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Brake Power and Load Analysis of Electromagnetic Braking System

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Abstract- **This study aimed to develop a model and prototype of a more sustainable electromagnetic braking system which can cope with the future demands of the automobile industry due to the increasing number of e-vehicles. The braking mechanism is been used in almost every type of mechanical vehicle and it utilizes crude oil as fuel which when burnt causes air pollution. To save the environment from air pollution e-vehicles have been introduced to the market. Electromagnetic brakes are been used in e-vehicles as these vehicles incorporate huge electric systems which may be damaged or ignited through any leakage from the hydraulic brake. In this study, engineering knowledge has been implemented to design and fabricate a model of the electromagnetic braking system (EMS) which works on the principle of eddy current. A 3D model of EMS was developed. Further, static displacement and brake power analyses were performed to check the strength of EMS and the performance of the prototype developed, respectively. At an average speed of 31 RPM, brake power produced was 3.9 W. Static structural analysis on a frame made of grey cast iron showed that there was negligible deformation for load up to 200 N. Electromagnetic braking system based on this analysis and model could meet the market needs for conveyor belt application as well. The observations from this study might be useful in the development of a more efficient electrical vehicle braking system with varying demands of momentum.**

Index Terms-- **Brake power, brake load, electromagnetic brake**

I. INTRODUCTION

In earlier ages, when the wheel was discovered, a need for something that would help to stop the rotation of the wheel was raised. So, the people thought of the idea to stop the wheel at will and they came up with the idea of a brake [1]. Mostly, a brake uses friction between the two surfaces that are being pressed with each other to convert the kinetic energy of the moving objects into another sort of energy e.g., heat [2]. It consisted of nothing more than just a simple lever that moved a block of wood against the wheel which used kinetic energy to stop the motion [3]. This method was effective but only on steel rimmed wheels, which were used in horse-drawn and steam-powered vehicles [1]. The brake is what makes it possible for humans to control a motor vehicle for a safer riding condition. For over a century, braking systems have evolved into more complex devices that adapt to different road conditions [4]. They are a key part of the amazing technology that makes up the automobile. Many forms of brakes have been developed over time as the technology of cars has advanced. Now a day's most commonly used braking system is the hydraulic brake system, almost every vehicle uses this type of brake [5].

Nowadays, hydraulic brakes are being used in every part of the world. Wherever a wheel is used, a hydraulic brake is used along with it. But now, as the era became modern, many car companies are launching their electrical vehicles (e-vehicles) and hydraulic brakes are not suitable for these types of vehicles [6]. The reason is that e-vehicles are based on the electrical system and no liquid fuel is used [7]. But the hydraulic brake system uses brake fluid as its working fluid that may leak anytime and it can damage the electrical circuits in the e-vehicle [8]. Therefore, the hydraulic brake is being replaced by advanced electromagnetic brakes [9].

A bike braking system was developed by Prajapati et al. [10] using an electromagnetic curl and a plunger. The system utilizes aluminium for the disc brake due to its better capability of producing eddy currents, an essential phenomenon for EMS. The electromagnetic impact moves the plunger in the direction of the brake. At the point when power is applied to the field, it makes an inner attractive motion. That transition is then moved into a hysteresis plate going through the field. The hysteresis circle is connected to the brake shaft. An attractive drag on the hysteresis plate allows a steady drag or possible stoppage of the yield shaft. Eddy current-based EMS was also researched by Totala et al. [11], who investigated contactless braking systems. Baharom et al. [12] also studied eddy current-based EMS and the system was based on the magnetic field across a moving conductor which makes an opposite attractive field by induced eddy currents.

Puttewar et al. [13] proposed pressure transducers and microprocessor-based EMS with the capability of sensing the pressure and applying the brakes as per the driver's requirements. The authors also designed an EMS by wrapping a copper wire around a nail and then connected to a battery. The designed system yields double the maximum force on the motor, thus showing the efficiency of the EMS. A mathematical model was presented by Harada et al. [14] to look at the impact of various sorts of attractive fields used in the EMS procedure. The authors utilized a mercury model test, which structures a nearby attractive field and a level attractive field in the width direction, on the fluid metal stream in the persistent projecting strand. Xiang et al. [15] investigated EMS with an electromagnetic clutch system.

The purpose of this study is to make a braking system more sustainable in the future with an increasing number of e-vehicles. The electromagnetic braking system proposed in this study will be more useful than the conventional braking system, which is already being used in cars. An electromagnetic braking system based on the analysis and model in this study could meet local market needs for conveyor belt applications as well. The observations from this study might be useful in the development of a more efficient e-vehicle braking system with varying demands and momentum.

II. METHODOLGY

The development of the EMS prototype in this study comprises of various steps including literature review development of 3D model prototype development, and data analysis followed by validations of results. The detailed methodology framework is shown in Figure 1.

A. DESIGN & 3D MODELING

The main function of the electromagnetic brake system is to stop the rotation of the wheel without losing energy as friction. The electromagnets are been used to stop the rotation of the wheel by producing magnetic field lines. It works on the principle of eddy current, which is induced in the conductor, a copper plate in the prototype. Thus, by changing the magnetic field in the conductor according to Faraday's law of induction, the braking system stops the rotation of the shaft. The brake power depends on the strength of electromagnets. Keeping in view all these requirements a 3D model using SOLIDWORKS software has been developed as shown in Fig. 1.

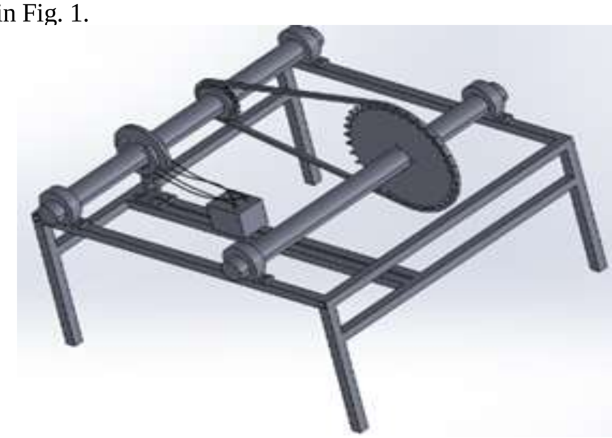

FIGURE 1. 3D Model of an EMS braking system

B. FABRICATION OF A PROTOTYPE

For the prototype, iron angles were welded together to make the frame. Electromagnets were made using spring and metal rods of suitable sizes for the prototype. Two shafts were attached to the frame, the one with the motor was named the drive shaft while the other was the driven shaft. Two gears were welded to these shafts. A 12 volts DC motor (2500 rpm) was connected to the driven end with help of a chain. The chain structure was preferred over the belt to avoid slippage and loss of energy. The belt undergoes slip and creep conditions which cause it to lose power [16]. An iron disk, connected to the shaft, rotates at the same speed as that of the shaft. Two electromagnets were placed near the iron disk which attract the iron disk as the magnetic field develops. This causes a restriction in shaft rotation and eventually stops it. Two batteries were used to power up the electromagnets and motor. The prototype is shown in Fig. 1. A List of hardware prototype components used in the experiment is mentioned in Table 1.

TABLE I
LIST OF HARDWARE PROTOTYPE COMPONENTS USED IN THE EXPERIMENT

Sr.	Component	Quantity	Type	Size
1.	Frame	1	Gray iron	2.5 sq. ft.
2.	Shaft	2	Stainless steel	2.8 ft. & 3.2 ft.
3.	Gear 1	2	Iron	3.5 inches
4.	Gear 2	2	Iron	2.5 inches
5.	Bearing	4	Bracket	1 inch
6.	Disk	1	Iron	6 inches
7.	Motor	1	DC	12 V 2500 RPM

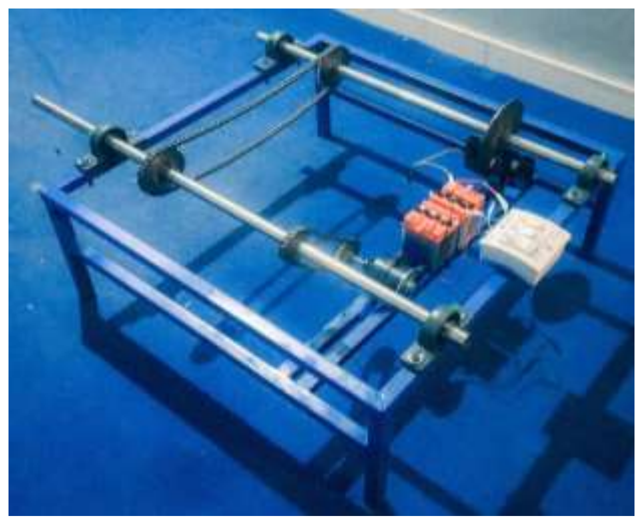

FIGURE 2. Prototype for EMS

C. ESTABLISHMENT OF WORKING MECHANISM

The working mechanism of the Ems prototype comprises several steps. Whenever the rotation of the wheel is needed to be stopped the brake pedal/ push button is been pressed, and it gives a signal to the battery to power up the electromagnets to get ready to stop the rotation. When electromagnets are powered up, a magnetic field is created which attracts the nearby copper disk. It causes a restriction to the rotation of the shaft. As the copper disk is connected to the wheel and moves at the same speed as that of the wheel. Thus, when the copper disk is attracted towards the electromagnets, the restriction produced to the rotation of the wheel slows it down. If the magnetic field produced is strong enough, it can completely stop the rotation of the wheel. The complete working mechanism is shown in Fig. 3.

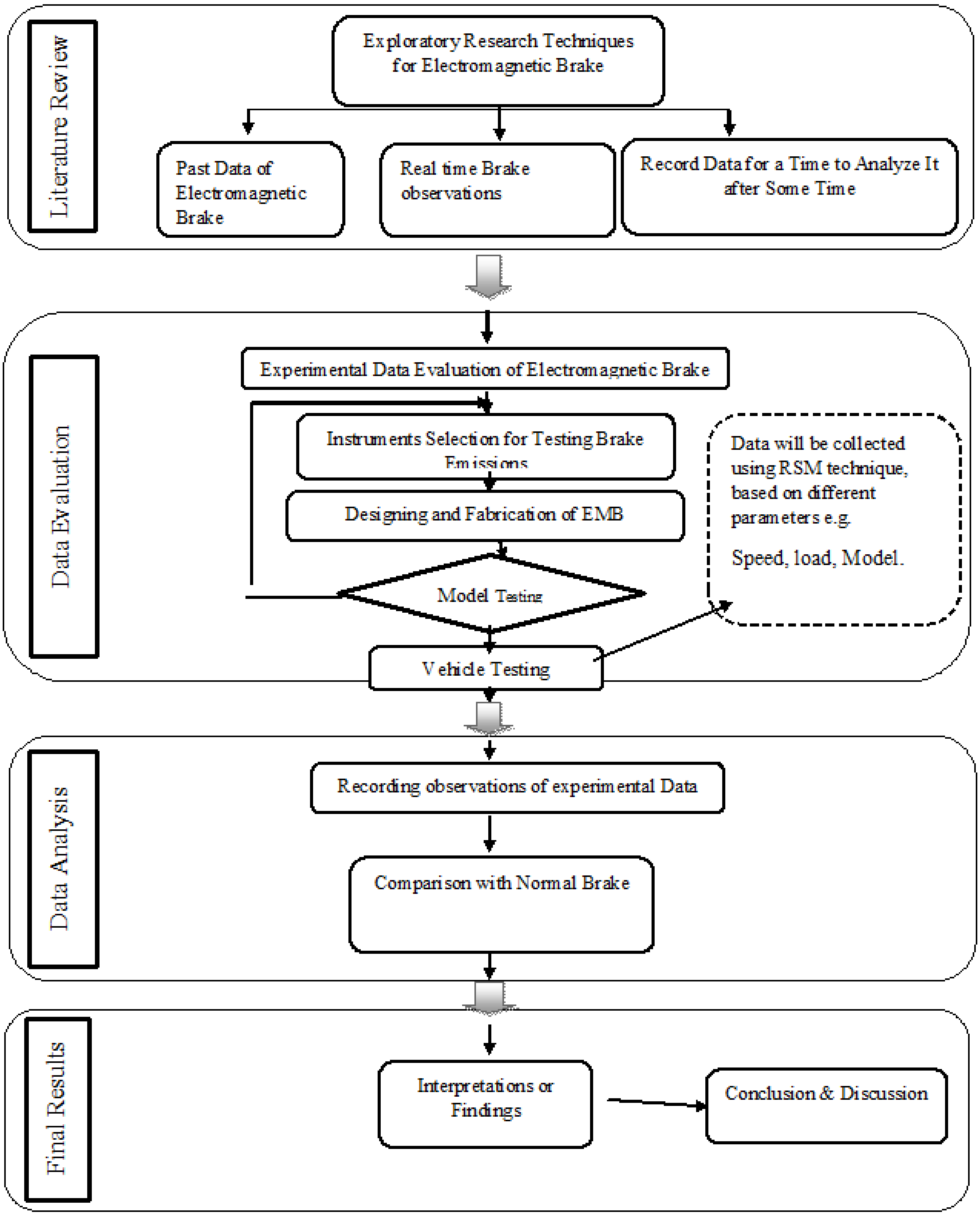

FIGURE 3. Methodology Framework

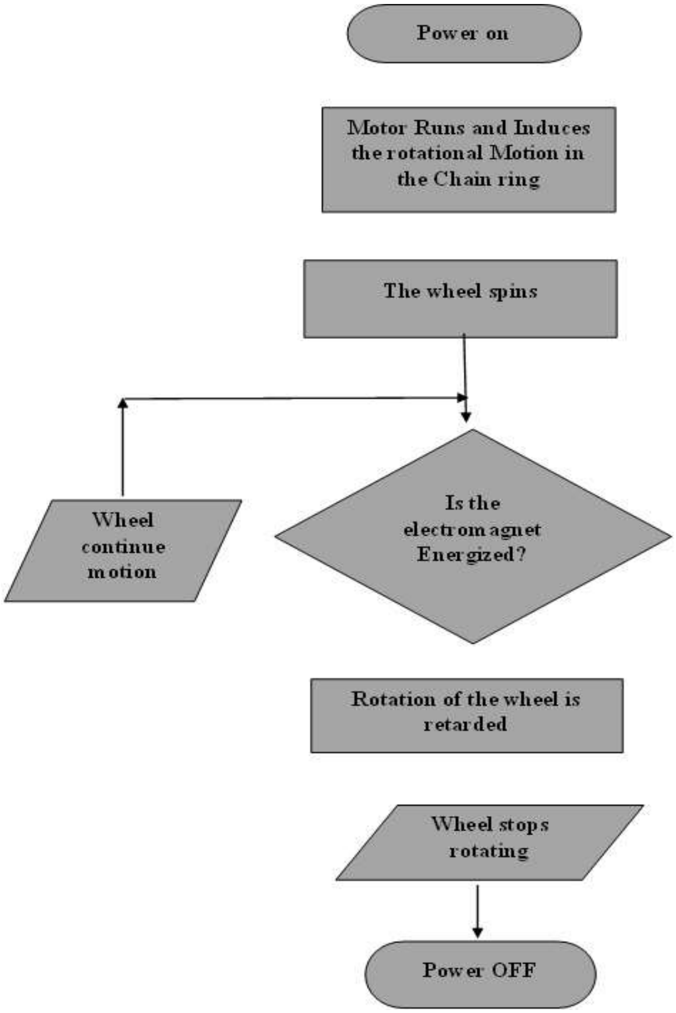

FIGURE 4. Working Mechanism of prototype

III. EXPERIMENTATION & ANALYSIS

To determine the effectiveness of the developed EMS braking system the required and applied brake power and the time required for the stopping have been calculated. The procedure is described below. Similarly, during braking, the frame of the EMS braking system has to bear the load and its structural integrity is necessary (see Fig. 4). Numerical Simulation has been performed to analyze stresses. The procedure for numerical simulation and boundary conditions are explained in the following sections.

A. BRAKE POWER & BRAKING TIME CALCULATION

The shaft or wheel speed was measured using a speedometer. A stopwatch was used to measure the time taken by EMS to stop the wheel. At three different RPMs (35, 30, and 28), the required break power is calculated using (1).

$$\text{Required Brake power} = 2\pi N/60 \quad (1)$$

B. STATIC ANALYSIS

Stress analysis was performed on the proposed structure using SolidWorks simulations (see Fig. 6 ad 7). Four different stresses (100, 200, 1000 and 5000N) were applied to the designed frame in a direction perpendicular to the frame as shown in Fig. 5. The purple arrows represent the applied force and the small green arrows indicate the fixture.

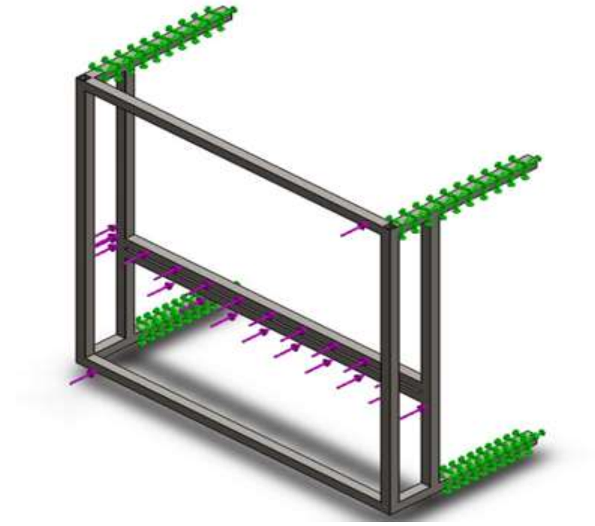

FIGURE 5. Boundary Conditions for Stress analysis

III. RESULTS & DISCUSSION

The results obtained as a result of the above experimentation and analysis are described in the following sections.

A. EFFECTIVENESS OF THE EMS BRAKING SYSTEM

The required and produced brake power at different RPMs, along with the stopping time calculated is tabulated in Table 2. The number of coils was 1500 and the magnetic force produced was 3 KN. The force was observed appropriate for a braking system application [3].

TABLE II
RESULTS FOR BRAKE POWER ANALYSIS

Sr.	RPM	Required brake power (W)	Produced brake power (W)	Stopping time (s)
1.	35	3.62	3.9	1
3	30	3.14	3.9	1
3.	28	2.91	3.9	1
4.	31	3.22	3.9	1

B. NUMERICAL SIMULATION

The outputs of Von Mises Stress and static displacement for four different forces are shown in Figure 5 and Figure 6, respectively. The analysis has shown not many changes by changing weights from 100N to 5000N. This shows that the designed structure/frame is strong enough to handle/withstand 5000N or 500kg weight [5]. No obvious deformations have been observed in the structure. This shows that the designed model can be replicated for a real-time scenario as developed in [6].

Static displacement results showed that the highest displacement can occur at the center of the structure. Thus, this area can be prone to breaking. To decrease the probability of malfunctioning the integrity of the whole system it is suggested that support at the center of the structure should be provided [9]. The support must be provided such that the functioning of the EMS braking system remains intact [15].

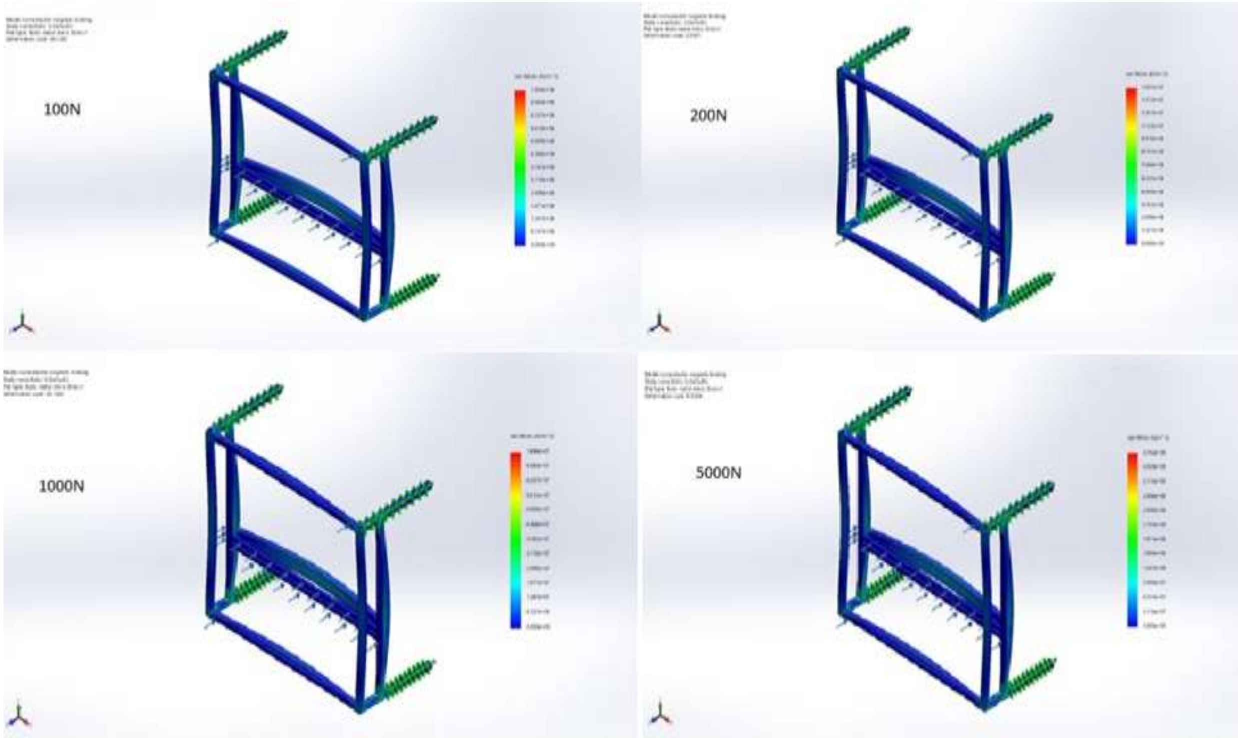

FIGURE **6.** Von Mises's stress results

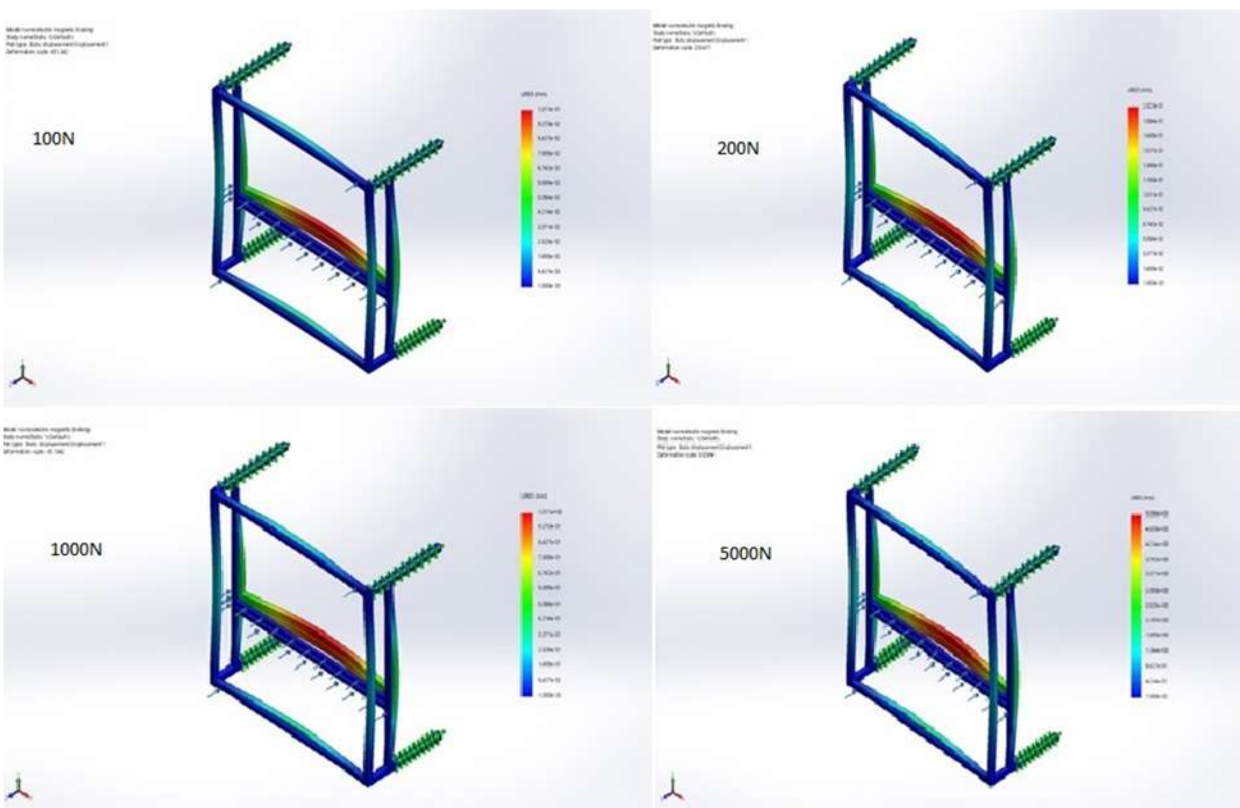

FIGURE **7.** Static displacement results

IV. CONCLUSIONS

It has been observed that the electromagnetic braking system is better than conventional braking systems. The electromagnetic power produced by the designed system has been found higher than the required power to stop the moving system. The stopping time is also found acceptable and better than the conventional system. At the same time, the EMS system has an advantage over conventional braking systems in terms of wear and tear as well as wasting energy in the form of heat. Also, the chances of failure of EMS are far less than in conventional systems. The designed and developed prototype can be used for any moving system, whether in industry or automobiles. Future work may include testing the developed system in real-time scenarios, in working automobiles or moving parts of the industry such as conveyor belts.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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