DESIGN, ANALYSIS & PERFORMANCE TESTING OF REGENERATIVE BRAKING SYSTEM

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Abstract - *We know that "Energy can neither be created nor be destroyed, it can only be converted from one form to another". This paper presents a very important method of regenerative braking. The regenerative braking system is the most prominent way for an electric vehicle to increase its potential. We are slowly reaching the age where electric vehicles are going to play a vital role in the automobile industry as well as for the betterment of the environment. The major reasons behind the less usage of electric vehicles are the battery charging time and the lack of adequate charging stations. The regenerative braking system can play a vital role to maintain the vehicle's strength and convert the unusable energy into a usable form. Also, there is a need for an alternate source to run the vehicles. Electric vehicles use a mechanical brake to increase the roughness of the wheel to stop the motion. However, from the point of view of energy, the mechanical brake releases much energy while the EV's kinetic energy is renewed into the usable one. The current braking system of a vehicle is based on hydraulic braking technology. Thus, this traditional braking method causes a lot of wastage of energy since it produces unwanted heat during braking. Thus, to eliminate all such disadvantages, the creation of regenerative braking has risen. Also, it helps in saving energy and providing higher efficiency to the vehicle. Hence the regenerative braking system looks like it will make its place in future vehicles. This system also allows the vehicle to generate energy each time the brakes are applied. The authors of the paper have tried to design a model for the same and have also analysed various parts so that they can get accurate readings on the tachometer. The addition to this braking system is the tachometer which will help us in telling the amount of energy generated and its speed through the mobile app developed using the Arduino based tachometer. The main aim that has been the focus is the Design, Analysis, and Performance testing of a regenerative braking system.*

Keywords-Regenerative, Arduino, Tachometer, Kinetic energy, Hydraulic braking

1. INTRODUCTION

This topic is based on smart energy. Due to limited resources, in the near future, we will be entering the renewable energy age mainly the electric age.

The Regenerative braking system is a mechanical framework that causes an interruption in movement by engrossing energy from a moving framework. It is utilized to decelerate and to stop a moving vehicle, wheel, hub, or to stop its movement, by methods for friction. The term 'Brake' can be defined as a mechanical subsystem of a vehicle that is responsible to diminish its speed or stop the motion of the vehicle. In braking mechanisms of general vehicles, the friction is used to handle the forward force of a moving vehicle. As the cushions of the brake slide or rub against the wheels that are attached to the axles, heat energy is generated. This heat energy released into the air, abuse as much as 29 % of the vehicle's made up force. After some time, this continuous cycle of friction and heat energy reduces the vehicle's fuel efficiency. The most extreme heat loss from the motor is to supplement the energy that was lost by brakes down. A large portion of it happens to be free as the heat gets converted into an unusable form. That lost heat energy which could have been used to accomplish work for all intents and purposes is unutilised. The arrangement which can be used to solve this kind of issue is the Regenerative braking system. This is another sort of braking mechanism that can use or reuse a great part of the automobiles' Kinetic energy and convert it into electrical energy or on the other hand in some cases mechanical energy. The energy converted can be stored as mechanical energy in flywheels, and as, electrical energy in the car battery, which can be used once more. Nowadays electric vehicles have much attention as an alternative to traditional combustion engine (ICE) vehicles. The invention of electric vehicles is no less than a huge revolution in the automobile industry, they are also known as green vehicles as they produce zero-emissions which means there is no release of toxic gases from the car that causes the various layers of depletion in our atmosphere such as ozone layer depletion. Nowadays, the population of electric vehicles is somewhat increasing in the market, due to an increase in demand. Also, some governments are encouraging the production of electric cars. Every step is taken by the world to save nature from excessive air pollution and the recession on natural resources such as oils and natural gasses in the earth. The event of the hybrid vehicle and Electric vehicle is becoming most popular. That may be seen because of the highly increased awareness of the world of global warming and the rise in the cost of fuel prices. Also, because of the increase in pollution which is a major concern in the environment, and an increase in oil prices, the EVs are going to be the first and the most preferred choice for transportation. In electrical vehicles that are operated with battery, the battery is the only source for energy and these batteries face problem like less charging and recharging cycles also gets poor after some years in response to the driving range. The mentioned problems are overcome by using a battery with anyone of the energy sources like ultra-capacitor, flywheel, electrochemical batteries, etc. Some processes are introduced to beat this problem; one of them is regenerative braking. The working principle of the regenerative braking system is a braking method that utilizes the mechanical energy from the rotating motor by converting kinetic energy into electrical energy and giving back into the battery source for recharge. Basically, the regenerative braking system can convert a reasonable amount of its kinetic energy to charge up the battery. In regenerative braking mode, it uses the motor to slow down the vehicle when the driver applies force to the brake pedal, and then the electric motor works in reverse direction resulting in the reduction of the speed of the vehicle. While rotating in opposite direction, the motor acts as the generator and recharges the battery of the vehicle using this system. These types of the braking system work effectively in a driving environment such as stop-and-go driving situations especially, in the urban city because as the vehicle stops frequently, the amount of heat loss is more, on the other hand, if we apply this kind of system we will be able to save a certain amount of energy that is being lost or is unusable. The regenerative braking system provides the majority of the total braking force during low speed and stop-and-go traffic where most of the deceleration is required or where more application of brakes is carried out. In the regenerative braking system, the braking controller is the main element or heart of the system because it controls the overall process of the motor. In other words, it monitors the major chunk of the workload of the motor. The functions of the brake controller are to keep track of the speed of the wheel, calculation of the torque, and generated electricity to be fed back into the batteries of the vehicles. This is how a basic regenerative Braking system works. Regenerative braking systems will play a huge part in this electric era.

2. LITERATURE REVIEW

The authors of this paper went about with the literature search focused mainly on topics related to electric vehicles (EV), hybrid electric vehicles (HEV).

When a motor is made to run by external means then it becomes a generator. A similar concept or principle is utilized for regenerative braking. The flywheel is also used for this purpose. The flywheel is a heavy rotating mass that stores the kinetic. This process of recovering energy is more efficient. In the case of recovering the energy through motor/generator and battery system, energy losses occur as mechanical energy is being transformed into electrical energy while charging the battery and during discharging electrical energy gets converted into mechanical form. The amount of energy stored by the flywheel is proportional to its mass, radius, and rotational velocity. The stored energy can be enhanced by increasing the moment of inertia and angular velocity of the flywheel. It can improve vehicle performance as it boosts the acceleration of the vehicle from stored energy.

With the help of advanced technologies of power electric components like an ultracapacitor, the performance of the regenerative braking system can be enhanced. The research indicates that regenerative braking systems are already being used in many electric vehicles and have an even greater scope in the future. This is because the rise in petrol prices promotes the need for progress in energy conservation and this system improves fuel consumption by 33%. To achieve maximum braking efficiency, the braking should be performed through a direct drive transaxle and a single gear. In order to eliminate engine friction losses, the engine should be disengaged from the drive wheels when regenerative breaks are applied.

It was observed that factors like an efficient use of friction brakes and the impact of air quality were improved while driving an EV with a regenerative braking system.

The operation time of the friction brake was reduced approximately by 50%. This indicates that the life span of the brakes is expected to be doubled. This is a considerable amount of decrease in the maintenance cost of the brakes and this cumulative cost saving could preferably contribute to a new EV battery over the years. By the implementation of the regenerative braking system, many other cost savings are expected related to fuel, oil, filters, etc. which will reduce the overall maintenance cost of the vehicle. It was observed that along with the reduction in energy consumption the regenerative braking system contributed to increasing the driving range between 11-22% depending on the drive cycle settings and the RBS parameters.

3. METHODOLOGY

3.1 COMPONENTS USED IN CARRYING OUT PERFORMANCE TESTING:

- Arduino.
- IR sensor.
- Bluetooth sensor.
- Wires.
- 1000 rpm motor (2 in quantity).

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- Voltage module.
- Wheel, Aluminum rods(2 in quantity).
- Dynamo (Brake gear).
- Adhesives.

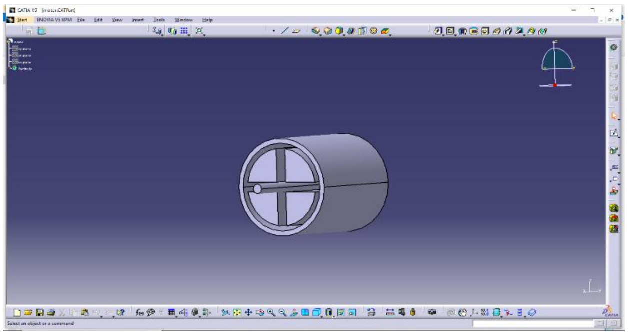

Fig 1: Motor

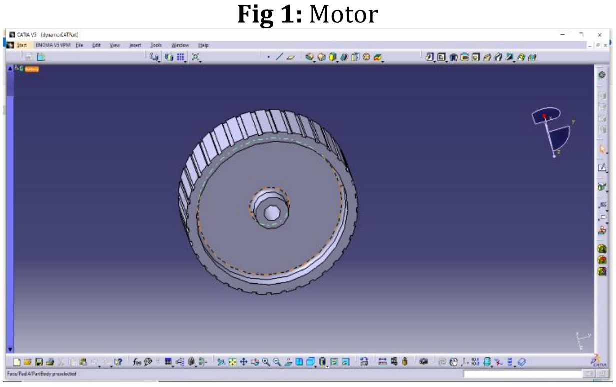

Fig 2: Dynamo

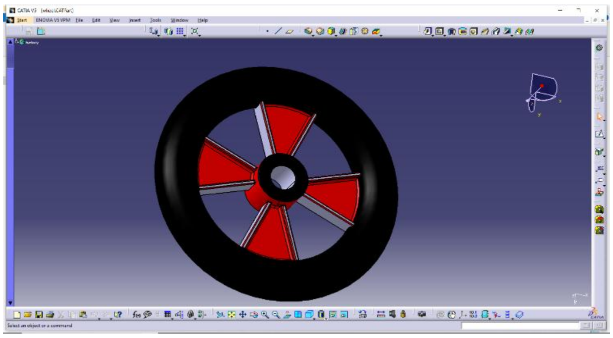

Fig 3: Wheel

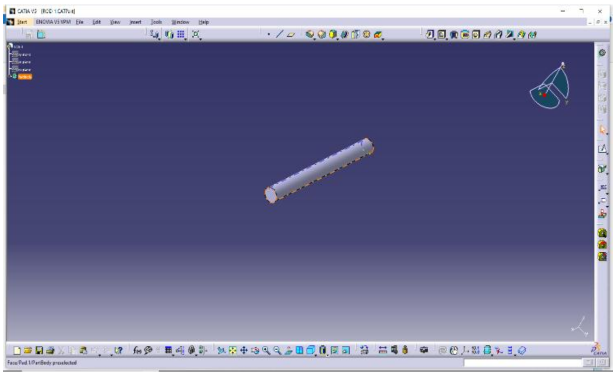

Fig 4: Aluminum Rod

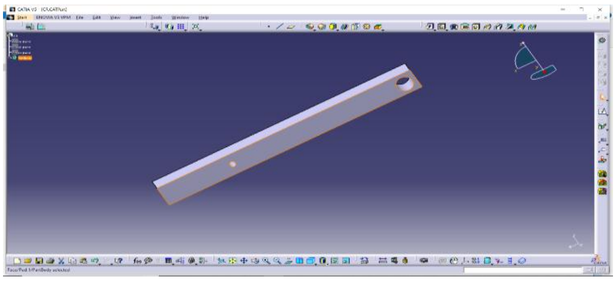

Fig 5: Crank on which Dynamo will be attached.

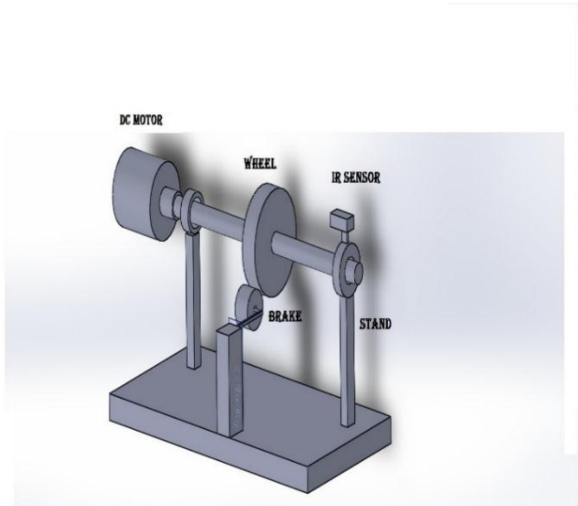

Fig 6: Theoretical idea of the setup

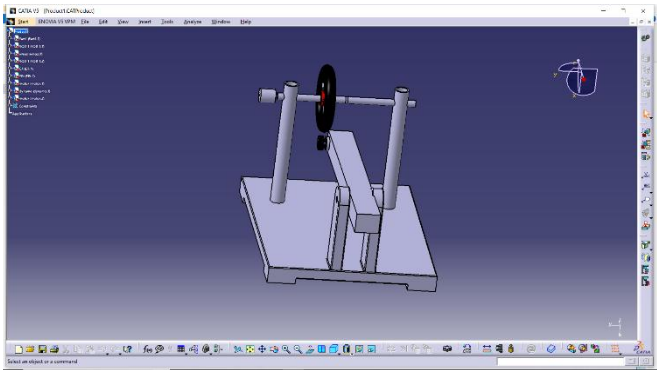

Fig 7: Catia Model of Actual Setup

4. PROCEDURE

4.1 FOR SETUP OF BRAKING SYSTEM:

1. Take two aluminum rods and drill holes in them at a considerable height and diameter according to the shaft of the wheel.
2. Take a sturdy plywood base and fix the two aluminum rods onto the base by drilling the base according to the diameter of the rods and by using adhesive so that the rods can withstand the high speed of the wheel.

3. Using a Lathe machine drill into the shaft with a drill of the same diameter as the motor and then couple the motor to the shaft using a simple screw or nut bolt arrangement.
4. Take the wheel shaft and couple them using simple nuts and bolts and mount this wheel onto the stand. Use mechanical bushes as a medium between the wheel shaft and the rods to reduce the friction between the shaft and rod and to ensure a smooth rotation of the wheel at high speeds.
5. Use plywood strips and some screws for making breaks which are based on the simple principle of a fulcrum.
6. Couple the second motor with the brake gears with a simple nut and bolt arrangement and then attach this motor on the brake setup. Attach the wires of this motor to the Arduino screen to get the generated output energy.

4.2 FOR AURDINO BASED TACHOMETER:

1. The authors of this report first covered the wheel with a black paper of radius 9.5 cm, having a strip of aluminum foil so that tachometer could detect the rpm of the wheel.
2. The Bluetooth sensor was attached to the right aluminum rod using a glue gun. Further, this sensor was connected to a mobile app as shown in 7A and 2B.
3. The author of this report further connected Arduino (Fig 7C) to the braking system.
4. The authors have used Arduino along with the voltage module and IR module to measure the voltage and rpm of the setup.
5.IR module will continuously measure the rpm and send it to Arduino and in the same way, the voltage module will measure the voltage after the application of the brakes.
6. The coding of Arduino is done in such a way, that it will take the readings of voltage and rpm simultaneously.
7. Both the readings are sent to Mobile application (fig 2.a and 2.b) through Bluetooth.
6. This mobile app has been developed in MIT app inventor and this mentioned app will help authors to know the value of rpm and voltage generated.

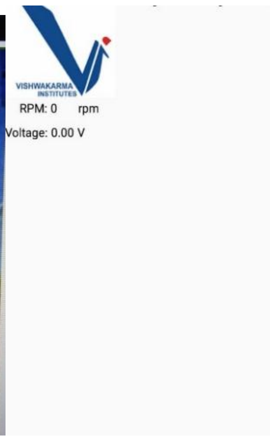

Fig 8A: Screen 1 of App **Fig 8B:** Screen 2 of App

Fig 8C: Arduino Uno

5. THEORY

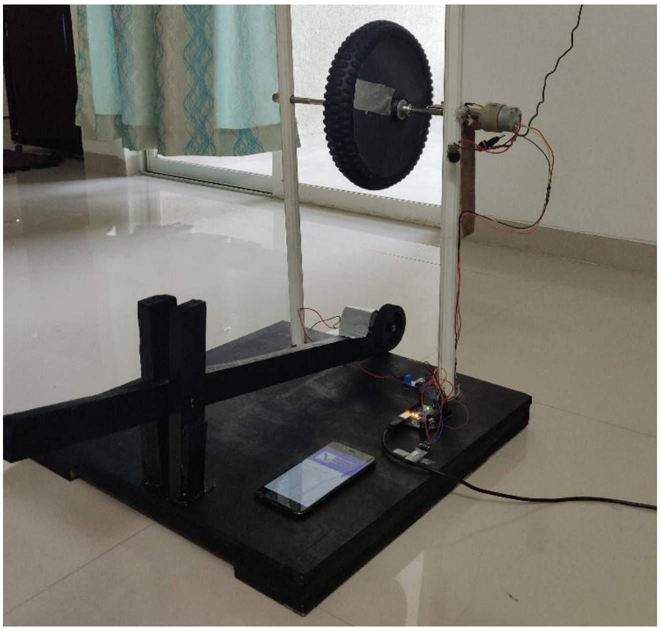

Fig 9: Actual Photo of the setup

The regenerative braking system is an advanced and supplementary braking system that is used along with the conventional braking system. The conventional braking causes friction between brake pads and brake disc. It converts the vehicle's kinetic energy into heat, which goes to waste. However, the regenerative system recovers some of the waste energy and puts it to work again. The system captures and converts this waste energy into electricity. The electricity thus regenerated; charges the battery of an electric or hybrid vehicle. In the regenerative braking system, the motor; which drives an electric vehicle, also performs the function of braking. The system consists of an electric motor with dual function. It works as a motor, in one direction, and as a generator, in the opposite direction. When it runs as a motor, it converts electrical energy into mechanical energy and drives the wheels. However, while braking; it runs in the opposite direction and becomes an electric generator. Applying the brakes of an electric or hybrid vehicle causes the electric motor to run in reverse direction i.e. in generator mode, thereby, slowing down the wheels.

6. TESTING

The authors of this report went about the project by having three runs to test the overall setup of the project. The first test run was done to get an idea about the parameters of the wheel and the motor especially. It was basically a test run for the efficiency of the mechanical setup which was to be done for the project. In the first test run, a motor of 500 Rpm and a bicycle wheel of around 250 grams was used. The coupling of the wheel was the first thing to be done in this test run. But the motor was not generating the amount of speed as needed. In the second test run the wheel was mounted on a stand with a plywood base and two aluminum rods attached to the base. These aluminum rods were drilled with a drill of the same diameter as the shaft of the wheel which was used. This time a motor of 750 Rpm was used but again we met with the same result of not enough speed generation. The breaking mechanism was done using a spring and hinge arrangement but due to excessive tension in the spring this setup of the braking system was dropped. In the third test run, a motor of 1000 Rpm was used. This motor produced the required speed and torque needed for the working of the project. Two mechanical bushes were used to reduce the friction between the wheel shaft and the aluminum rods which in turn also smoothened the rotational flow of the wheel. A simple braking system with plywood, based on the principle of the fulcrum was done which was tested and met with the requirements of the project. The tachometer was calibrated to the required rating with the use of an actual digital tachometer and the required readings were taken and a graph was plotted.

7. ANSYS ANALYSIS

Static structural analysis is a branch of ANSYS that deals with numerical simulation methods and makes use of different algorithms to solve and analyze the problems that involve various kinds of forces. Static structural requires various settings like pressure, force, and various other factors.

7.1 MESHING

The partial differential equations that govern fluid flow and heat transfer are not usually amenable to analytical solutions, except for very simple cases. Therefore, to analyze fluid flows, flow domains are split into smaller subdomains (made up of geometric primitives like hexahedra and tetrahedra in 3D and quadrilaterals and triangles in 2D).

A. PROPERTY OF MATERIAL TAKEN AS FOLLOWS

Table-1: Material Properties for Wood (Base)

Material	Wood
Young's modulus	68.9 GPa
Poisson's Ratio	0.334
Density	1900kg/m3
Coefficient of thermal expansion	5e-05
Yield strength	2.8e+08

Table-2: Material Properties for Steel

Material	Structural steel
Young's modulus	215 GPa
Poisson's Ratio	0.265
Density	7850 kg/m3
Coefficient of thermal expansion	7.2e-06
Yield strength	2.5e+08

The authors of this paper have decided on a fixed force that they will apply on each part so that the results obtained will be for equal force and can be easily scaled up and scaled down for any other force.
Force for every part-2500N

B. PROPERTIES OF MESHING FOR BASE (STATIC STRUCTURAL ANALYSIS)

Table-3: Meshing Properties (Base)

Property	Description
Display Style	Body Colour
Physics Preference	Mechanical
Size Function	Curvature
Relavance Centre	Fine
Max Face Size	6.69640mm
Defacture Size	3.482e-002mm
Nodes	88017
Elements	50008

Table-4: Meshing Properties of Base

Property	Description
Force	2500N On The center of the base
Fixed Support	Lower Part Of Base

The authors of this paper assumed the total weight of the wheel and rod acting in a downward direction and hence applied the force in that direction for analysis.

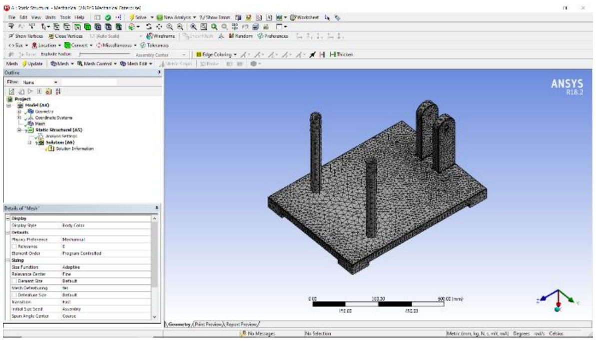

Fig 10A: Base Meshing

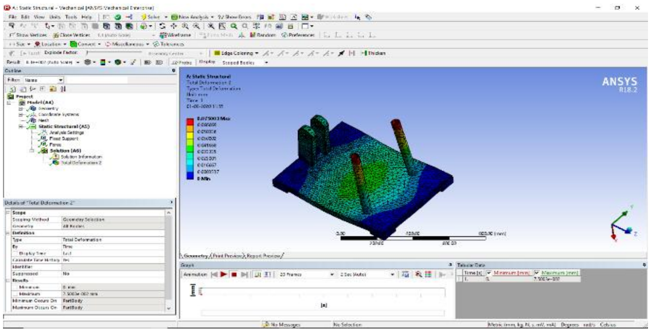

Fig 10B: Total Deformation of Base

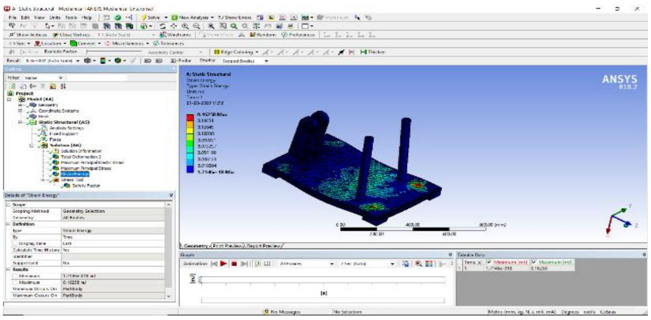

Fig 10C: Max Principal Elastic Strain at Base

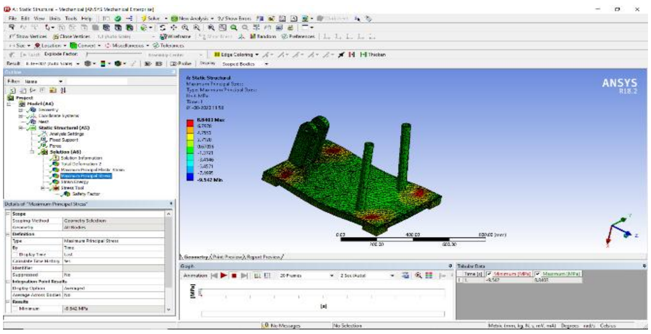

Fig 10D: Maximum Principal Stress at Base

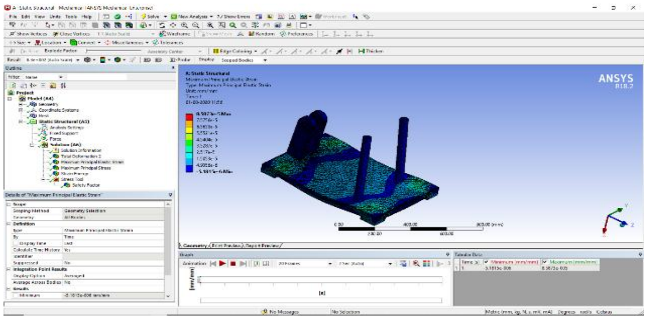

Fig 10E: Strain energy at Base

C.RESULT TABLE FOR BASE

Table-5: Result (Base)

NAME OF PROPERTY	VALUE
TOTAL DEFORMATION	0.0075mm
MAX.PRINCIPLE ELASTIC STRAIN	0.0008587mm/mm
MAX.PRINCIPLE STRESS	8.84MPa
STRAIN ENERGY	0.16258mJ
FACTOR OF SAFETY	15 (max) The part is within safety limit

D.PROPERTIES OF DYNAMO (STATIC STRUCTURAL ANALYSIS)

Table-6: Meshing Properties (Dynamo)

Property	Description
Display Style	Body Color
Physics Preference	Mechanical
Size Function	Adaptive
RelavanceCenter	Fine
Max Face Size	6.7890mm
Defacture Size	2.732e-002
Nodes	45298
Elements	25977

The authors of this paper assumed the dynamo is connected from sideways to the rod and hence fixed the interior of the dynamo and assumed force from sideways direction, and therefore applied force in that direction for analysis.

Table-7: Ansys settings for Dynamo

Property	Description
Force	2500N on the right and left side of the dynamo
Fixed Support	Interior parts of the hole that is in middle of the dynamo

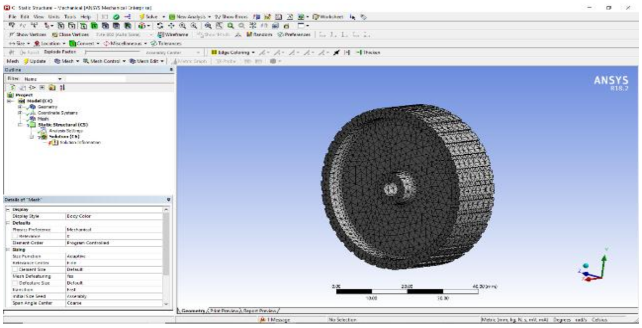

Fig 11A: Meshing of Dynamo

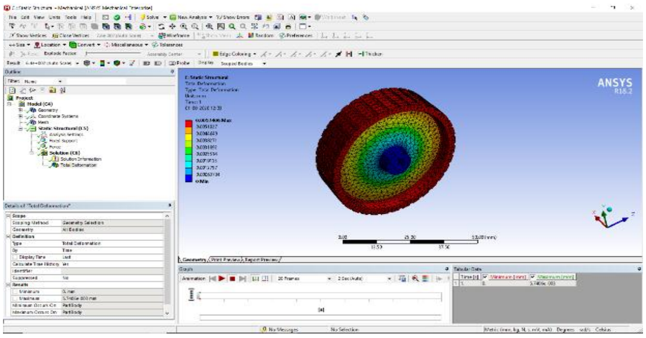

Fig 11B: Total Deformation of Dynamo

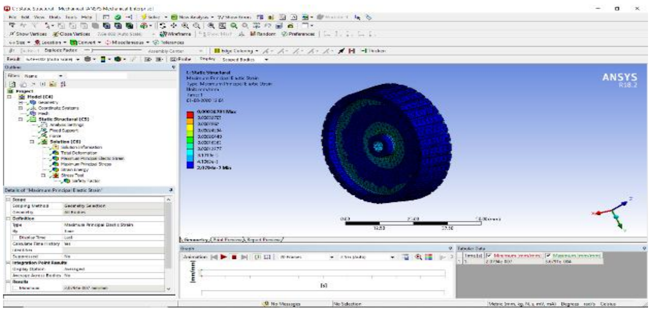

Fig 11C: Maximum Principal Strain on Dynamo

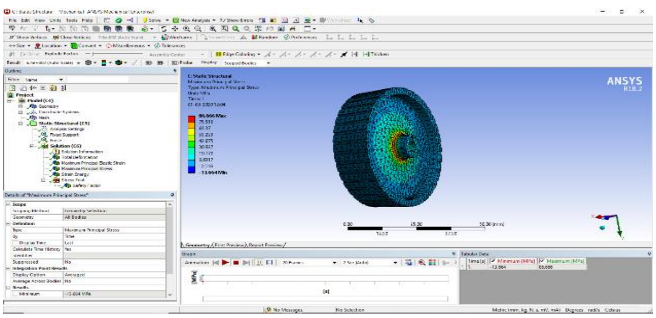

Fig 11D: Maximum principal Stress on Dynamo

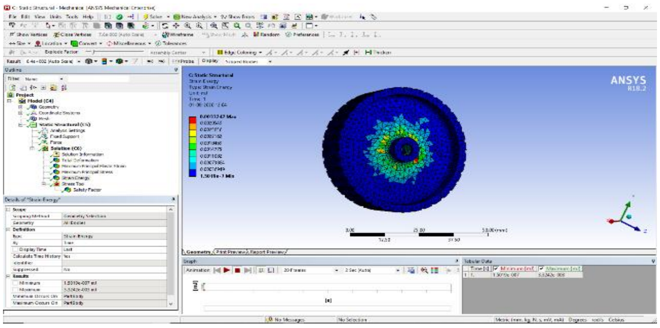

Fig 11E: Strain Energy

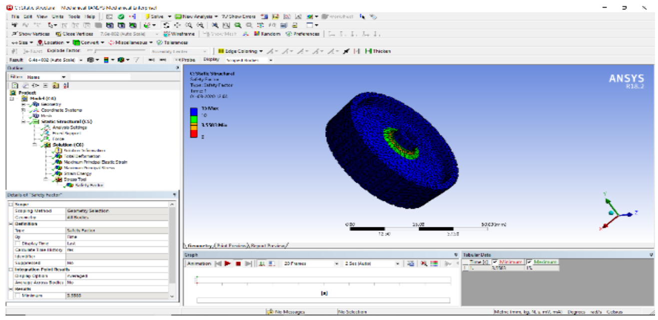

Fig 11F: Factor of Safety

E. RESULT TABLE FOR DYNAMO

Table-8: Result (Dynamo)

NAME OF PROPERTY	VALUE
TOTAL DEFORMATION	0.0057mm
MAX.PRINCIPLE ELASTIC STRAIN	0.00036791mm/mm
MAX.PRINCIPLE STRESS	86.666MPa
STRAIN ENERGY	0.0033242mJ
FACTOR OF SAFETY	15 (max) The part is within the safety limit

F. PROPERTIES OF MOTOR (STATIC STRUCTURAL ANALYSIS)

Table-9: Meshing

Property	Description
Display Style	Body Colour
Physics Preference	Mechanical
Size Function	Adaptive
RelavanceCenter	Fine
Max Face Size	6.7890mm
Defacture Size	2.732e-002
Nodes	38596
Elements	20555

Properties (Motor)

The authors of this paper assumed that the motor is coupled from sideways with rod and hence fixed the rotator of the motor that is being coupled and assumed force from a backward direction and therefore applied force in that direction for analysis.

Table-10: Ansys settings for Motor

Property	Description
Force	2500N on the backside of the motor
Fixed Support	Interior parts that are being coupled (middle of the motor)

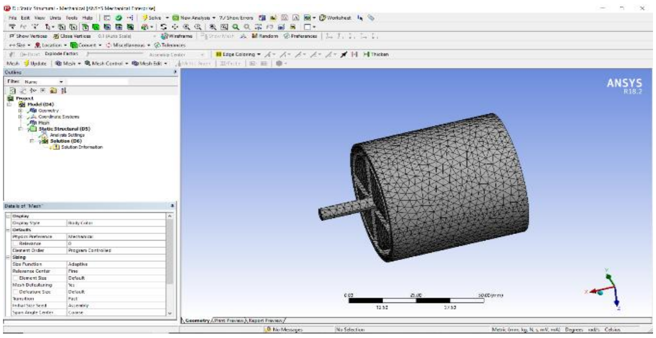

Fig 12A: Meshing of Motor

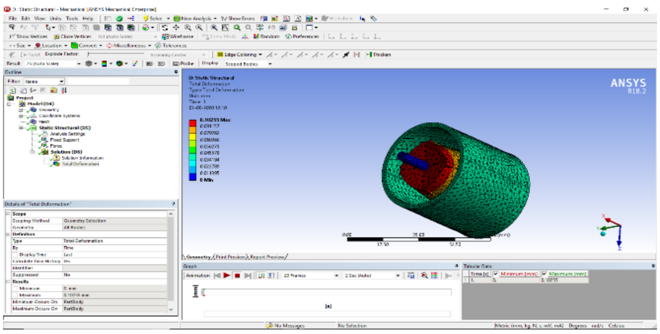

Fig 12B: Total Deformation of Motor

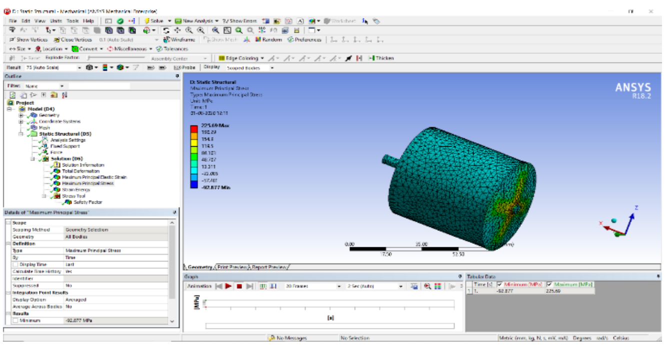

Fig 12C: Maximum Principle Stress on Motor

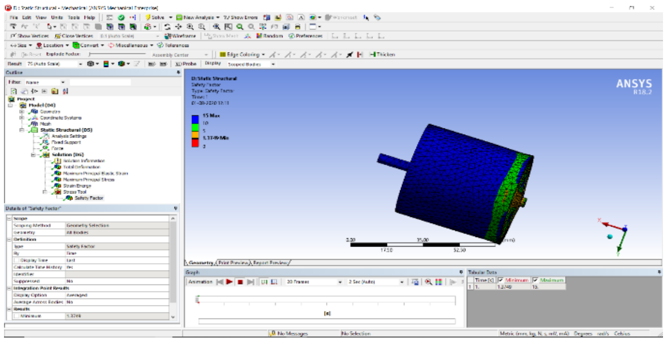

Fig 12D: Factor of Safety

G. RESULT TABLE FOR MOTOR

Table-11: Result (Motor)

NAME OF PROPERTY	VALUE
TOTAL DEFORMATION	0.10255mm
MAX.PRINCIPLE ELASTIC STRAIN	0.00026791mm/mm
MAX.PRINCIPLE STRESS	225.666MPa
STRAIN ENERGY	0.0033242mJ
FACTOR OF SAFETY	15 (max) The part is within the safety limit

H. PROPERTIES OF WHEEL (STATIC STRUCTURAL ANALYSIS)

Table-12: Meshing Properties (Wheel)

Property	Description
Display Style	Body Colour
Physics Preference	Mechanical
Size Function	Curvature
RelavanceCenter	Fine
Max Face Size	4.68460mm
Defacture Size	2.3423-002mm
Nodes	56591
Elements	31571
Element Order	Linear

The authors of this paper assumed that as Wheel is coupled from sideways with the rod and hence fixed the side part of the Wheel that is being coupled and assumed force from sideways (on the red grill part)direction and therefore applied force in that direction for analysis.

Table-13: Ansys settings for Wheel

Property	Description
Force	2500N on side of the wheel
Fixed Support	Interior parts that are being coupled (middle of the wheel)

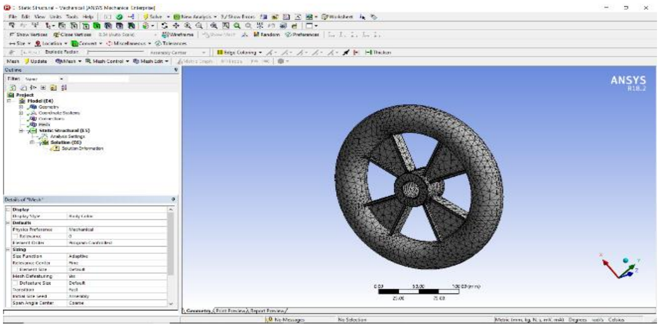

Fig 13A: Meshing of Wheel

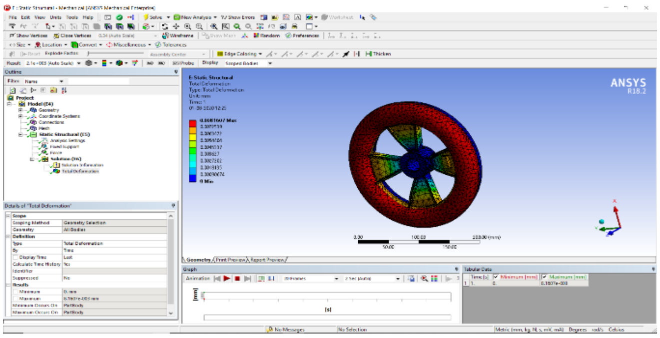

Fig 13B: Total Deformation of Wheel

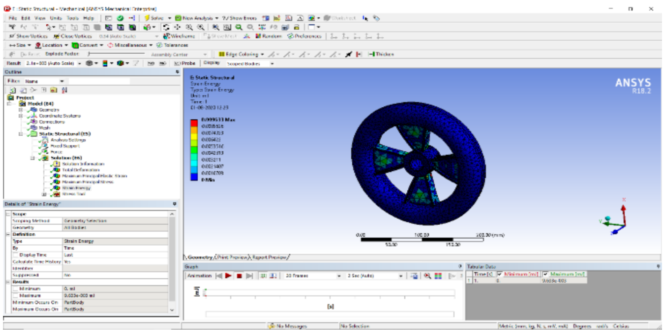

Fig 13C: Strain Energy

I.RESULT TABLE FOR WHEEL

Table-14: Result (Wheel)

NAME OF PROPERTY	VALUE
TOTAL DEFORMATION	0.0081607mm
MAX.PRINCIPLE ELASTIC STRAIN	0.000016791mm/mm
MAX.PRINCIPLE STRESS	102.666MPa
STRAIN ENERGY	0.00963242mJ
FACTOR OF SAFETY	15 (max) The part is within the safety limit

8. ADVANTAGES

The advantage of regenerative braking systems over the conventional braking system is that the kinetic energy which is lost at the time of braking can be converted back into electrical energy and stored in a battery.

Although the initial cost is high, the regenerative braking system not only helps in energy conversation but also reduces brake wear and therefore reduces the overall maintenance cost of the vehicle.

A mobile application was developed and an Arduino along with a voltage module and IR module was installed in the braking system with the help of which the performance of the braking system can be monitored continuously.

Simulation of mechanical properties like maximum principal stress, maximum principal strain, total deformation, and strain energy of the parts used in the system (motor, dynamo, wheel, and base) was carried out using ANSYS software and all the parts are well within the safety limits.

9. LIMITATIONS

It only makes sense to have regenerative braking on electric or hybrid vehicles.

These sorts of vehicles have already gotten electric motors built into the drivetrain and so they only require some additional electronics to harness the energy produced from regenerative braking. It wouldn't make any sense to add a generator to a vehicle that doesn't use very much electricity.

It's not necessarily cheap to add regenerative braking to an electric vehicle. Not all electric motors support regenerative braking. Series wound motors do not work well as generators because they can't handle fluctuating loads.

The amount of recoverable energy from regenerative is limited by battery pack size.

While there is a lot of potentially recoverable kinetic energy, we can only save a small portion of it based on how fast we can charge our batteries. Charging batteries too fast will destroy them. With the study done to write this paper, the authors can say that large battery banks can handle higher charging currents than small ones.

Regenerative braking causes a reversal in the torque direction on the motor, which can eventually loosen the motor mounting bolts (on some vehicles).

This is only a potential issue for vehicles not designed to drive in reverses, such as bicycles or motorcycles. The regenerative system won't work at very low speeds.

The voltage produced by the generator is a function of the load and the RPM. (The current produced is a function only of the load.) The vehicle must be traveling fast enough to generate a voltage larger than the battery bank voltage to enable charging.

10. RESULT AND DISCUSSION

Table-15: Results (Voltage & Speed)

SR.NO	VOLTAGE(V)	SPEED(RPM)
1.	4.5	500
2.	7	600
3.	9	700
4.	10	750
5.	10.27	810
6.	12.1	1000

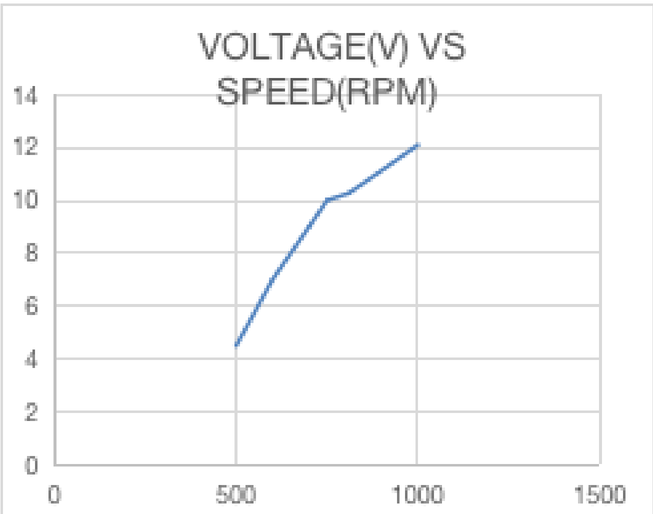

Chart 1: Graph of voltage versus speed

1. From Table 15 it can be observed that as the voltage increases there is a gradual increase in rpm of the wheel.
2. Chart 1 shows the variation between voltage and the rpm, which is depicted by an almost linearly increasing graph.
3. From the above observations, it can be concluded that the maximum potential generated is 12.1V, which is capable of glowing 6 LEDs.

11. CONCLUSIONS

Regenerative braking systems require further research to develop a better system that captures more energy and stops faster. As time passes, designers and engineers will perfect regenerative braking systems, so these systems will become more and more common.

We can conclude that as soon as we increase the rpm of the wheel, the voltage generated is also increased.

Hence, we can with the backing of scientific studies say that the voltage generated is directly proportional to RPM.

12. FUTURE SCOPE

Although the regenerative braking system is more efficient than conventional braking, it is still not common or popular as electric vehicles and hybrid electric vehicles are still in the development phase or are still under design review phase. Energy stored in a battery is accustomed to various electrical appliances such as air conditioning, lights, mobile charging, etc.

As regenerative braking increases the efficiency of the vehicle, it also increases its weight and that is a major problem. It can be overcome by using lighter materials for regenerative circuit components and studying material sciences. The use of more efficient systems could lead to huge savings in the automobile sector which will automatically reflect in the country's economy.

Losses within the process of generation should be reduced so as to make it more efficient and the maintenance required for this technique should be taken into consideration for future use. As the way forward for the automobile industry is electrical and hybrid vehicles, this regenerative braking system is going to be a revolutionary.

13. ACKNOWLEDGEMENT

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