disc[1]
- Electromagnets are preferred over permanent magnets as electrical actuation is faster than mechanical actuation with lower losses

C. *Mathematical Modelling*

A mathematical model is developed to check the variation of brake torque with respect to air gap and disc thickness

D. *3-D CAD Modelling*

Solidworks 2016 Part modelling and assembly construction is done for both the eddy current brakes and the disc brake.

E. *Computational Simulation*

- Motion Study is performed using Solidworks 2016
- Thermal Analysis of the disc brake is performed in ANSYS Workbench'
- Simulation of the eddy current brakes is performed using COMSOL Multiphysics

V. MATHEMATICAL MODELLING

We need to develop a mathematical model for the eddy current braking system which gives accurate results over low as well as high speed ranges.

To develop this model we first find the value of the magnetic field intensity which will be defined by the equation –

$$B = \frac{\mu_0 n i}{l_g} \tag{1}$$

Where,

B is the magnetic field intensity

μ_0 is the vacuum permeability = 12.568 x 10-7 NA-2

n is the number of electromagnetic turns

l_g is the air gap

i is the current flowing through the disc

Then the current density at that point is found which is defined by the equation –

$$J = \sigma(R\dot{\theta} \text{ x B}) \tag{2}$$

Where,

J is the current density

σ is the electrical conductivity of the disc

R is the distance between center of disc and center of pole

$\dot{\theta}$ is the angular velocity of the brake disk

B is the intensity of the magnetic field developed at that point (from equation (1))

The equation for the brake torque is defined as –

$$T_b = \left(\frac{P_d}{\dot{\theta}}\right) \tag{3}$$

Where,

T_b is the brake torque developed

P_d is the pole diameter

But the value of the pole diameter can be simplified using (2) as follows –

$$P_d = \rho J^2 \text{ x Volume} = \sigma R^2 S d \dot{\theta}^2 B^2 \tag{4}$$

Where,

ρ is the density of the disc

S is the pole area

d is the disc thickness

So from (1) and (4), we get the final value of the brake torque which can be obtained from the equation –

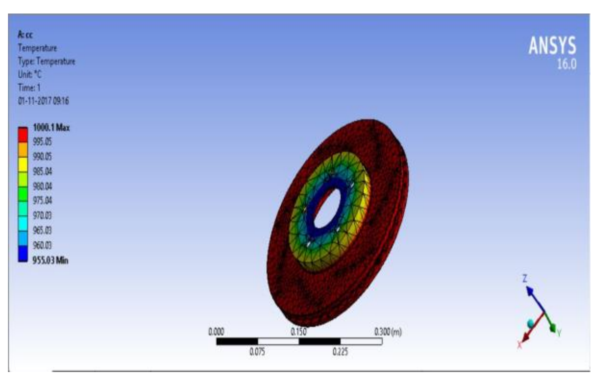
$$T_b = \sigma R^2 S d \dot{\theta} \left(\frac{\mu_0 n}{l_g}\right)^2 i^2 \tag{5}$$

VI. RESULTS AND DISCUSSIONS

A. *Disc Brake Results*

The disc brake is first modelled in Solidworks 2016. Thermal analysis is then performed on the disc brake. "Fig. 1" shows the analysis results. As we observe there is a huge loss of energy as heat. Application of a conventional mechanical brake requires huge amounts of brake torque which causes a great loss of energy. Also, over time the brake pads wear off and need to be replaced. There is also the issue of glazing of these brake pads and requires higher fuel consumption.

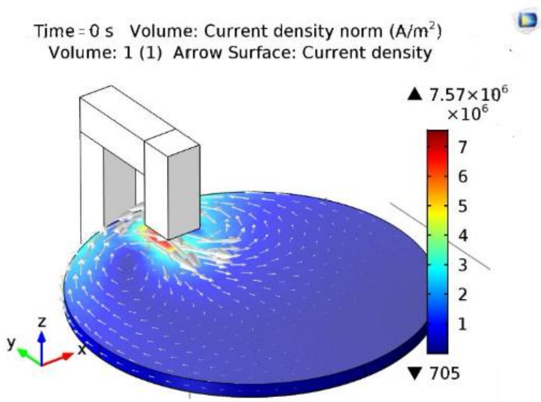
Figure 1. Example of a ONE-COLUMN figure caption.



B. Eddy Current Brake Results

The eddy current brake is simulated in COMSOL Multiphysics software to generate the eddy current density plot as shown in “fig 2”.

Figure 2. Eddy Current Density Plot



The analysis of brake torque against the various parameters is now performed for further clarity.

First the variation of brake torque with respect to thickness of the rotor disc is analyzed, then the variation of brake torque with respect tp air gap between electromagnets is tested.

TABLE I. DESIGN PARAMETERS

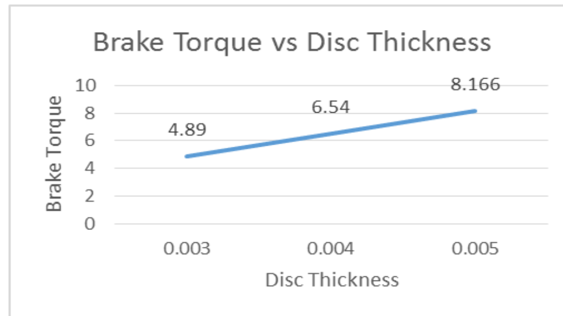
S. No	Design Parameters		
		Value	*Units*
1	Rotor disc radius, r	190	mm
2	Air gap, l_g	3,4,5	mm
3	Number of turns of electromagnet, n	250	-
4	Disc Thickness, d	3,4,5	mm
5	Pole Diameter, P_d	60	mm
6	Distance between center of disc and center of pole,R	70	mm
7	Pole Area, $S = \pi.(P_d/2)^2$	282.8	mm^2
8	Angular Velocity, $\dot{\theta}$	15.789	rps
9	Electrical Conductivity, σ	2.73E+07	S/m
10	Permeability of Vaccum, μ_0	1.26E-06	N/A^2

TABLE II. EXPERIMENTATION PARAMETERS I

Experimentation Parameters keeping Air Gap constant					
Air Gap	*Magnetic Flux Density*	*Disc Thickness*	*Current Density*	*Potential Difference*	*Torque*
0.003	0.523	0.003	1.58E+07	77.36	4.89
0.003	0.523	0.004	1.58E+07	103.15	6.53
0.003	0.523	0.005	1.58E+07	128.93	8.166

As per the design parameters in Table I and the experimentation parameters in Table II, the variation of brake torque with respect to disc thickness was first plotted keeping air gap constant as shown in “fig. 3”.

Figure 3. Brake Torque vs. Disc Thickness

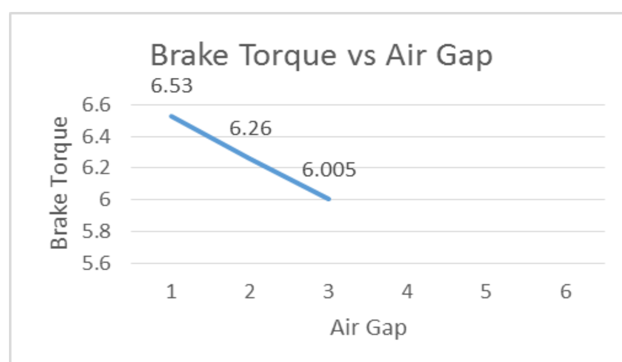


As per design parameters of Table I and the experimentation parameters of Table III, the variation of brake torque with respect to disc thickness keeping air gap constant at 0.03 mm was plotted as shown in “fig 4”

TABLE III. EXPERIMENTATION PARAMETERS II

Experimentation Parameters keeping Disc Thickness constant					
Disc Thickness	*Magnetic Flux Density*	*Air Gap*	*Current Density*	*Potential Difference*	*Torque*
0.004	0.523	0.003	1.58E+07	103.15	6.533
0.004	0.392	0.004	1.18E+08	58.024	6.264
0.004	0.3142	0.005	9.48E+08	37.136	6.005

Figure 4. Brake Torque vs. Air Gap



VII. Conclusion

We can deduce from the analysis conducted that the braking torque in the Eddy Current Braking System varies with Disc thickness and Air gap as shown in the graphs plotted above. There exists a direct relation between the brake torque and the disc thickness and air gap.

We also observe that the Eddy current braking system is more efficient as well as economical than a conventional Mechanical braking system as it offers following advantages–

- ECB are non-mechanical, no moving parts hence no friction.
- Fully resettable, no parts need to be replaced
- Can be activated at will via electrical signal
- Low maintenance cost
- Operates at any rotational speed.

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References

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