A (Project Stage – II) Report on

Design and Analysis of Electro-magnetic Braking System

to be submitted in partial fulfilment of the requirements

for the award of degree of

BACHELOR OF ENGINEERING
(Mechanical Engineering)

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PUNE – 411 018, MAHARASHTRA

2023-2024

Certificate

This is to certify that the following group of bonafide students from the Mechanical Engineering Department have successfully completed the prerequisites as laid down by the Savitribai Phule Pune University, Pune in the form of a report as per the course structure for the Project Stage – II.

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It is herewith certified that this project work has not been submitted for award of any degree/diploma to any other university in India or abroad.

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Declaration by the candidates

With this, I certify that the report entitled "Design & Analysis of Electro-magnetic Braking System" was submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering in Mechanical Engineering to Savitribai Phule Pune University, Pune is an authentic record of project work carried out by us under the supervision and guidance of Prof. Dr. Nitin P. Sherje.

The work incorporated in this report has not been submitted elsewhere for the award of any degree/diploma in India or abroad.

Exam Seat No.	Roll No.		Name of the project group students	Signature
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Acknowledgements

We would like to express our heartfelt and sincere appreciation to all those who provided us guidance to complete this Project Stage II.

Special thanks to our Project Guide Hon**. HOD & Prof. Dr. Nitin Sherje** whose guidance, stimulating suggestions and motivation helped us to reach this milestone. Also, our sincere appreciation for all the valuable time he spent proofreading and correcting many of our mistakes.

We would also like to express our sincere appreciation for all faculty of Mechanical Department for guiding us during the duration of this Project Stage II.

Abstract

Electro-magnetic Braking is a method that uses principle of electro-magnetic induction to generate braking force. Electro-magnetic braking works on creating a resistance force that opposes the motion of the object thereby slowing it down. In this paper we have designed and analysed one such electro-magnetic braking system. The conventional braking system is bulky and its power to weight ratio is low. Electro-magnetic braking system overcomes this disadvantage. The effectiveness of the braking system remains constant and heat dissipation becomes optimal according to surrounding conditions. Minimal maintenance and minimal wear and tear with progressive technological advancement in the system, providing better response time and increased lifecycle of the system. This designing and analysing being done for small commercial vehicles will prove to be a significant change in the braking and automobile sectors. The commercial braking system can be replaced by this electromagnetic braking system providing advantages such as improved and efficient braking, increased lifespan.

Keywords: - Electro-magnetic Braking, Design, Analysis, Dissipation, Technological Advancement.

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Nomenclature

Abbreviations:

PCC (Presidents' Conference Committee)

U.S. (United States)

RPM (Revolutions Per Minute)

ABS (Anti-lock Braking System)

ERS-K (Energy Recovery System-Kinetic)

MGU-K (Motor Generator Unit-Kinetic)

SECU (Standard Electronic Control Unit)

BBW (Brake-by-Wire)

UIC (Union Internationale des Chemins de fer)

EP (Electro-Pneumatic)

ECP (Electronically Controlled Pneumatic)

ECB - Eddy Current Brake

NdFeB - Neodymium-Iron-Boron

SHPB - Split Hopkinson Pressure Bar

EMB - Electromagnetic Brake

BBW - Brake-by-Wire

TPSS - Traction Power Substations

MRT - Mass Rapid Transit

DC - Direct Current

EV - Electric Vehicle

BG - Bond Graph

NEDC - New European Driving Cycle

FTP-75 - Federal Test Procedure 75

BLDC - Brushless DC (motor)

ECL - Eddy Current Loss

SMC - Soft Magnetic Composite

Ansoft - Likely refers to a simulation software tool used in the analysis.

MATLAB - Matrix Laboratory, a programming platform for simulation and analysis

COMSOL - COMSOL Multiphysics, a simulation software tool

Arduino - An open-source electronics platform

ATmega328P - A microcontroller used in Arduino platforms.

Greeks:

α (alpha) - could denote various coefficients (thermal, angular acceleration, etc.)

β (beta) - could denote phase angles or coefficients

γ (gamma) - could denote shear strain or angles

δ (delta) - could denote change or difference

ε (epsilon) - could denote strain or permittivity

θ (theta) - could denote angles

λ (lambda) - could denote wavelengths or eigenvalues

μ (mu) - could denote permeability or friction coefficient

ρ (rho) - could denote density or resistivity

σ (sigma) - could denote stress or conductivity

τ (tau) - could denote torque or time constants

φ (phi) - could denote magnetic flux or phase angles

ω (omega) - could denote angular velocity or frequency

Subscripts/Superscripts:

< ∘ C (less than _ degrees Celsius)

> ∘ C (greater than _ degrees Celsius)

45½ (45 and one-half miles per hour)

48½ (48 and one-half miles per hour)

^2 - denotes square (second power)

^3 - denotes cube (third power)

′ - prime (denotes derivative or specific value)

″ - double prime (denotes second derivative or specific value)

1. Introduction

A brake is a mechanical device that inhibits motion by absorbing energy from a moving system. It is used for slowing or stopping a moving vehicle, wheel, axle, or to prevent its motion, most often accomplished by means of friction.

Most brakes commonly use friction between two surfaces pressed together to convert the kinetic energy of the moving object into heat, though other methods of energy conversion may be employed. For example, regenerative braking converts much of the energy to electrical energy, which may be stored for later use. Other methods convert kinetic energy into potential energy in such stored forms as pressurized air or pressurized oil. Eddy current brakes use magnetic fields to convert kinetic energy into electric current in the brake disc, fin, or rail, which is converted into heat. Still other braking methods even transform kinetic energy into different forms, for example by transferring the energy to a rotating flywheel. Brakes are generally applied to rotating axles or wheels but may also take other forms such as the surface of a moving fluid (flaps deployed into water or air). Some vehicles use a combination of braking mechanisms, such as drag racing cars with both wheel brakes and a parachute, or airplanes with both wheel brakes and drag flaps raised into the air during landing. Almost all wheeled vehicles have a brake of some sort. Even baggage carts and shopping carts may have them for use on a moving ramp. Most fixed-wing aircraft are fitted with wheel brakes on the undercarriage. Some aircraft also feature air brakes designed to reduce their speed in flight. Notable examples include gliders and some World War II-era aircraft, primarily some fighter aircraft and many dive bombers of the era. These allow the aircraft to maintain a safe speed in a steep descent. The Saab B 17 dive bomber and Vought F4U Corsair fighter used the deployed undercarriage as an air brake. Friction brakes on automobiles store braking heat in the drum brake or disc brake while braking then conduct it to the air gradually. When traveling downhill some vehicles can use their engines to brake.
When the brake pedal of a modern vehicle with hydraulic brakes is pushed against the master cylinder, ultimately a piston pushes the brake pad against the brake disc which slows the wheel down. On the brake drum it is similar as the cylinder pushes the brake shoes against the drum which also slows the wheel down.

Frictional brakes are most common and can be divided broadly into "shoe" or "pad" brakes, using an explicit wear surface, and hydrodynamic brakes, such as parachutes, which use friction in a working fluid and do not explicitly wear. Typically, the term "friction brake" is used to mean pad/shoe brakes and excludes hydrodynamic brakes, even though hydrodynamic brakes use friction. Friction (pad/shoe) brakes are often rotating devices with a stationary pad and a rotating wear surface. Common configurations include shoes that contract to rub on the outside of a rotating drum, such as a band brake; a rotating drum with shoes that expand to rub the inside of a drum, commonly called a "drum brake", although other drum configurations are possible; and pads that pinch a rotating disc, commonly called a "disc brake". Other brake configurations are used, but less often. For example, PCC trolley brakes include a flat shoe which is clamped to the rail with an electromagnet; the Murphy brake pinches a rotating drum, and the Ausco Lambert disc brake uses a hollow disc (two parallel discs with a structural bridge) with shoes that sit between the disc surfaces and expand laterally.

A drum brake is a vehicle brake in which the friction is caused by a set of brake shoes that press against the inner surface of a rotating drum. The drum is connected to the rotating roadwheel hub. Drum brakes generally can be found on older car and truck models. However, because of their low production cost, drum brake setups are also installed on the rear of some low-cost newer vehicles. Compared to modern disc brakes, drum brakes wear out faster due to their tendency to overheat.

The disc brake is a device for slowing or stopping the rotation of a road wheel. A brake disc (or rotor in U.S. English), usually made of cast iron or ceramic, is connected to the wheel or the axle. To stop the wheel, friction material in the form of brake pads (mounted in a device called a brake calliper) is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction cause the disc and attached wheel to slow or stop.

Pumping brakes are often used where a pump is already part of the machinery. For example, an internal-combustion piston motor can have the fuel supply stopped, and then internal pumping losses of the engine create some braking. Some engines use a valve override called a Jake brake to greatly increase pumping losses. Pumping brakes can dump energy as heat, or can be regenerative brakes that recharge a pressure reservoir called a hydraulic accumulator.

Most modern passenger vehicles, and light vans, use a vacuum assisted brake system that greatly increases the force applied to the vehicle's brakes by its operator.[4] This additional force is supplied by the manifold vacuum generated by air flow being obstructed by the throttle on a running engine. This force is greatly reduced when the engine is running at fully open throttle, as the difference between ambient air pressure and manifold (absolute) air pressure is reduced, and therefore available vacuum is diminished. However, brakes are rarely applied at full throttle; the driver takes the right foot off the gas pedal and moves it to the brake pedal - unless left-foot braking is used.

Because of low vacuum at high RPM, reports of unintended acceleration are often accompanied by complaints of failed or weakened brakes, as the high-revving engine, having an open throttle, is unable to provide enough vacuum to power the brake booster. This problem is exacerbated in vehicles equipped with automatic transmissions as the vehicle will automatically downshift upon application of the brakes, thereby increasing the torque delivered to the driven wheels in contact with the road surface.

Heavier road vehicles, as well as trains, usually boost brake power with compressed air, supplied by one or more compressors.

Parking brake or handbrake is the secondary braking system in a vehicle that is used to keep a vehicle stationary during parking, especially if it’s on an inclination. This braking system is relatively simple and works independently to a normal braking system in a car. There are manual parking brake systems that use the proven cable system to activate drums or disc brakes. There are also electric parking brakes which work on the theory of brake-by-wire systems as we discussed above. Most modern cars are now featuring an electronic parking brake instead of the rudimentary cable system.

Mechanical brakes are the oldest one of the trios which have been around till the 1950s. It’s a simple system that used pulleys, cables, cams, and other equipment to apply friction to the brakes from the brake pedal inside the cabin. When a driver steps on the brake pedal, a cable is used to pull a brake line which then activates the brakes on the wheel. Although mechanical brakes were around for almost 50 years, the industry moved away from this system as it was proved unreliable over time since it featured many moving parts that were also susceptible to wear and tear with usage. There were also concerns regarding brake force and precision of the system, eventually leading to its replacement.

Hydraulic braking system replaced the aging mechanical system around the 1950s and it is used by carmakers to this day. Hydraulic brakes, as the name suggests, works on the principle of hydraulics. In simple terms, there’s brake fluid (stored in a reservoir), that is non-compressible and can work in high temperatures. When the pedal is pushed in, the fluid sends pressure through the brake lines to a master cylinder which then sends pressure to the actual braking system on the wheels. This system is widely used even today and there have been major advancements to this setup over the years. However, the working and the basic principle remains the same.

The latest and the most cutting-edge type of braking system is the brake-by-wire system which eliminates any form of mechanical or hydraulic system to transmit the brake force to the wheels. Brake-by-wire system uses a position sensor that sends signals when the brake pedal is pushed in to activate the brakes on the wheels. This system is also known as electromechanical brakes as the end braking is done by a piston and calliper setup which is a mechanical system. Modern day electric cars use this type of braking system. A good example of a brake-by-wire system would be the Porsche Taycan.

ABS is one of the most crucial inventions when it comes to automotive safety and braking. The ABS is one of the most overlooked safety features and one that is extremely capable of avoiding a crash. In simple words, when sudden brake force is applied, the wheels tend to lock up restricting the steering of a vehicle leading to a potential accident. With ABS, the brake force is distributed intermittently when it detects a lock up, thereby helping us steer away. ABS comes handy in wet and slippery road conditions where normal brakes would slide all the way to an obstacle.

The ABS system primarily uses wheel speed sensors that are connected to an ABS pump. When any of the wheel speed sensors detect a loss of traction, the brake force to that individual wheel or side is altered and brake force is applied intermittently to help regain traction.

A current F1 car’s braking system is made up of the brake discs, Callipers, pedal and master cylinder – all linked by pipework and with a brake-by-wire unit controlling the rear brakes. Despite the deceleration available, the brakes are heavily regulated to limit their ability to deliver even greater performance.

Slowing the car from 210mph approaching the 13th turn around the Montreal’s Circuit Gilles Villeneuve, the driver will brake for just 2.09 seconds slowing to 83mph in a mere 122 meters, which is about 20 car lengths! To achieve this amazing feat, more is required than just the brakes, it needs the wide Pirelli slick tyres for the traction, plus huge amounts of downforce and powerful leg muscles.

It’s only possible to get this 5G performance because the car has so much grip at the tyre contact patch. To make the best of the braking potential available, most effort is required at the start of the braking event, when downforce is the highest. The braking effort from the driver is not quite on/off, as they will need to ease back on the pedal as the downforce decreases with speed, to balance the retardation with the grip available. This blend of downforce, tyres and braking system makes F1 cars the most efficient decelerating race machines in motorsport.

Everything depends on the bite of the brakes on the discs, so F1 cars run carbon discs and pads with aluminium six pot callipers. Carbon fibre is used for two main reasons and it's not the myth about steel brakes being less powerful. Fundamentally, carbon fibre is lighter than a steel disc, but it also copes with running at high temperature better than steel. Having first appeared on aircraft, with the technology being introduced to F1 by Gordon Murray at Brabham in the early eighties, the compromise with carbon discs is the cost. Anything lighter on an F1 car is worth the cost, so carbon disc brakes have been the de facto choice since the early teething problems were worked out in the eighties.

Over this time, the disc and pad pairing has been rapidly developed. They are both made from the same friction material and thus both wear out at similar rates. Maintaining a working temperature has been the challenge with these brakes – too cool (<300c) and the brakes don't bite as hard, too hot (>1000c) then the material oxidizes and wear increases. Keeping heat in the brakes is achieved with the careful sizing of the brake ducts, and this is less of a problem. However, overheating is a much greater issue. If the brakes are run white hot for too long, the oxidisation will wear the disc too thin, and the disc can fail catastrophically. Initially, radial cooling holes like steel discs were run. As teams were able to exploit the brake materials even more, they needed more cooling, so the number of cooling holes increased commensurately. From 100 in 2005 to some 1500 in 2019, the cooling holes are at the point where any more would structurally weaken the disc too much. This limitation is based on the rules that the disc must only be 32mm thick and capped at 278mm. These rules work to prevent even more powerful and expensive brakes, while also allowing them to be fitted inside the regulation sized 13" wheel rim. At this size, the brake disc weighs just 1200 grammes.

In first practice, a new pair of discs/pads will be bedded in, then removed and reused as the qualifying\race brakes. Meanwhile, a used set will be fitted for the rest of free practice which gives the parts a life of just 500 miles! Brake material is supplied to the team by two key suppliers: Brembo and Carbone Industries.

The disc mounts the axle via an intermediate ring, known as a disc bell. This is a precision-machined part that matches the inner splines on the disc and the corresponding splines on the axle. The splines do the majority of transferring the torque from disc to axle, although bolts are also used. These are limited as the hole for the bolt invites stress into the assembly.

Teams may manufacture their own disc bells, or the brake manufacturer may do so. Either way, the precision is crucial to prevent stress occurring which may see the disc or the bell fail.

Cooling for the disc is routed around the upright in carbon fibre ducting and into the cooling hole son the inside of the disc. Every team has their own method of achieving this, either ducting direct to the disc or routing air through channels in the disc bell then into the disc. Gripping the disc is the calliper, again a heavily regulated part, to limit its potential performance. Current F1 callipers are limited to one per corner, six pistons, two mountings and made from aluminium based alloys. Despite these limitations, iterative design sees the Calliper as stiff for ever decreasing weights, the use of Finite Element Analysis (FEA) software packages being critical to the calliper body design. Equally, the thermal stress on the Calliper is researched with simulation tools. Heat builds up in the Calliper body as the disc runs through the central channel, making the Calliper hottest near the last of the opposing piston pairs.

Luckily, the need to cool and lighten the Calliper sees the body skeletonised, with drillings and openings around the piston bores to save weight and reject heat. Even the pistons have a ring of radial drillings to cool the piston and brake fluid behind it from the heat of the carbon friction material at work. Likewise, the carbon brake pads can have drillings to try to insulate the Calliper from the heat. Made from aluminium lithium alloy, or other aluminium alloys with a stiffness limit of 80Gpa, the Calliper body is machined from solid. Brembo is currently the dominant manufacturer and AP racing are also a common supplier, while 920e supply Racing Point and Akebono supply McLaren. Although six piston callipers are demanded by the rules, teams can run smaller numbers of pistons. Since the 2014 rules exploited more braking from the ERS-K, the rear brakes are hardly required at some circuits, only when initial braking is high is the Calliper used to brake – the rest of the braking effort coming from the regenerative braking effect. So, teams can run four piston rear callipers to save some weight, and balance the effort and cooling required from them.

If the sharp end of the braking system is the discs and Callipers, then the action all stems from the humble brake pedal. F1 brakes can no longer have any power assistance, so the brake line pressure must all be generated by the driver pressing on the pedal to operate the master cylinders. What's more, the driver brakes with solely their left foot, which needs to exert some 125kg on the pedal for the maximum braking effort. It's hard to exert such a high load with any deftness with muscle alone, but luckily for the driver, the G-forces from the braking also act on the left leg, adding to the muscle's effort to apply the 125kg pressure.

Typically, the pedal is now made from carbon fibre to the team's own design. It's a strong safety critical part, yet still weighs very little. The footplate is adapted to suit the driver's preference to hold the foot in position over bumps and through corners. Additionally, to suit different drivers, the leverage ratio between pedal and master cylinders can be achieved with different pedal designs. Currently, the pedal operates two master cylinders. These create the pressure in the fluid line to the front and rear brakes, and each master cylinder provides a separate supply of brake fluid from separate reservoirs mounted in the nose. This split system dates back to the days when brakes failed more regularly – still a safety factor nowadays. Should there be a brake failure, the car will be almost controllable with just the front or rear brakes working.

The master cylinders themselves are microcosm of F1 complexity. Still fundamentally just a piston compressing fluid within a cylinder to create pressure, the contemporary master cylinder is a two-stage device. There is a stepped piston, the initial stroke compresses the first piston to create a sudden large pressure increase, this rapidly moves the pads back into contact with the disc and then applies pressure for maximum initial braking. Then the second piston is used to maintain that pressure for the duration of the braking event. Master cylinders tend to be supplied by the Calliper supplier, although that isn't necessarily always the case. As there are two master cylinders, one each for front and rear brakes, there needs to be a means to balance the pressure between them to match the car's weight distribution and grip. The master cylinders may have different bore sizes, but there's also the adjustable bias bar mechanism. One end of each master cylinder attaches to a pivoting beam known as a bias bar. The pivot is aligned with the pedal, and if the master cylinders are equidistant along the bias bar, there's a 50%-50% split in effort between them. If the driver adjusts the bar to have one master cylinder offset more than the other, the front to rear bias can be varied. This adjustment can be achieved with a rotating adjuster or a more complex adjuster with pre-sets. This is what we used to see the driver adjusting with their hand around the lap. The bias bar still exists, but the bias is now more easily achieved with the brake-by-wire system via steering wheel buttons.

Another effect with the brake bias is not just the static split of front to rear braking, but also how the bias changes through the braking event. As the rear of the car will get lighter from weight transfer during a long braking episode, the bias ideally needs to shift with it. This used to be achieved with the pedal and bias bar geometry, but again is now much easier to adapt via the Brake-by-Wire system. Brake fluid is transferred under pressure through pipework from the master cylinders leading to each Calliper through the wishbone legs.

Wherever there is movement required, flexible braided pipes are used. Elsewhere, rigid pipes are used to maintain pressure within the system.

Since 2014, with the change in the energy recovery systems (ERS), the use of a Brake-by-Wire (BBW) system has been allowed for the rear brakes. As the ERS-K recovers energy under braking, the drag of the MGU acts as a brake, also slowing the car. However, this effect isn't constant, the braking effort from the MGU-K will vary depending on its Regen setting and how charged the battery is.

With this change in ERS braking effort, the driver will suffer imbalanced braking, sometimes getting rear braking from ERS, sometimes not and not always with any warning. So, the FIA allow a system termed BBW to control the rear brakes. There is still a rear master cylinder at the pedal, but the brake line terminates at the BBW unit mounted inside the gearbox. This unit recognises the braking demand by the driver and based on the pressure in the rear brake line, it will then know whatever regenerative braking effort the ERS will apply via a signal from the SECU. It then deducts one from the other and via a hydraulically operated active master cylinder it will apply only the pressure at the rear brakes needed to off the ERS effect, giving the driver a balanced braking event. That's the simple explanation! The actual software to give a consistent braking effort to the driver is far more complex. Moreover, the driver will get a different feel at the pedal, as the rear master cylinder is effectively capped off, so some compliance is put into the system with valves and accumulators to replicate the conventional pedal 'feel'. Being safety critical, the BBW unit has a failsafe. Should the sensors or active master cylinder fail, the brakes return to being operated by the pressure in the rear brake line. Also, to prevent any pseudo anti-lock brake software being used, wheel speed cannot be a factor in the system. Now, with electronic brake bias possible, the drivers use controls on the steering wheel to alter brake bias and brake bias migration, never needing to take a hand off the steering wheel to adjust them. So, the next time you see a driver braking into a corner from 200mph to close to a standstill, it's worth contemplating just how much is going on when the driver stamps on the pedal.

A railway brake is a type of brake used on the cars of railway trains to enable deceleration, control acceleration (downhill) or to keep them immobile when parked. While the basic principle is similar to that on road vehicle usage, operational features are more complex because of the need to control multiple linked carriages and to be effective on vehicles left without a prime mover. Clasp brakes are one type of brakes historically used on trains.

In the earliest days of railways, braking technology was primitive. The first trains had brakes operative on the locomotive tender and on vehicles in the train, where "porters" or, in the

United States brakemen, travelling for the purpose on those vehicles operated the brakes. Some railways fitted a special deep-noted brake whistle to locomotives to indicate to the porters the necessity to apply the brakes. All the brakes at this stage of development were applied by operation of a screw and linkage to brake blocks applied to wheel treads, and these brakes could be used when vehicles were parked. In the earliest times, the porters travelled in crude shelters outside the vehicles, but "assistant guards" who travelled inside passenger vehicles, and who had access to a brake wheel at their posts, supplanted them. The braking effort achievable was limited and it was also unreliable, as the application of brakes by guards depended upon their hearing and responding quickly to a whistle for brakes.

An early development was the application of a steam brake to locomotives, where boiler pressure could be applied to brake blocks on the locomotive wheels. As train speeds increased, it became essential to provide some more powerful braking system capable of instant application and release by the train operator, described as a continuous brake because it would be effective continuously along the length of the train.

In the United Kingdom, the Abbots Ripton rail accident in January 1876 was aggravated by the long stopping distances of express trains without continuous brakes, which – it became clear – in adverse conditions could considerably exceed those assumed when positioning signals. This had become apparent from the trials on railway brakes carried out at Newark in the previous year, to assist a Royal Commission then considering railway accidents. In the words of a contemporary railway official, these showed that under normal conditions it required 800 to 1200 yards to bring a train to rest when travelling at 45½ to 48½ mph, this being much below the ordinary travelling speed of the fastest express trains. Railway officials were not prepared for this result and the necessity for a great deal more brake power was at once admitted.

In British practice, only passenger trains were fitted with continuous brakes until about 1930; goods and mineral trains ran at slower speed and relied on the brake force from the locomotive and tender and the brake van—a heavy vehicle provided at the rear of the train and occupied by a guard.

Goods and mineral vehicles had hand brakes which were applied by a hand lever operated by staff on the ground. These hand brakes were used where necessary when vehicles were parked but also when trains were descending a steep gradient. The train stopped at the top of the gradient, and the guard walked forward to "pin down" the handles of the brakes, so the brakes were partially applied during the descent. Early goods vehicles had brake handles on one side only but, from about 1930, brake handles were required on both sides of good vehicles. Trains containing hand-braked vehicles were described as "unfitted": they were in use in Britain until about 1985. From about 1930, semi-fitted trains were introduced, in which goods vehicles fitted with continuous brakes were marshalled next to the locomotive, giving sufficient braking power to run at higher speeds than unfitted trains. A trial in January 1952 saw a 52-wagon, 850-ton, coal train run 127 miles (204 km) at an average of 38 miles per hour (61 km/h), compared to the usual maximum speed on the Midland main line of 25 miles per hour (40 km/h) for unfitted freight trains. In 1952, 14% of open wagons, 55% of covered wagons and 80% of cattle trucks had vacuum brakes.

In the early days of diesel locomotives, a purpose-built brake tender was attached to the locomotive to increase braking effort when hauling unfitted trains. The brake tender was low, so that the driver could still see the line and signals ahead if the brake tender was propelled (pushed) ahead of the locomotive, which was often the case. By 1878 there were over 105 patents in various countries for braking systems, most of which were not widely adopted.

As train loads, gradients and speeds increased, braking became a more significant problem. In the late 19th century, significantly better continuous brakes started to appear. The earliest type of continuous brake was the chain brake which used a chain, running the length of the train, to operate brakes on all vehicles simultaneously. The chain brake was soon superseded by air-operated or vacuum operated brakes. These brakes used hoses connecting all the wagons of a train, so the operator could apply or release the brakes with a single valve in the locomotive.

These continuous brakes can be simple or automatic, the essential difference being what happens should the train break in two. With simple brakes, pressure is needed to apply the brakes, and all braking power is lost if the continuous hose is broken for any reason. Simple non-automatic brakes are thus useless when things really go wrong, as is shown with the Armagh rail disaster. Automatic brakes on the other hand use the air or vacuum pressure to hold the brakes off against a reservoir carried on each vehicle, which applies the brakes if pressure/vacuum is lost in the train pipe. Automatic brakes are thus largely "fail safe", though faulty closure of hose taps can lead to accidents such as the Gare de Lyon accident.

The standard Westinghouse Air Brake has the additional enhancement of a triple valve and a local reservoir on each wagon, enabling the brakes to be applied fully with only a slight reduction in air pressure, reducing the time that it takes to release the brakes as not all pressure is voided to the atmosphere. Non-automatic brakes still have a role on engines and first few wagons, as they can be used to control the whole train without having to apply the automatic brakes.

Most tractive units, passenger coaches and some freight wagons are equipped with a hand-operated parking brake (handbrake). This acts directly (mechanically) on the vehicle's brake linkage. The activation of such a brake prevents wheel rotation independently of the pneumatic brake and is therefore suitable for securing parked wagons and coaches from unintentional movement. Only mechanical brakes can be used for this purpose, since the holding power of air brakes can decrease due to unavoidable leaks.

There are two types. The handbrake that can be operated on board the vehicle is used firstly to prevent it from rolling away and secondly to regulate the speed for certain shunting operations and to stop trains if the automatic brake fails. It is usually designed as a screw brake and is operated from a brakeman's platform or, in the case of passenger coaches, from inside the coach, usually from an entrance area. On UIC freight wagons, this braking weight is framed in white (white like the rest of the brake inscription, alternatively black on a white or light-coloured background). Hand brakes on tenders and tank locomotives are often designed as counterweight brakes.

The manually operating parking brake is only suitable for securing static railway vehicles from rolling away. It can be designed as a hand wheel or as a spring-loaded brake, the operating handles are marked in red frames on freight wagons. A direction-dependent pawl brake is often installed in vehicles on rack railways. It only brakes when going downhill. When driving uphill, the applied ratchet brake is released by a ratchet mechanism and prevents the train from rolling backwards.

The higher performing EP brake uses a "main reservoir pipe" feeding air to all the brake reservoirs on the train, with the brake valves controlled electrically with a three-wire control circuit. If the wire is disconnected, the brakes automatically apply, so the fail-safe nature of other brake systems is retained. This provides between four and seven braking levels, depending on the class of train. It also allows for faster brake application, as the electrical control signal is propagated effectively instantly to all vehicles in the train, whereas the change in air pressure which activates the brakes in a conventional system can take several seconds or tens of seconds to propagate fully to the rear of the train. This system is not however used on freight trains due to cost.

Electronically controlled pneumatic brakes (ECP) are an American development of the late 20th Century to deal with very long and heavy freight trains and are a development of the EP brake with even higher level of control. In addition, information about the operation of the brakes on each wagon is returned to the driver's control panel. With ECP, a power and control line is installed from wagon to wagon from the front of the train to the rear. Electrical control signals are propagated effectively instantaneously, as opposed to changes in air pressure which propagate at a rather slow speed limited in practice by the resistance to air flow of the pipework, so that the brakes on all wagons can be applied simultaneously, or even from rear to front rather than from front to rear. This prevents wagons at the rear "shoving" wagons at the front, and results in reduced stopping distance and less equipment wear. There are two brands of ECP brakes available in North America, one by New York Air Brake and the other by Wabtec. These two types are interchangeable.

Electromagnetism is a branch of physics that deals with the study of the electromagnetic force, which is one of the four fundamental forces of nature. It describes the interaction between electrically charged particles and magnetic fields. Electromagnetic phenomena encompass a wide range of phenomena, including the behaviour of electrically charged particles when subjected to electric and magnetic fields, the generation of electromagnetic waves such as light, and the electromagnetic properties of matter. Key concepts in electromagnetism include electric fields, magnetic fields, electromagnetic induction, Maxwell's equations, and the electromagnetic spectrum. This field of study has significant applications in various areas, including electrical engineering, electronics, telecommunications, and modern technology.

Brake connections between wagons may be simplified if wagons always point the same way. An exception would be made for locomotives which are often turned-on turntables or triangles. On the new Fortescue railway opened in 2008, wagons are operated in sets, although their direction changes at the balloon loop at the port. The ECP connections are on one side only and are unidirectional.

Electromagnetism is a fundamental force of nature that unifies electric and magnetic phenomena into a single framework, described by Maxwell's equations. These equations mathematically express how electric charges and currents produce electric and magnetic fields, and how these fields in turn affect charges and currents.

Some of the key concepts that must be understood are that an electric field is a region around an electrically charged object where another charged object experiences an electric force. Electric fields are produced by electric charges and are characterized by their strength and direction. A magnetic field is a region around a magnet or a moving electric charge where another magnetic or moving charged object experiences a magnetic force. Magnetic fields are produced by magnets, electric currents, and changing electric fields. Electromagnetic induction is the process by which a changing magnetic field induces an electric current in a conductor. This phenomenon is the basis for the operation of electric generators, transformers, and inductive charging systems. Maxwell's equations are a set of four fundamental equations that describe how electric and magnetic fields behave and interact. They were formulated by James Clerk Maxwell and are foundational to the theory of electromagnetism. Electromagnetic waves are propagating disturbances in electric and magnetic fields that travel through space at the speed of light. Examples include radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation. It includes radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays, arranged in order of increasing frequency and decreasing wavelength.

Electromagnetism has numerous applications in everyday life, technology, and science. It underpins the functioning of electrical circuits, motors, generators, transformers, communication systems, medical imaging devices, and much more. Understanding electromagnetism has been essential for the development of modern technology and has revolutionized fields such as electronics, telecommunications, and energy production.

An electromagnetic braking system is a sophisticated mechanism that harnesses the principles of electromagnetism to bring a moving object to a halt. Unlike traditional friction-based braking systems, which rely on the physical contact between brake pads and rotors to generate stopping force, electromagnetic braking operates without any mechanical contact, offering numerous advantages in terms of efficiency, durability, and precision. In this system, when the brakes are engaged, an electric current is passed through a coil or series of coils, creating a magnetic field. This magnetic field interacts with the metal components of the braking system, typically a conductive disc or rail, inducing eddy currents. These eddy currents, in turn, produce a force opposing the motion of the object, effectively slowing it down. By controlling the intensity and duration of the electric current, the braking force can be finely tuned, allowing for smooth deceleration or rapid stops depending on the requirements. Electromagnetic braking systems are commonly found in applications where precise control, high performance, and minimal wear and tear are paramount, such as high-speed trains, elevators, hybrid and electric vehicles, and industrial machinery. They offer significant advantages over traditional braking systems, including reduced maintenance costs, improved energy efficiency, and enhanced safety due to their ability to provide consistent

braking force regardless of environmental conditions or wear. As technology continues to advance, electromagnetic braking systems are poised to play an increasingly important role in shaping the future of transportation and industrial automation, offering a sustainable and reliable solution for deceleration, and stopping needs.
The working of an electromagnetic braking system, the steps are as follows,

The process begins with the activation of the braking system, which triggers the flow of an electric current through a coil or set of coils within the braking mechanism. This current is typically provided by a power source, such as a battery or generator. As the electric current flows through the coils, it creates a magnetic field around them according to Ampere's law. This magnetic field extends into the surrounding space, forming a zone of influence where the braking action will occur. When the braking system is engaged, the moving object, such as a vehicle's wheel or a rotating machinery component, enters the magnetic field generated by the coils. As it penetrates this field, it interacts with the magnetic lines of force, inducing eddy currents within its conductive material, according to Faraday's law of electromagnetic induction. These eddy currents, circulating within the material of the moving object, create their own magnetic field, which opposes the original magnetic field generated by the coils. This opposition generates a resistive force, often referred to as electromagnetic braking force or electromagnetic drag force, which acts against the direction of motion of the object. The resistive force produced by the interaction between the induced currents and the original magnetic field gradually slows down the motion of the object. This deceleration process continues until the object comes to a complete stop or reaches the desired lower speed. The intensity and duration of the electric current flowing through the coils can be precisely controlled and adjusted according to the requirements of the braking application. This control allows for fine-tuning of the braking force, enabling smooth and precise deceleration tailored to the specific operational needs, whether it's gradual slowing down or rapid stopping. Electromagnetic braking systems offer several advantages over traditional friction-based braking systems. These include reduced wear and tear on braking components, improved efficiency due to the absence of physical contact and resulting friction, enhanced safety and reliability, and the ability to provide consistent braking performance regardless of environmental conditions.
By harnessing the principles of electromagnetism, electromagnetic braking systems provide a sophisticated and versatile solution for a wide range of applications, from transportation and

industrial machinery to elevators and amusement park rides, where precise control and reliable braking performance are essential.

Electromagnetic braking systems are integral components across a spectrum of industries, owing to their exceptional versatility and performance. In the realm of transportation, they serve as linchpins in high-speed trains, facilitating precise deceleration without the wear and tear associated with traditional friction-based braking systems. Moreover, in the burgeoning electric and hybrid vehicle sector, electromagnetic braking systems shine as pivotal elements of regenerative braking, converting kinetic energy into electrical energy during deceleration, thus enhancing overall efficiency and extending vehicle range. Beyond transportation, industrial machinery benefits immensely from the deployment of electromagnetic brakes, particularly in sectors reliant on rotating components. From machine tools requiring swift yet controlled stops to conveyor systems necessitating precise speed regulation, electromagnetic braking systems provide the agility and accuracy demanded by modern manufacturing processes. Furthermore, in the renewable energy arena, these systems play crucial roles in both wind and hydropower applications, ensuring optimal turbine speed control for efficient energy production and grid stability. Even in the realm of entertainment, electromagnetic braking systems contribute to the exhilarating experiences offered by amusement park rides, where they govern vehicle speed with precision, ensuring both safety and excitement for riders. The widespread adoption and continuous advancement of electromagnetic braking systems across these diverse sectors underscore their indispensability and potential for further innovation in the modern technological landscape.

The need for electromagnetic braking systems stems from the limitations and challenges associated with traditional friction-based braking methods, as well as the evolving requirements of modern industries and technologies. The key reasons why electromagnetic braking systems are increasingly sought after are that electromagnetic braking systems offer precise control over braking force and deceleration, allowing for smooth and accurate stopping of moving objects. This level of control is essential in applications where precise positioning, speed regulation, and safety are paramount, such as high-speed trains, elevators, and industrial machinery. Unlike friction-based braking systems that dissipate braking energy as heat, electromagnetic braking systems can capture and convert kinetic energy into electrical energy through regenerative braking. This energy recovery capability improves overall efficiency and reduces energy consumption, particularly in electric and hybrid vehicles and renewable energy systems. Since electromagnetic braking systems operate without physical contact between braking components, they experience minimal wear and tear compared to traditional friction-based brakes. This results in reduced maintenance requirements, longer lifespan of braking components, and lower operating costs over time. Electromagnetic braking systems can be tailored to suit a wide range of applications and operational requirements. They can be integrated into various systems, from transportation vehicles to industrial machinery, elevators, and amusement park rides, demonstrating their versatility and adaptability across different industries. The precise control and consistent braking performance offered by electromagnetic braking systems enhance safety and reliability in diverse applications. These systems can provide stable braking force regardless of external factors such as temperature, humidity, or surface conditions, reducing the risk of accidents and ensuring operational reliability in critical scenarios. With an increasing focus on sustainability and environmental stewardship, electromagnetic braking systems align with efforts to reduce carbon emissions and improve resource efficiency. By enabling energy recovery and optimizing braking efficiency, these systems contribute to greener and more sustainable transportation and industrial practices.

Overall, the need for electromagnetic braking systems arises from the demand for superior performance, efficiency, safety, and environmental responsibility in modern industrial and transportation applications. As technology continues to advance, electromagnetic braking systems will play an increasingly vital role in meeting these evolving needs and shaping the future of braking technology.

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.

The main function of the electromagnetic brake system is to stop the rotation of the wheel without losing energy as friction. The electromagnets are being 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.

The design of the electromagnetic braking system started with making of the schematic diagram and arrangement of components according to the requirements of the project. To get the optimal flux distribution and accurate power output, the arrangements of 9 sections of Solenoids/ Copper magnets was chosen. The arrangement was made in such a way that the negative and positive sections were arranged alternately in a manner of 2 positive sections alternating with 1 negative section for the outer ring of magnets and vice versa for the inner rings i.e., 2 negative sections alternating 1 positive section.

2. Literature review

"Electromagnetic Braking system" by N. B. Totala, Priya Bhosle, Seema Jarhad, Kamlesh Kuchekar have discussed about the limitations of drum brakes, hydraulic brakes and pneumatic brakes electromagnetic brake is a better and reliable solution. By using the electromagnetic brake as supplementary retardation equipment, the friction brakes can be used less frequently, and therefore practically never reach high temperatures. The brake linings would last considerably longer before requiring maintenance, and the potentially "brake fade" problem could be avoided. Thermal stability of the electromagnetic brakes is achieved by means of the convection and radiation of the heat energy at high temperature. The electromagnetic brakes have excellent heat dissipation efficiency. Electromagnetic brakes have better thermal dynamic performance than regular friction brakes.[1]

"Improved braking torque generation capacity of an Eddy current brake with time varying magnetic field: A numerical study" by Kerem Karakoc a, n, Edward J. Park a, b, Afzal Suleman Eddy current brakes are electrically controlled and Eddy current brakes (ECB) are electrically controlled and non-contact actuators used as assistive brakes in vehicles. ECBs exhibit insufficient generated braking torque at low speeds. In order to overcome this, the use of AC magnetic fields with fixed and variable frequencies in different waveforms is investigated at both low and high speeds. Finite element analysis validated by an existing analytical model is performed for DC and AC magnetic fields. In addition, the frequency of the applied field is optimized using genetic algorithms on a generic ECB configuration.[2]

"An investigation on braking systems used in Railway vehicles" by Mustafa Gunaya, Mehmet Erdi Korkmaz have discussed about the high safety and comfort expectations under varying conditions have required the development of brake systems in railway vehicles. The main factors affecting the performance and function of the brake system are braking force, mass, and speed of the vehicles, stopping or braking distance, railway condition and environmental factors. In this work, the brake systems such as disc and tread brakes, dynamic brakes, aerodynamic brakes, vacuum brakes, electro-pneumatic brakes have been reviewed. The braking systems are examined in two main groups as adhesion dependent and independent brakes. Evaluations have been made on brake disc-pad mechanisms which are the most important components in all brake systems in terms of safe operation especially for freight and high-speed trains. In this context, the experimental and numerical analysis studies on the interactions of brake system components including brake disk-pad geometries and material properties have been considered. Accordingly, research and development studies based on finite element modeling and prototype manufacturing is recommended to produce high efficiency and safety brake systems compatible with rail system vehicle.[3]

"An analysis of permanent magnetic eddy current Braking system" by Shivshankar R, Dr.G.V. Naveen Prakash have discussed about investigations on permanent magnet eddy current braking system were carried out with Neodymium – Iron – Boron (NdFeB) magnets of 12.5 mm thickness and 50 mm diameter. Investigations were carried out with Copper, Aluminium, Brass discs of 4 mm, 6 mm and 8 mm thickness at 2000 rpm, 3000 rpm and 4000 rpm totalling to 27 experiments. It is observed that Copper disc 6 mm thickness has 84.8%, 86.3%, 81.8% speed reduction. Time taken for speed reductions are 16 seconds, 15 seconds, and 22.5 seconds respectively. Aluminium disc of 8 mm thickness was observed to have 70.6%, 86% and 85.1% speed reduction. Time taken for speed reductions are 3.3 seconds, 10 seconds, and 18 seconds respectively. Brass disc of 4 mm thickness was observed to have speed reduction of 61.8%, 60% and 57.4%. The time taken for speed reductions are 25.2 seconds, 20 seconds, and 24.5 seconds respectively. Considering that the density of Aluminium is less, cost effective and time taken for higher percentage of speed reduction is less compared to Copper and Brass, Aluminium disc of 8 mm thickness is the best material for transportation and other applications.[4]

"A Design method for booster motor for brake by wire system" by Bumin meng, Zhengzhao Zhou have discussed that the brake-by-wire (BBW) system is an essential part of the intelligent electric vehicle, which is determination of the braking safety and recovery efficiency. To design a safe and efficient booster motor, the design of booster motor for BBW system is discussed in this paper. Through comparative analysis, experimental simulation and assessment argument, the scheme of designing a booster motor for brake-by-wire system is completely described. First, the mainstream structure of the BBW system and the main challenges it faces in the assisted motor are discussed. Second, comparing the motors of different types and structures, the motor body and control system scheme suitable for the characteristics of the booster motor system are determined. Then, through the simulation analysis of the ansoft and matlab, the optimization scheme of the motor and performance improvement are proposed. Further, through the actual design of a set of the booster motor system, the safe and efficient motor designing are verified, and the problems involving functional safety are discussed. Finally, focus on the problem while simulation and experiment, some important countermeasures to improve current technology and prospect of in-depth study are pointed out.[5]

"Simultaneous measurement of moment of inertia and braking torque of electric motors applying additional inertia" by Attila Szanto, Eva Adamko, Gyorgy Juhasz, Gusztav Aron Szik Have discussed about a method for the simultaneous measurement of the moment of inertia and braking torque of the rotor of electric motors. The procedure is based on retardation tests on the motor applying additional loads on its rotor with different moments of inertia but equal masses. The equal masses provide equal braking torques in the supporting bearings. Besides the detailed description of the experimental setup and method – a procedure for determining the optimal values of the loading moments of inertia is also presented. At these optimal values, the errors of the experimentally determined moment of inertia and braking torques are minimal. Additionally, the effect of the temperature change of the bearings on the accuracy and precision of the method is also analyzed and discussed. Finally, the method's experimentally validated accuracy and precision are reported, and measurement results on an induction motor are presented as an example.[6]

"Analytical modelling of eddy current brakes with application of time varying magnetic fields" by Kerem karakoc, Afzal Suleman have discussed that Eddy current brakes have several potential advantages, i.e., contactless operation, faster response, reduced number of components and easy implementation of various controllers. However, the braking torque generation is limited at low speeds. Here, to increase the braking torque generation, time varying field application is studied. A new analytical model is derived for in-depth theoretical analysis and future controller design purposes. The braking torque generated is calculated using magnetic vector potential and eddy currents. Then, this model was validated using an accurate finite element model. Results show that the braking torque increases with the application of time-varying fields.[7]

"Dynamic mechanical characteristics of NdFeB in electromagnetic brake" by Lei Li, Gou-Lai Yang have discussed about with the continuous development of artillery, the disadvantages of hydraulic recoil brakes gradually appear. At the same time, the appearance of high-performance NdFeB permanent magnet makes it possible to apply electromagnetic braking technology to recoil mechanism. In this paper, prototype tests of a certain artillery were carried out to verify the feasibility of the electromagnetic brake (EMB) and obtain the electromagnetic braking force. Due to the brittleness of NdFeB, to eliminate the worry about the safety of EMB, SHPB experiments of NdFeB were carried out. Then, based on the assumption of uniform crack distribution, the law of crack propagation and damage accumulation was described theoretically, and the damage constitutive model suitable for brittle materials was proposed by combining the Zhu-Wang-Tang (ZWT) equation. Finally, the numerical simulation model of the artillery prototype was established and through calculation, the dynamic mechanical characteristics of NdFeB in the prototype were analyzed.[7]

"Design and Fabrication of Electromagnetic braking system" Krushabh Chaudahri, Vijay Talhodikar, Rakesh Kawale have discussed that electromagnetic braking system is a modern technology braking system used in light motor & heavy motor vehicles. This system is a combination of electro-mechanical concepts. It is electromagnetic brake is an essential complement to the safe braking of heavy vehicles. It aims to minimize the brake failure to avoid the road accidents. It also reduces the maintenance of braking system. An advantage of this system is that it can be used on any vehicle with minor modifications to the transmission and electrical systems. An Electromagnetic Braking system uses Magnetic force to engage the brake, but the power required for braking is transmitted manually. The disc is connected to a shaft and the electromagnet is mounted on the frame when electricity is applied to the coil a magnetic field is developed across the armature because of the current flowing across the coil and causes armature to get attracted towards the coil.[8]

"Design and fabrication of Efficient Electromagnetic braking system for Bangladesh railway: A prototype approach" by Raise Uddin Chowdhury, Rafat Mahmud Hridoy. Md. Rafiquzzaman, Aftab Uddin Sifat have discussed that electromagnetic brake is a new and revolutionary concept. Electromagnetic braking system is a modern technology braking system used in light motor & heavy motor vehicles. The purpose of this research work is to develop a concept of designing and fabricating an electromagnetic braking system for Bangladesh railway which can be used in lieu of existing frictional braking system. The methodology is based on creating a magnetic field on the heads of E-shape core through electricity and attaching circular ferromagnetic material parts under every train carriage. This created magnetic field penetrates train wheels and circular ferromagnetic parts to steadily reduce train motion. This research work finds the proposed electromagnetic braking system reliable and efficacious. The proposed electromagnetic braking system is found to be efficacious for both high and low speed train. This paper presents the implementation of electromagnetic braking system through a prototype.[9]

"Application of Electromagnetic Braking Torque and Different braking modes programmed with ATMEGA328P microcontroller in Electromagnetic Braking System" by Sirsendu Mahata, Kingshuk Kundu, Pritam Chakraborty have discussed that electromagnetic braking system uses magnetic force to stop the vehicle. In the present design, a disc with requisite number of solenoids has been arranged for achieving the purpose. While trying to stop the vehicle, the pilot needs to turn on the brake switch to supply electric power. Thereby a magnetic field will be developed on the ambience of the solenoids which will prohibit the rotation of the disc and eventually the vehicle will come to a halt. The wheel torque is evaluated from various experimental data and in this paper a comparison is made between the braking torque and wheel torque. Realistic calculation in this paper reveals that value of braking torque using electromagnetic brake can be made greater than the torque of the wheel, which is needed to stop any vehicle. Different braking modes have been achieved with Arduino, ATmega328p microcontroller-based programming using ultrasonic sensors.[10]

"Design and fabrication of Electromagnetic Braking System: A Critical Review" by Mr. Vishwjeet Ambade, Mr. Saurabh Kawale, Mr. Pradeep Harinkhede have discussed that the electromagnetic braking brake system uses magnetic force to reduce or stop the speed of rotation of the wheels. The concept of electromagnetic braking comes with the blessings and barriers of calliper pressure and heat dissipation. The electromagnetic braking system relies on magnetic electricity to transport parts of the brake gadget. The device introduces the command that if the magnetic field is initiated inside the rotating disk, then the opposite side produces a modern eddy motion or rotation of the disc brake. Highlights of the electromagnetic braking machine are braking discs, solenoid, circuit board, sloping converter, and battery power. In other words, human operators, senders, drivers, and passengers, measure the context of a news situation using idiosyncratic information or linguistic evidence in common decisions. The braking device is an ancient example of speeding up the braking system at the same time and minimizing losses. In this paper, the focus is on comparisons between Electromagnetic brake machines and traditional exhaust braking gadgets. The focus of the Electromagnetic machine to improve the safety of the tool is currently to keep the loss to a minimum. The only purpose of the research is to look at the benefits of both structures in addition to exposing their ambiguity.[11]

"Comparison of regenerative braking energy recovery of a DC Third rail system under various operating conditions" by Dick sang Hoo, Kein Huat Chua, yun Send Lim, Stella Morris have discussed that accurately representing the train trajectory characteristics resulting from the railway power system and the dynamic load changes based on the train position can be challenging. The power exchange between trains and the fluctuating rail resistance between them add to the computational complexity. Given these challenges, the aim of this study is to develop a comprehensive model of DC third rail systems based on the operational requirements and parameters of the MRT Line 2 Malaysia. Moreover, the simulation method should be adaptable to investigate potential energy savings through regenerative braking systems, thereby maximizing the energy efficiency of electric railways. This study outlines the development of a framework that models the power flow within an electric rail network using a specific case study example. A simulation is presented with 15 trains operating on a double rail track to validate the model for multiple train operations. Notably, the simulation methodology developed in this research is unique compared to other approaches found in relevant literature. It integrates both the power system and train trajectory, incorporating actual system information from a practical DC third rail system to generate precise trajectory outcomes. The results show that implementing a regenerative braking energy recovery system in all traction power substations (TPSSs) has the potential to achieve significant electrical energy savings of up to 55.75% for the entire system.[12]

"Multi-domain Modelling of Electric Vehicles including lead acid battery Dynamics" by Luis Silva, Pablo M., Cristian H. De Angelo have discussed about a multi-domain model of an Electric Vehicle (EV) including lead-acid battery dynamics is presented. The model is composed by the batteries, the electric traction system, and the mechanical model. The modeling formalism chosen is Bond Graph (BG) that allows representing each EV sub-system in a compact and modular way. A key benefit of BG is that the sub-systems developed can be easily interconnected independently of their physical nature. Once the complete model is constructed the whole system performance can be evaluated. Simulation results are presented to demonstrate the multi-domain feature of the proposal and the energetic performance with/without regenerative braking.[13]

"Regenerative Braking control strategy for pure electric vehicles based on fuzzy neural network" by Wanmin Li, Haitong Xu, Xiaobin Liu, Yang Wang have discussed about the efficiency and safety of regenerative brake energy recuperation systems for electric vehicles. A three-input single-output fuzzy controller is developed to allocate hydraulic and electric braking forces, considering brake intensity, vehicle speed, and battery SOC's impact on regenerative braking performance. Fuzzy neural networks are utilized due to their effectiveness in solving complex, nonlinear, and fuzzy systems, along with their robustness to parameter changes and external disturbances. The fuzzy process of the controller is optimized using a self-tuning algorithm for designing membership function parameters, resulting in a fuzzy neural network controller. Moreover, electric and hydraulic braking forces are redistributed. Simulation using AVL Cruise software is conducted under NEDC and FTP-75 working conditions. The suggested brake energy recovery control approach using fuzzy neural networks successfully recovers braking energy, achieving energy recovery efficiencies of 14.52% and 39.61% under NEDC and FTP-75 conditions, respectively.[14]

"A new electric braking system with energy regeneration for a BLDC motor driven electric Vehicle" by Joseph Godfrey, V. Sankarnarayanam have discussed that a new electric braking system is proposed for a brushless DC (BLDC) motor driven electric vehicle (EV) in this paper based on stopping time and energy regeneration. This new braking system is developed by combining various regenerative methods and plugging. Other than the existing performance measures such as boost ratio, braking torque, and maximum conversion ratio; stopping time and energy recovery for various methods are studied for different running conditions. It is observed that the stopping time is less for plugging and increases in the order of two, three and single switch method. In addition, energy recovery is better for single and three switch method. Based on these performances, a new braking strat egy is proposed which combine all the regenerative braking methods including plugging and switch among themselves based on the brake pedal depression. The effectiveness of the proposed method is shown using both simulation and experiment results.[15]

"Simple Circuit Simulation Models for Eddy Current in Magnetic Sheets and Wires" by y. Shindo, O. Noro have discussed about FeGaB thin films have excellent magnetostrictive and soft magnetic properties. Unfortunately, severe eddy current loss (ECL) due to its low resistivity makes its employment in energy-efficient structures challenging. Inserting insulating layers into magnetostrictive films is an effective technique to suppress ECL and enhance soft magnetic characteristics. Unresolved is how to exhaustively account for multiple contributing factors and obtain the optimal composite materials design. This study constructed an ECL simulation model of a soft magnetic composite (SMC) using finite element analysis in the COMSOL Multiphysics software.[16]

"Design and Fabrication of Electromagnetic Braking System." By Sharad Khot, Shubhangi Chougule, And Rahul Kundiya have discussed that This system is designed as a "frictionless" system and although it is not completely frictionless it eliminates the need for standard hydraulic brake pads and rotors which wear and fail due to friction and material loss. This could save the consumer time and money in maintenance. This project aims to create a electromagnetic braking system model capable of applying brakes without any friction loss and without losing the energy supplied. It uses two electromagnets which runs by the supply of power from the circuit. Also, there is a wheel which is attached to the motor so when the power the supplied, by the help of motor the wheel rotates. Then a fan is attached near electromagnets to cool the electromagnets from excessive heating. A metal bar is in the vicinity of the electromagnets and wheel so when the electromagnets produce eddy currents which stops the rotating wheel or rotor. This model helps in a way to be a used a retardation equipment in vehicles.[17]

"Analysis of Electromagnetic Braking System" by Dr. S. R. Pawar, Subham Satam, Saif Ali Shaikh, and Amit R. Shah have discussed about development an electromagnetic braking system model capable of applying brakes without any friction loss and without losing the energy supplied. It uses two electromagnets which runs by the supply of power from the circuit. Also, there is a wheel which is attached to the motor so when the power the supplied, by the help of motor the wheel rotates. Then a fan is attached near electromagnets to cool the electromagnets from excessive heating. A metal bar is in the vicinity of the electromagnets and wheel so when the electromagnets produce eddy currents which stops the rotating wheel or rotor. This model helps in a way to be used as retardation equipment in vehicle.[18]

The literature review covers a broad spectrum of research on electromagnetic braking systems, emphasizing their advantages over traditional braking methods and exploring different aspects of design, performance, and applications. Studies compare electromagnetic brakes with drum, hydraulic, and pneumatic brakes, highlighting their reliability and thermal stability. Research focuses on improving braking torque generation, optimizing braking efficiency, and exploring new control strategies, particularly for electric vehicles and railways. Overall, the literature underscores the significance of electromagnetic braking systems in enhancing safety, efficiency, and performance across various industries and applications.

2.1 Problem Statement

Increasing demands for efficient, reliable, and sustainable braking solutions in various industries have underscored the need for advancements in electromagnetic braking systems. While traditional friction-based braking methods exhibit limitations such as wear, maintenance requirements, and thermal instability, electromagnetic braking systems offer promising alternatives. However, challenges remain in optimizing braking performance, control strategies, and integration with existing systems to meet the evolving needs of modern applications. Thus, there is a critical need for research and development focused on enhancing the design, efficiency, and effectiveness of electromagnetic braking systems to address these challenges and unlock their full potential across diverse industries, including transportation, industrial machinery, renewable energy, and entertainment.

2.2 Project objectives

i. **Optimization of Electromagnetic Braking Efficiency**: Efficiency is increased significantly compared to conventional braking systems due to various factors like the design of the brake, materials used, and control systems.

ii. **Energy Regeneration**: This system may also include the beneficial factor such as energy regeneration ability.

iii. **Environmental Impact and Sustainability:** Environmental impact and sustainability of electromagnetic braking systems has already been proved to be more advantageous than conventional braking system.

iv. **Low Maintenance:** This system is more reliable in maintenance sector than conventional braking systems as it has less wear and tear among parts and is a frictionless and contact-less braking system.

2.3 Research gap

The percentage by which the efficiency of Braking increases is not defined accurately as there are no means to test the brakes. This can only be done after the fabrication and working is concluded.

Weight to power ratio for each commercial vehicle will be different, which hasn’t been defined accurately for each vehicle.

Amount of Force in ‘Tesla’ is not accurate as it changes according to the amount of current supplied.

3. Methodology

i. Design & Modelling

The process began with identifying the specific requirements and objectives of the braking system, including braking force, operating conditions, compatibility with existing systems, and regulatory standards. Conceptual designs were developed by exploring various configurations of the braking system components, such as coils, magnetic materials, braking discs or rails, and cooling systems. Factors such as space constraints, weight limitations, and ease of integration were considered. Mathematical modelling techniques, such as finite element analysis, were utilized to simulate the electromagnetic and mechanical behaviour of the braking system. Electromagnetic fields, eddy current generation, heat dissipation, and mechanical response were modelled to optimize design parameters. Optimization studies were conducted to determine the optimal parameters of the braking system components, such as coil geometry, magnetic field strength, and cooling system design. The aim was to maximize braking performance while minimizing energy consumption and thermal effects. Prototypes of the braking system were fabricated based on the conceptual designs and simulation results. Coils, braking discs or rails, and other components were developed using appropriate materials and manufacturing techniques. Experimental tests and validation studies were conducted on the prototypes to verify performance and reliability under various operating conditions. Braking force, response time, energy efficiency, thermal stability, and durability were tested. The design process was iterated based on experimental results and feedback, making refinements and improvements to address any identified issues or optimize performance further. The design, modelling, and experimental findings were documented in technical reports or research papers. Detailed descriptions of the methodology, results, and conclusions were provided to facilitate knowledge sharing and future research.

ii. Material Selection

The process began with understanding the specific requirements of the electromagnetic braking system, including operating conditions, braking force, temperature tolerance, and durability. Key components of the braking system that required material selection, such as the braking disc or rail, coils, and housing, were identified. Material properties required for each component were analysed based on the system requirements. Factors such as magnetic permeability, electrical conductivity, thermal conductivity, strength, and corrosion resistance were considered. Various material options that met the required properties for each component were evaluated. This included ferromagnetic materials such as iron, steel, and alloys for the braking disc or rail, and copper or aluminium for the coils. Performance testing and analysis of candidate materials were conducted to assess their suitability for the electromagnetic braking system. This involved testing for magnetic properties, electrical conductivity, thermal stability, and mechanical strength under simulated operating conditions. A cost analysis of the selected materials was performed to ensure alignment with the project budget and cost constraints. Compatibility with other components of the braking system and effective integration into the overall design were ensured for the selected materials. Potential risks associated with the selected materials, such as reliability issues, manufacturing challenges, or environmental concerns, were identified, and mitigation strategies were developed as needed. The material selection process was iterated as necessary based on testing results, feedback, and new information that arose during the design and development stages.

iii. **Analysis**

The objectives and scope of the analysis were clearly defined, including specific performance metrics to be evaluated, such as braking force, response time, energy efficiency, and thermal stability. Mathematical and computational models of the electromagnetic braking system were developed, including electromagnetic fields, eddy current generation, mechanical response, and thermal effects. Software tools such as finite element analysis (FEA) or computational fluid dynamics were used to simulate system behaviour under various operating conditions. Key parameters of the braking system, such as coil geometry, magnetic field strength, material properties, and operating conditions, were identified and assigned appropriate values based on design specifications and experimental data. Simulations of the electromagnetic braking system were conducted using the developed models and identified parameters. Simulation results were analysed to evaluate system performance, including braking force generation, response time, energy dissipation, and temperature distribution. Sensitivity analysis was performed to assess the impact of variations in key parameters on system performance. Critical parameters that significantly affected braking performance were identified and prioritized for further optimization. The accuracy of the simulation results was validated by comparing them with experimental data or analytical solutions where available. It was verified that the model accurately represented the behaviour of the actual electromagnetic braking system under different conditions. Opportunities for improving system performance through design optimization were identified. Parameters such as coil geometry, magnetic field strength, or cooling system design were adjusted to maximize braking efficiency and minimize energy consumption. Potential risks or limitations of the electromagnetic braking system were identified based on the analysis results. Factors such as reliability, durability, and safety were evaluated to ensure that the system met design requirements and regulatory standards. The analysis methodology, simulation results, and findings were documented in technical reports or research papers. Detailed descriptions of the analysis process, assumptions, and conclusions were provided to facilitate knowledge sharing and future research.

iv. **Validation**

An experimental setup was developed that closely mimicked the conditions of the electromagnetic braking system under analysis. This setup included all relevant components such as coils, braking discs or rails, power supply, and measurement instruments. Experiments were conducted to collect data on the performance of the electromagnetic braking system. Parameters such as braking force, response time, energy dissipation, and temperature distribution were measured under various operating conditions. The experimental data were compared with the results obtained from simulation models developed earlier. It was ensured that there was agreement between the experimental and simulated data within an acceptable margin of error. Sensitivity analysis was performed to assess the impact of variations in key parameters on system performance. It was determined whether changes in parameters resulted in expected changes in system behaviour. Repeat experiments were conducted to verify the repeatability and consistency of the results. It was ensured that the performance of the electromagnetic braking system was consistent across multiple trials. The performance of the electromagnetic braking system was compared against established benchmarks or standards, if available. It was verified that the system met or exceeded performance expectations. The experimental setup, data, and analysis methods were presented for review to ensure validity. The validation process, including experimental setup, data collection methods, analysis techniques, and results, was documented. Detailed descriptions of any discrepancies between experimental and simulated data and potential explanations for these differences were provided. The results of the validation process were used to identify areas for improvement in the electromagnetic braking system design or analysis methodology. Iterative changes were made as necessary to improve the accuracy and reliability of future analyses.

4. Design and Modelling of Component

i. 2D Representation

The design of the electromagnetic braking system started with making of the schematic diagram and arrangement of components according to the requirements of the project. To get the optimal flux distribution and accurate power output, the arrangements of 9 sections of Solenoids/ Copper magnets was chosen. The arrangement was made in such a way that the negative and positive sections were arranged alternately in a manner of 2 positive sections alternating with 1 negative section for the outer ring of magnets and vice versa for the inner rings i.e., 2 negative sections alternating 1 positive section.

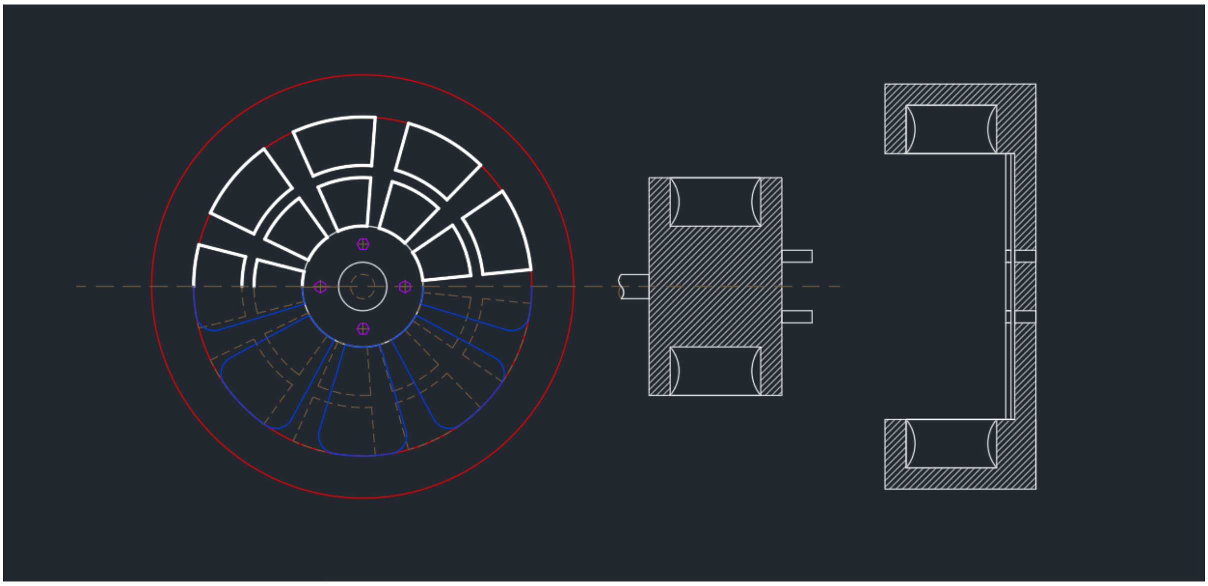


Fig. No. 1. Schematic Diagram of System Components

The Arrangement of these 9 sections of inner and outer magnets was mounted on the Hub and Casing respectively. The Hub and Casing were modelled such that they can be mounted in place of the commercial braking system having Disc/ Drum brakes. The outer casing being mount on the rim and tyre assembly will hold the outer set of the magnet rings and act in place of the commercial brake disc. The Outer casing is made of Mild Steel, which is non-magnetic as well as strong and sturdy to be used in mechanical operations. The Hub is made of the same material. It is mounted on the driven shaft and acts in place of the brake pads of a commercial brake. It is a stationary part which holds the inner magnet ring assembly.

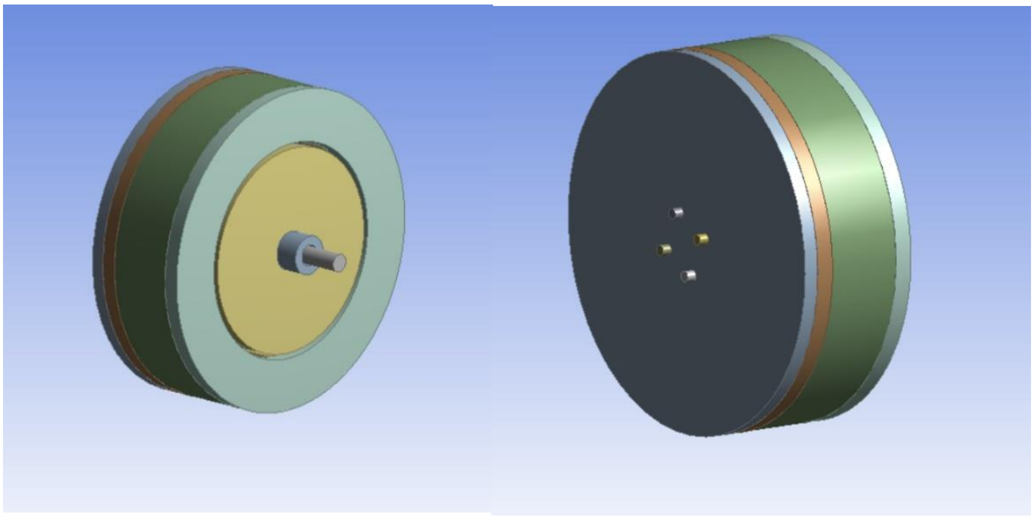


Fig. No. 2. 3D Model of Electro-magnetic Braking System.

ii. **3D Modelling**

This model was generated using AUTO-CAD. Dimensions and specifications were considered of a light commercial vehicle as the project is designed based on light commercial vehicle braking system.

According to the schematic diagram, the HUB holds the inner magnets ring assembly, and the Casing holds the Outer Magnet ring assembly.

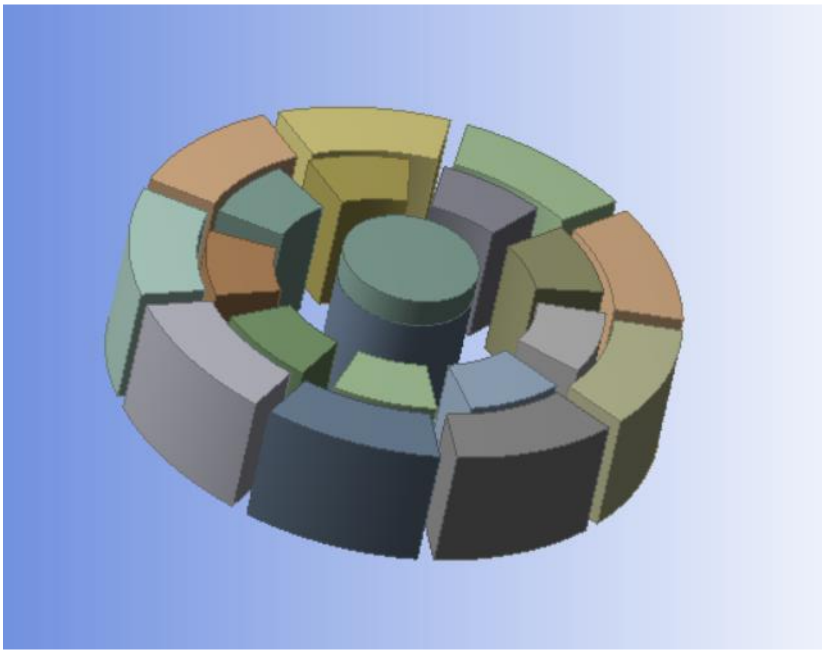


Fig. No. 3. Magnetic Ring Assembly.

The Magnets assembly are arranged as shown.

5. Result & Analysis

Meshing in Ansys involved dividing the geometry into small, simple elements to solve complex simulations accurately.

Geometry was imported or created for analysis in Ansys. The appropriate meshing method i.e., Hexa/ Prism was chosen based on the geometry and analysis requirements. Mesh controls were defined to refine or coarsen the mesh in specific regions to capture important features accurately. Mesh quality was verified to ensure elements were of suitable shape and size for accurate simulation results. The mesh quality results were obtained as,

Table No. 01. Mesh Quality

Mesh	Element Quality
Minimum	0.74929
Maximum	0.99994
Average	0.96702
Standard Deviation	3.6403e-002

Meshing settings like element size, growth rate, and bias were adjusted to optimize the mesh for the analysis. The mesh was generated and reviewed to ensure it accurately represented the geometry and captured critical details. Iterations were made on the meshing process if needed, refining, or adjusting mesh controls until satisfactory results were achieved.

The specified results of number of nodes and elements were 50771 and 8678 respectively. There was no suppression in the design. Multizone method was used while meshing. The Mapped Mesh Type was Hexa/Prism. Boundary Conditions were specified according to the model itself, no outside parameters, or spaces.

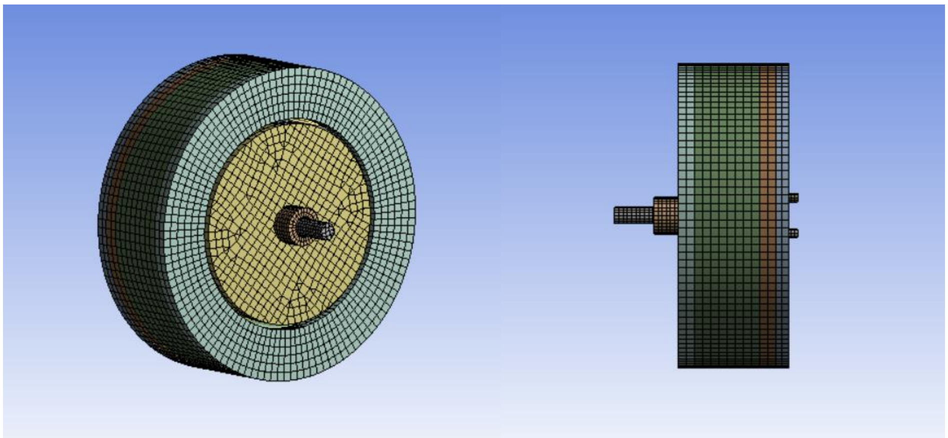


Fig. No. 4. Meshing of the Components.

The Mesh setting is defined below,

Table No. 02. Mesh Settings

Mesh Settings	
Suppressed	No
Method	Multi-zone
Mapped Mesh Type	Hexa/Prism
Surface Mesh type	Uniform
Free Mesh type	Hexa Core
Element Order	Use Global Setting
Src/Trg Selection	Automatic
Source Scoping Method	Program Controlled
Source	Program Controlled
Sweep Size Behaviour	Sweep Sized
Sweep Element Size	Default
Element Option	Solid

After the Model and Geometry was finalized, the component material was selected.
The material selection dialog box in Ansys was opened. This is usually found in the pre-processing section of the software. Ansys provides a material library containing various predefined materials. The category related to Cast Aluminium materials was looked for. Once in the Cast Aluminium materials category, the specific type of Cast Aluminium to be used was selected. Ansys typically offers a range of Cast Aluminium materials with different properties such as yield strength, Young's modulus, Poisson's ratio, density, thermal conductivity, etc. After selecting the appropriate Cast Aluminium material, it was assigned to

the relevant components or regions in the geometry. This ensured that the Cast Aluminium properties were applied to those parts during the simulation. For the magnets section, the material selection dialog box in Ansys was opened. This is usually found in the pre-processing section of the software. Ansys provides a material library containing various predefined materials. The category related to copper materials was looked for. Once in the Copper materials category, the specific type of copper to be used was selected. Ansys typically offers a range of copper materials with different properties such as yield strength, Young's modulus, Poisson's ratio, density, thermal conductivity, etc. After selecting the appropriate Copper material, it was assigned to the relevant components or regions in the geometry. This ensured that the Copper properties were applied to those parts during the simulation.

The parameters on which the component was analysed were as follows,

- **Structural Analysis – Total Deformation, Stress Plots, etc.**
- **Thermal Analysis – Temperature, etc.**
- **Magnetostatic Analysis – Magnetic Flux Density.**

6.1 Structural Analysis (Total Deformation)

The material properties of the structure were defined, including parameters. A mesh was generated for the geometry to ensure it was fine enough to capture the details of the structure accurately. Appropriate boundary conditions were applied to the model, including fixed supports, prescribed displacements, loads, or any other conditions relevant to the analysis. The analysis was set up in Ansys Mechanical or another appropriate module. The type of analysis (e.g., static, transient, etc.), the solver settings, and any other relevant parameters were specified. The analysis was solved, and Ansys computed the deformation of the structure based on the applied loads and boundary conditions. Once the analysis was complete, the results were reviewed. In the post-processing stage, the total deformation of the structure was visualized using contour plots or animations. The results were analysed to understand how the structure deformed under the given loading conditions. Attention was paid to areas of high deformation, and any potential issues or areas for improvement were identified. The results were validated by comparing them with analytical solutions, experimental data, or engineering judgment.

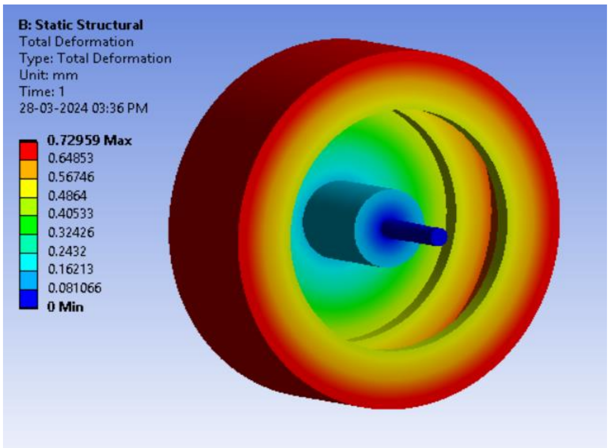


Fig. No. 5. Total Deformation of the Components.

The Component was subjected to torque of 51kN-mm, then the component was tested under basic boundary conditions.

When considering a commercial braking system, the whole system undergoes a momentum equal to the testing conditions. The permissible values for Deformation are 1mm considering Factor of safety and 1.5mm Maximum under max load conditions. The obtained values were under the permissible values indicating that the component was safe and optimal.

6.2 Structural Analysis (Equivalent Stress)

The geometry of the structure to be analysed was imported or created. The material properties of the structure were defined, including parameters. A mesh was generated for the geometry to ensure it was fine enough to capture the details of the structure accurately. Appropriate boundary conditions were applied to the model, including fixed supports, prescribed displacements, loads, or any other conditions relevant to the analysis. The analysis was set up in Ansys Mechanical or another appropriate module. The type of analysis (e.g., static, transient, etc.), the solver settings, and any other relevant parameters were specified. The analysis was solved, and Ansys computed the stress distribution of the structure based on the applied loads and boundary conditions. Once the analysis was complete, the results were reviewed. In the post-processing stage, the total stress distribution of the structure was visualized using contour plots or animations. The results were analysed to understand how the structure deformed under the given loading conditions. Attention was paid to areas of high stress distribution, and any potential issues or areas for improvement were identified.

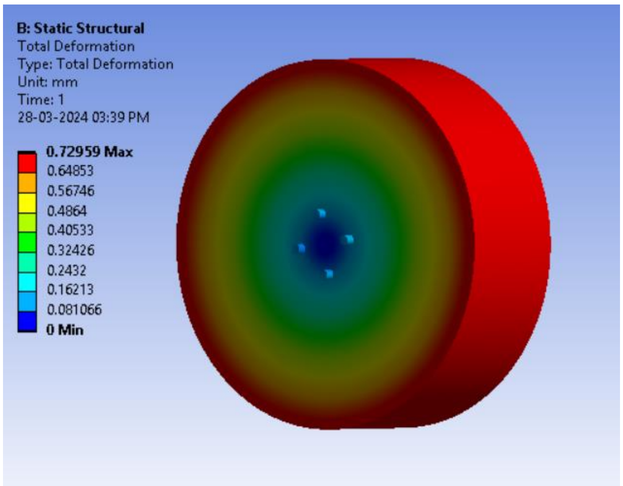


Fig. No. 6. Total Deformation of the Components. (SV)

The results were validated by comparing them with analytical solutions, experimental data, or engineering judgment.

Similarly, the permissible values for the Equivalent stress were till 140, measured in mega Pascal (MPa). The component can endure values up to 140 MPa considering FOS. And the values obtained during analysis were under the permissible values.

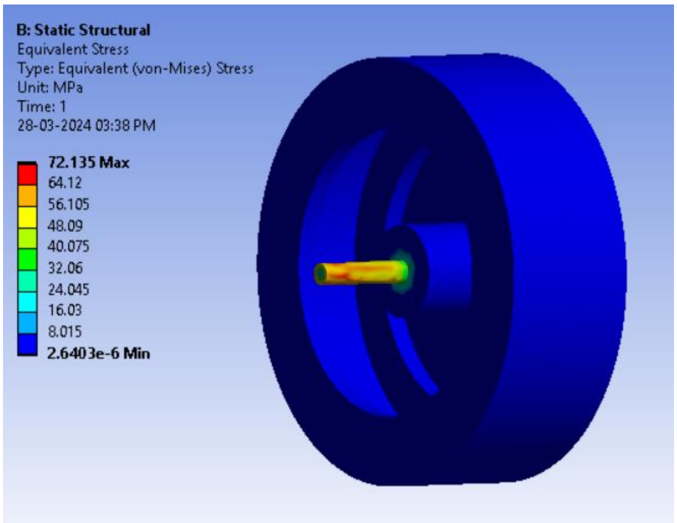


Fig. No. 7. Equivalent Stress Analysis of Component

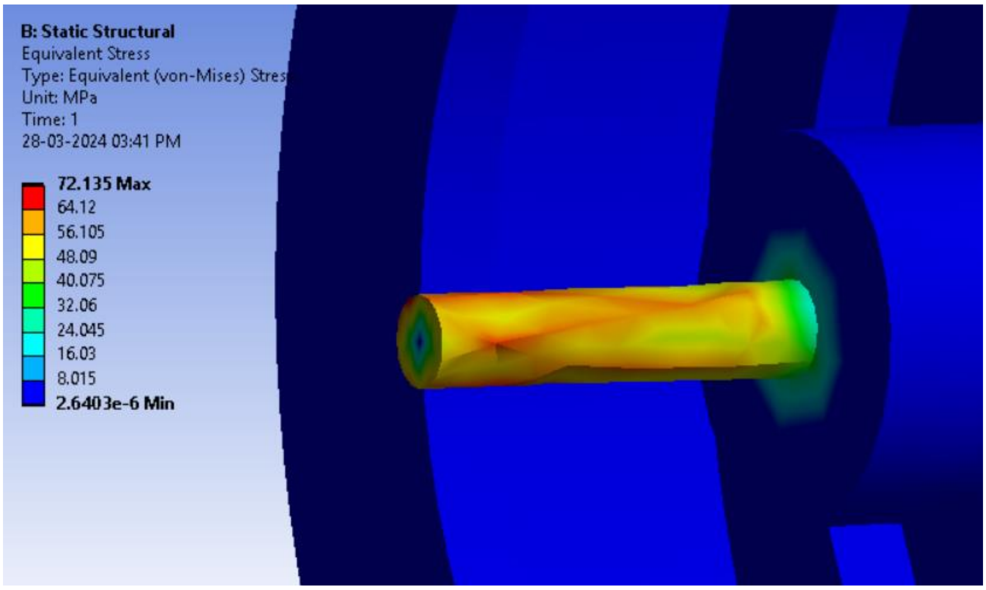


Fig. No. 8. Equivalent stress Analysis (Enlarged View)

6.3 Thermal Analysis (Temperature)

The geometry of the thermal system was imported or created in Ansys.

Material properties, including thermal conductivity, specific heat, and density, were defined for the components of the system. A mesh was generated for the geometry to discretize it into smaller elements, ensuring accurate simulation results. Boundary conditions such as initial temperatures, heat fluxes, convection coefficients, and radiation properties were applied to the model. The transient analysis was set up in Ansys, specifying the time-dependent boundary conditions, time step size, and total analysis duration. The appropriate solver settings for transient thermal analysis were configured, considering factors such as convergence criteria and solution methods. The transient thermal analysis was solved in Ansys, with the software calculating the temperature distribution over time based on the applied boundary conditions. Once the analysis was complete, the results were post-processed to visualize the temperature distribution at different time steps and analyse the transient behaviour of the system. The results were interpreted to understand how the temperature varied over time and its impact on the thermal performance of the system.

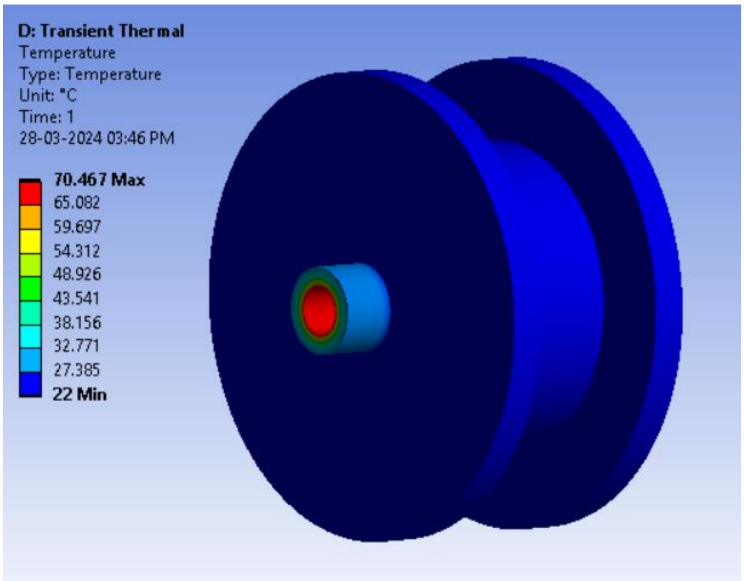


Fig. No. 9. Transient Thermal Analysis

The commercial Braking system can undergo temperature spikes up to 95 Degrees which is also our permissible value for Temperature Analysis. The Hub experiences the most difference in temperatures as it is a rotating part and is mounted on the Driven shaft. The obtained values for the temperature analysis were a maximum of 70.467 Degree with a minimum of 22.627 degree.

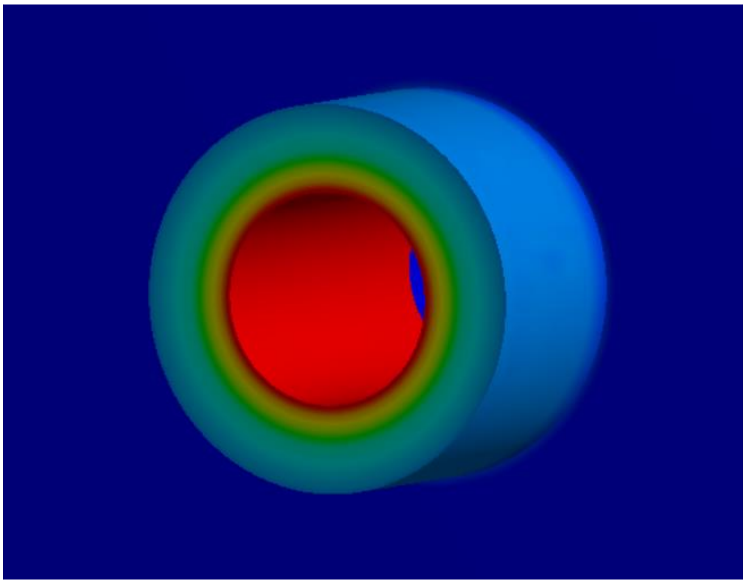


Fig. No. 10. Transient Thermal Analysis (Enlarged)

6.4 Magnetostatic Analysis (Maximum Flux Density)

The geometry of the magnetic system was imported or created in Ansys. Material properties, such as magnetic permeability, were defined for the materials in the system. A mesh was generated for the geometry to discretize it into smaller elements, ensuring accurate simulation results. Boundary conditions, including magnetic field boundary conditions, were applied to the model. This could involve specifying the direction and magnitude of the magnetic field or setting up symmetry conditions. The magnetostatic analysis was set up in Ansys, specifying the solver type, convergence criteria, and other relevant parameters. The magnetostatic analysis was solved in Ansys, with the software calculating the magnetic field distribution in the system under the specified boundary conditions. Once the analysis was complete, the results were post-processed to visualize the magnetic field distribution and analyse its behaviour within the system. The results were interpreted to understand the magnetic field strength and distribution throughout the system, identifying any areas of interest or potential issues.

For this analysis, the boundary conditions were taken as the component dimensions itself because if the magnetic reaction spreads to outer components it will cause a drop in efficiency of the magnetic braking resulting in arise of safety concerns of vehicle as well as its passengers. Usually, when a commercial brake is applied, the force generated is around the related parameters taken in consideration which have been analysed in previous sections namely Deformation, temperature, and stress. Considering the same in magnetostatic analysis for the Flux density value, the maximum permissible values are measured in Tesla (T) or Mini-Tesla (mT). for our component, the maximum permissible values came out to be around

0.0257mT. And like previous results the obtained values were under the permissible range and proved the component to be safe for manufacturing and solid uses.

The maximum obtained values were 0.01872mT, which is below the permissible values. And the area of magnetic effect is well within the boundary conditions applied during the starting phase of analysis.

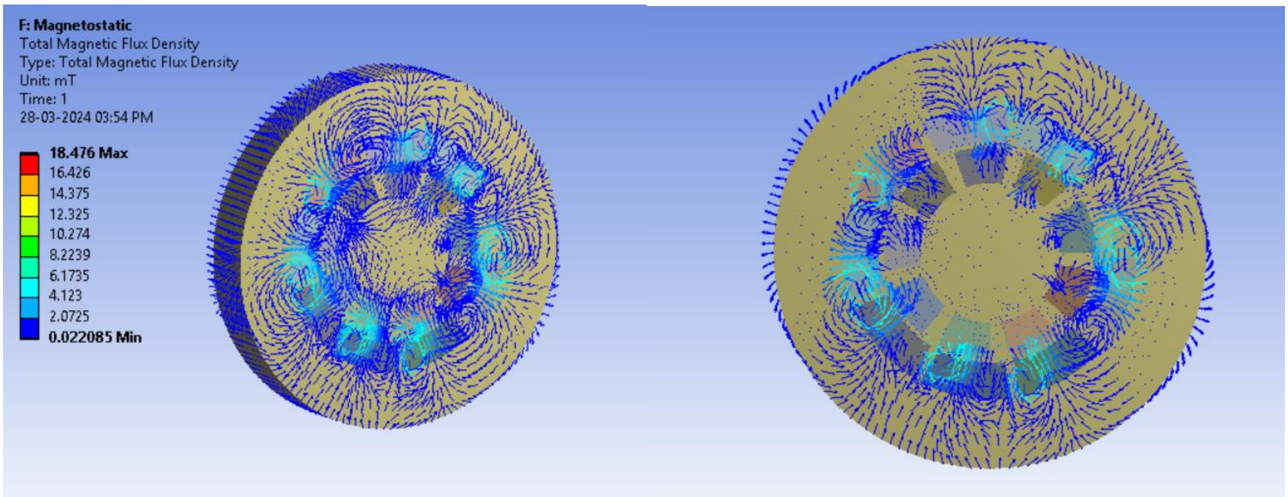


Fig. No. 11. Magnetostatic Analysis (Magnetic Flux Density)

6. Results & Discussion

Table No. 03. Validation Chart

Parameters	Minimum Permissible	Minimum Obtained	Maximum Permissible	Maximum Permissible
Total Deformation	1mm	0mm	1.5mm	0.72959
Equivalent Stress	0 MPa	2.640e-6 MPa	140 MPa	72.135 MPa
Transient Thermal	25°C	22°C	100°C	70.467°C
Flux Density	0 mT	0.022085 mT	25.7 mT	18.476 mT

All permissible values were taken from the referred paper and journals.

When considering a commercial braking system, the whole system undergoes a momentum equal to the testing conditions. The permissible values for Deformation are 1mm considering Factor of safety and 1.5mm Maximum under max load conditions. The obtained values were under the permissible values indicating that the component was safe and optimal. The Obtained values were maximum 0.72959 mm of deformation.

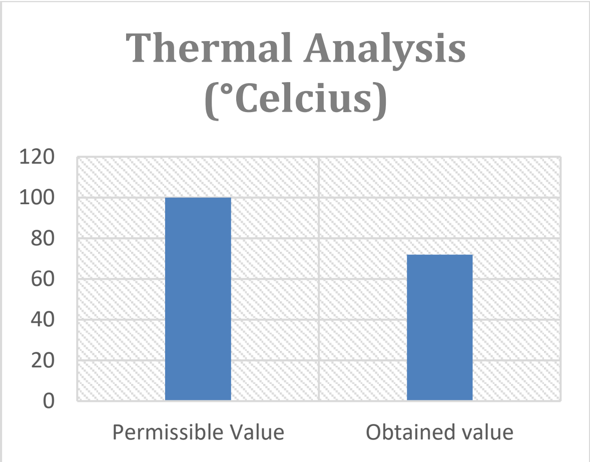
The values for Maximum and Minimum Equivalent Stress were taken from Ferguson Perforators papers. The permissible values for the Equivalent stress were till 140, measured in mega Pascal (MPa). The component can endure values up to 140 MPa considering FOS. And the values obtained during analysis were under the permissible values.

The commercial Braking system can undergo temperature spikes up to 95 Degrees which is also our permissible value for Temperature Analysis. The Hub experiences the most difference in temperatures as it is a rotating part and is mounted on the Driven shaft. The paper "Brake Testing Methodology Study – Driver Effects Testing", done by US Dept. of Transportation. (National Highway Traffic Safety Administration) on March 1999, The Values of Temperature generated during the test in the braking system were calculated as 65° C minimum to 100° C Maximum. These same values were taken in our consideration during Analysis. The obtained values for the temperature analysis were a maximum of 70.467 Degree with a minimum of 22.627 degree**.**

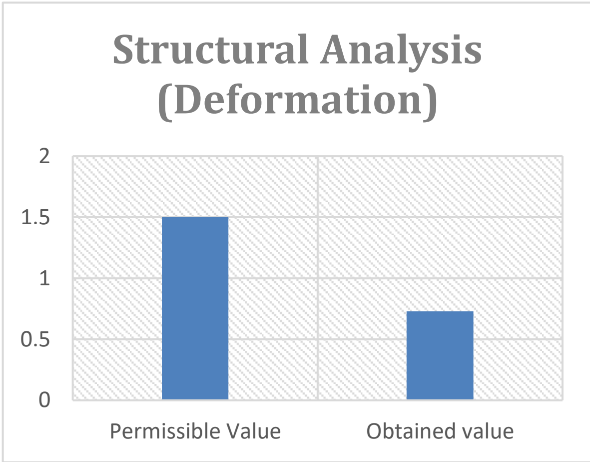
For the Magnetostatic Analysis, usually when a commercial brake is applied, the force generated is around the related parameters taken in consideration which have been analysed in previous sections namely Deformation, temperature, and stress. Considering the same in magnetostatic analysis for the Flux density value, the maximum permissible values are measured in Tesla (T) or Mini-Tesla (mT). for our component, the maximum permissible values came out to be around 0.0257mT. In the paper "Design and Fabrication of Electromagnetic Braking System: A Critical Review" by Mr. Vishwajeet V. Ambade, Mr. Saurabh Kawale, Mr. Pradeep Harinkhede, Mr. Nilesh Thakre, Mr. Saroj Patle, Mr. Manish Dolas the stress distribution and area of effect were taken same as the standard values and like previous results the obtained values were under the permissible range and proved the component to be safe for manufacturing and solid uses.

The maximum obtained values were 0.01872mT, which is below the permissible values. And the area of magnetic effect is well within the boundary conditions applied during the starting phase of analysis.

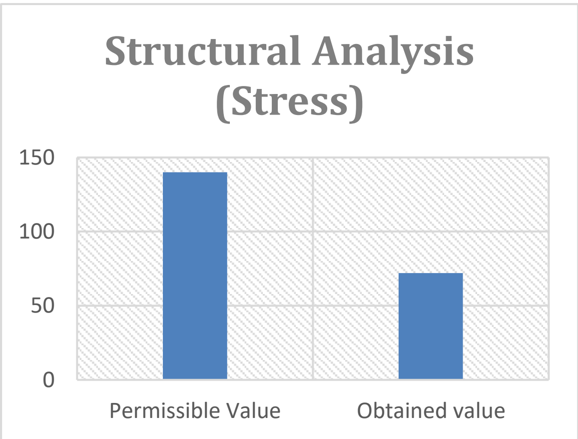
Graph No. 1 Thermal Analysis (°Celsius)



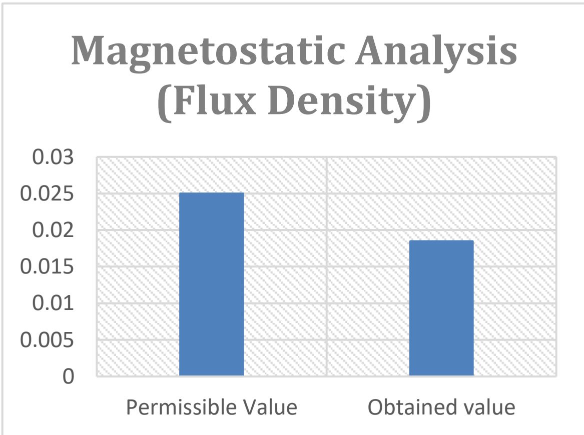
Graph No. 2 Structural Analysis (Deformation)



Graph No. 3 Structural Analysis (Stress)



Graph No. 4 Magnetostatic Analysis



8. Conclusion

In conclusion, the Electromagnetic Braking System represents a change or innovation in the automotive and industrial sectors. Its advantages, such as regenerative braking, reduced maintenance, and enhanced safety, and sustainable and efficient transportation.

Hence, we conclude that efficiency is increased significantly compared to conventional braking systems due to various factors like the design of the brake, materials used, and control systems. This system may also include the beneficial factor such as energy regeneration ability. Environmental impact and sustainability of electromagnetic braking systems has already been proved to be more advantageous than conventional braking system.

This system is more reliable in maintenance sector than conventional braking systems as it has less wear and tear among parts and is a frictionless and contact-less braking system.

This way we achieved our all-project outcome such as: -

i. Usage of Electro-magnetic Brakes over Drum Brakes
ii. No Frictional Loss
iii. Increased Braking efficiency.

9. Future Scope

Electro-magnetic braking system not only helps in effective braking but also in avoiding accidents caused due to slipping and reduces maintenance costs by a significant amount. Furthermore, the electro-magnetic brakes prevent the danger that can arise due to prolonged use of brakes with minimal heat dissipation. Electro-magnetic braking system are found to be more reliable than others.

The scope of electromagnetic braking systems encompasses various applications across multiple industries where the controlled deceleration or stopping of moving objects is required. Here are some of the areas where electromagnetic braking systems find utility:

i. **Automotive Industry**: Electromagnetic braking systems are used in hybrid and electric vehicles as regenerative braking systems. These systems convert kinetic energy into electrical energy during braking, which is then stored in batteries or capacitors for later use, thus improving overall efficiency and range.

ii. **Railway Transportation**: Electromagnetic braking systems are employed in trains and trams for smoother braking and reduced wear on mechanical components. They are particularly useful in high-speed trains where precise control over braking is essential for safety and passenger comfort.

iii. **Industrial Machinery**: Many industrial machines utilize electromagnetic brakes for quick and precise stopping, such as in conveyor systems, cranes, hoists, and winches. These brakes provide reliable stopping power and can be controlled remotely or automatically.

iv. **Elevators and Escalators**: Electromagnetic brakes are crucial components in elevator and escalator systems for ensuring passenger safety. They provide backup braking in case of power failure and contribute to smooth operation during normal use.

v. **Wind Turbines**: In wind turbines, electromagnetic brakes are employed as safety mechanisms to halt the rotation of blades during maintenance or in case of high winds. They prevent over speeding and protect the turbine from damage.

vi. **Material Handling Equipment**: Electromagnetic brakes are utilized in various material handling equipment such as cranes, lifts, and forklifts to control the movement of heavy loads and ensure safety during operation.

vii. **Roller Coasters and Amusement Rides**: Electromagnetic brakes play a critical role in controlling the speed and ensuring the safety of passengers in roller coasters and other amusement park rides.

viii. **Bicycles and Scooters**: Some electric bicycles and scooters utilize electromagnetic brakes as part of their braking systems, contributing to smoother braking performance and energy regeneration.

Overall, the scope of electromagnetic braking systems is broad and extends across numerous industries and applications where controlled deceleration, safety, and energy efficiency are paramount. As technology advances, the applications of electromagnetic braking systems are likely to expand further, offering enhanced performance and reliability in various fields.

The Electromagnetic Braking System represents a change or innovation in the automotive and industrial sectors. Its advantages, such as regenerative braking, reduced maintenance, and enhanced safety, and sustainable and efficient transportation.

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