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"Design and Simulation of Regenerative Suspension System Combined with Electromagnetic Braking System"

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Considering the rate of depletion of the available oil-based fuels, Renewable Energy Technologies are receiving significant attention in these years. It is therefore necessary to find alternatives to energy sources. This project focuses on one such alternative. A study is done on vehicle suspension systems and braking systems. Suspension in vehicles produces linear vibrations due to the roughness on the roads. These vibrations are absorbed by the shock absorbers and dissipated in the form of heat. In case of braking systems (pure mechanical systems) huge amounts of heat are lost due to friction. This study proposes a design of a system where the heat lost in suspension systems is extracted, converted into usable form of energy(electricity) and stored in batteries. This stored energy is further used in the operation of electromagnet powered brakes. Using the Regenerative Suspension System reduces the waste of energy in the shock absorbers and gives an alternative energy source and use of the Electromagnetic Braking System ensures frictionless braking. Thus the overall consumption of energy is reduced by a notable amount.

KEYWORDS: *Renewable energy, Regenerative suspension, Electromagnetic braking, frictionless braking.*

I.INTRODUCTION

Today's world is full of modern technologies and energy harvesting has been one of the most promising industries that can be used in future automobiles. Considering the rate of depletion of the available oil-based fuels, it is necessary to find alternatives to energy sources. This project focuses on one such alternative for automobiles. This project emphasizes the implementation of energy produced by suspension systems on powering braking systems. A study is done on types of vehicle suspension system and braking system. Considering the disadvantages of both these systems, where part of energy is wasted, the alternative system needs to be given a thought. The limitations in these systems serve as a driving factor to design a combined system where energy loss can be minimized. This study presents a promising way of minimizing energy losses, which has been a popular topic with the ever depleting energy sources.

II.EXPERIMENTAL SETUP

A setup incorporating both these systems will be designed which will enable us to test the functionality and compatibility of both the systems. The proposed model of this system will consist of four modules:

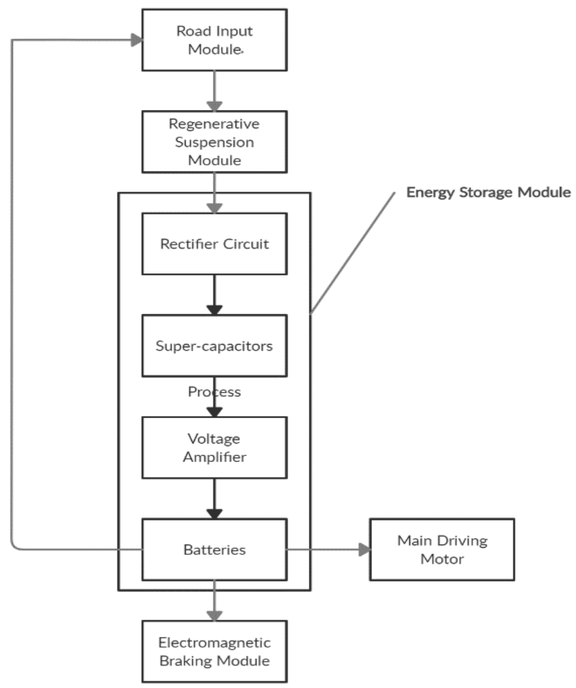

Fig 2.1 Block Diagram of System

1. Road Input Module:

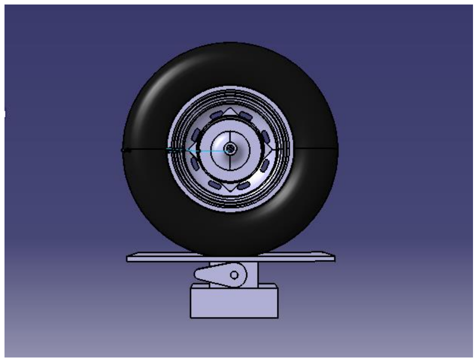

Fig 2.2 Road input System

This system consists of a rotating cam operated by a servo motor, which is used to simulate a bump condition.Motor speed can be varied to change the frequency of bump and the displacement can be changed by using cam of different radii.
Three cams are used to provide the following displacements : 20mm, 40mm, and 50mm.

2. Regenerative Suspension Module:

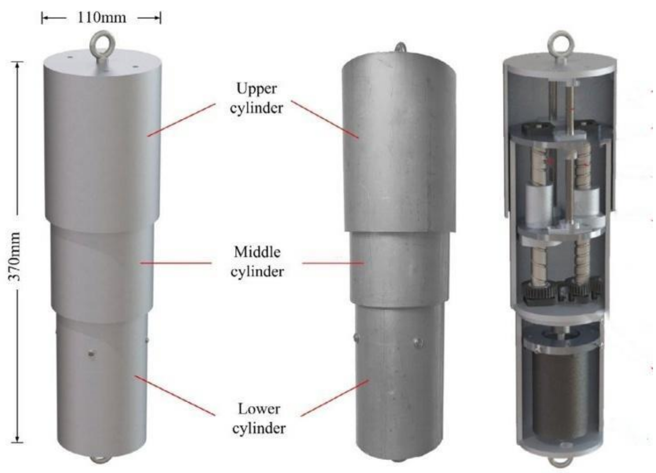

Fig 2.3 Regenerative shock absorber

Twin Ball type of regenerative suspension was used in this experiment. This type of regenerative suspension provides reduction in vibration along with riding comfort. There are three sub-modules in this system: Suspension module, Transmission, Power generation.

- Suspension module: This is basically divided into three parts which are upper, lower and middle cylinder. When suspension vibrates, there occurs linear displacement between upper and middle cylinder, both of them are attached with the lower cylinder via screw bolt.

- Transmission: This module consists of two rods, a pair of ball screws and nuts, overrun clutches, three gears and generator. The reciprocating motion in the vibration module is converted into unidirectional shaft rotation in the transmission module.
- Generator: A generator is fixed to the lower cylinder with a circular plate. The amplitude and frequency will determine the rotational speed of the generator.

3. Energy Storage Module:

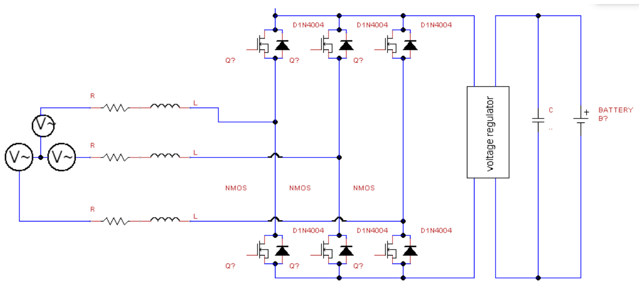

Fig 2.4 Energy storage circuit

This module consists of a charging circuit and a battery pack.The power generated by the damper is fed to the circuit which has supercapacitors and rectifiers. The electric energy is first stored in the supercapacitors and is then rectified. This rectified output is used to charge the battery pack which powers both the motors and the brakes.

4. Electromagnetic Braking Module:

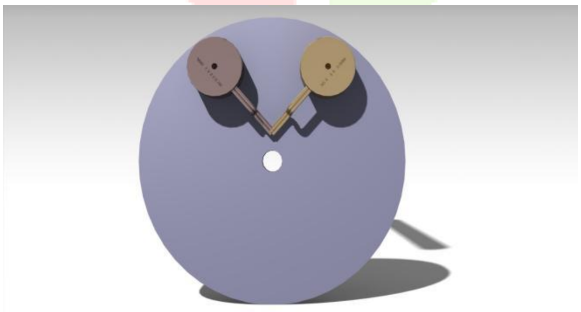

Fig 2.5 Electromagnetic Braking Module

Components:

- Disc liner
- Braking Coil
- Tension Spring
- Battery
- Wheel
- Electromagnet
- Friction material

This system works on the principle of electromagnetism. When a certain amount of voltage or current is passed through the coil, it produces magnetic lines of flux. This flux travels from the small gap between the field coil and armature; magnetically pulling the armature against the hub, and creates a holding force. At this stage, torque is transferred fully as there is no relative slip. Once the current flow stops, the spring holds back the armature from the hub to create a gap. Friction lining is used to slow down wear in brakes.

III.COMPONENT SPECIFICATIONS

1. Selection of Electromagnet

For this particular experiment, we have selected features of an Activa 125cc scooter.

Kerb Weight= 111 kg

Wheel base= 1260 mm= 1.26 m

Acceleration = 0 – 60 kmph in 8.72sec = 1.94 m/s2

Passenger weight = 65 kg
…(assumed average passenger weight)

Total Weight = Body weight + Passenger weight
= 120 + 65*2 = 250 kg

Using formula, Front weight = Total wt*(WB-x)/WB - Total wt*(h/WB)*Long. accln

where,
x= horizontal position of CG from the axle
h= height of CG

Longitudinal Acceleration = Acceleration / 9.81
= 1.94/ 9.81 = 0.2g

The centre of gravity of most two wheelers is located midway between the axles and at a height equal to one half the wheelbase. Using this approximation, the value for weight distribution on the front wheel becomes:

Front Weight = 250*(1.26-0.63)/1.26-250*0.63/1.26*0.2
= 100 kg

Hence, we have availed two electromagnets of 60 kg lifting capacity each to decelerate the vehicle.

2. Selection of motor

We have chosen a DC Hub Motor as this project uses a DC Power Supply as the source. Also we are directly connecting the DC hub motor to the wheel and there is no form of transmission between the motor & the wheel. Considering the weight of the vehicle, Wheel Diameter (approx 0.3m) and Speed Requirements (on an average 400 rpm), torque and speed requirements of the motor are 0.5hp and 1500 rpm. The speed and torque requirement of the motor is taken on the basis of cost-effectiveness of the project to implement on the experimental setup as our project only requires to generate enough torque to the wheel in order for it to spin.

3. Selection of battery

This battery is going to be used for powering the Electromagnets in the Braking System and the motor which is paired to the wheel.

4.5.1 Calculating total load
Total Load = Electromagnet wattage + Motor wattage
= 3*8 + 100

=124W

Current required = Power consumed by load / Voltage of the battery
= 125/24
= 5.2A

In order to run the entire system for 1hr, we will need a 5.2Ah battery
That's why we selected a 6Ah battery. We will use two 6Ah 12V batteries in series to get the required voltage.

4. Generator Specifications

Parameter	Value
Rated Voltage	12 V
Rated Speed	100 rpm
Max. permissible speed	200 rpm
Rated Power	6 W
Rated Current	0.5 A

Table 3.1Generator Specifications

IV.DESIGN CALCULATIONS

A. Design of Shaft 1:

Shaft Material: A36
Having Sut = 260 ,
Syt = 140
Mb = 15000 Nmm
Kb=1.5

So for allowable shear stress;

0.18* Sut = 46.8 ,0.3 * Syt = 42 ;

So allowable shear stress = 0.75*46.8 = 35.1N/mm^2

1) Equivalent torque =

$$\textbf{EQUIVALENT TORQUE} = \sqrt[2]{(M_t \times K_t)^2 + (M_b \times K_b)^2}$$

= 22500 Nmm

2) Diameter of shaft =

$$\zeta\textbf{allowable} = \frac{16 \times \textit{Equivalent torque}}{\pi \times d^3}$$

35.1 = 16 * 22500/ (3.14 * d3)

DS1 = 14.83 mm ~ 15mm

B. Design of Shaft 2:

Shaft Material: PETG (3D Printing)
Having Sut = 11 MPa ,
Mb = 5000 Nmm(from BMD) ,
Kb=1.5

So for allowable shear stress;

0.18* Sut = 1.98 MPa

So allowable shear stress = 0.75*1.98 = 1.485 N/mm^2

1) Equivalent torque =

$$\textbf{EQUIVALENT TORQUE} = \sqrt[2]{(M_t \times K_t)^2 + (M_b \times K_b)^2}$$

=7500 Nmm

2) Diameter of shaft =

$$\zeta\textbf{allowable} = \frac{16 \times \textit{Equivalent torque}}{\pi \times d^3}$$

1.485 = 16 * 7500/ (3.14 * d3)

DS2 = 29.52 mm ~ 30mm

C. Output Power Calculation:

We are using a 12V Brushless DC motor with a Wattage of 6W as the power generating device. The specifications of this generator are listed in Table 3.1.

1) Displacement (y) - 20mm
Lead of screw nut (l) = 10mm
RPM of screw nut (N1) = 2 rpm
Transmission ratio (r) = 5
RPM of generator = r * N1
= 10 rpm
Power generated (PO) = 6 * 10/ 100
= 0.6 W

2) Displacement (y) - 30mm
Lead of screw nut (l) = 10mm
RPM of screw nut (N1) = 3 rpm
Transmission ratio (r) = 5
RPM of generator = r * N1
= 15 rpm
Power generated (PO) = 6 * 15/ 100
= 0.9 W

3) Displacement (y) - 40mm
Lead of screw nut (l) = 10mm
RPM of screw nut (N1) = 4 rpm
Transmission ratio (r) = 5
RPM of generator = r * N1
= 20 rpm
Power generated (PO) = 6 * 20/ 100
= 1.2 W

4) Displacement (y) - 50mm
Lead of screw nut (l) = 10mm
RPM of screw nut (N1) = 5 rpm
Transmission ratio (r) = 5
RPM of generator = r * N1
= 25 rpm
Power generated (PO) = 6 * 25/ 100
= 1.5 W

5) Displacement (y) - 60mm
Lead of screw nut (l) = 10mm
RPM of screw nut (N1) = 6 rpm
Transmission ratio (r) = 5
RPM of generator = r * N1
= 30 rpm
Power generated (PO) = 6 * 30/ 100
= 1.8 W

6) Displacement (y) - 70mm
Lead of screw nut (l) = 10mm
RPM of screw nut (N1) = 7 rpm
Transmission ratio (r) = 5
RPM of generator = r * N1
= 35 rpm
Power generated (PO) = 6 * 35/ 100
= 2.1 W

7) Displacement (y) - 100mm
Lead of screw nut (l) = 10mm
RPM of screw nut (N1) = 10 rpm
Transmission ratio (r) = 5
RPM of generator = r * N1
= 50 rpm
Power generated (PO) = 6 * 50/ 100
= 3 W

D. Result Table:

Displacement (mm)	RPM of Generator (rpm)	Calculated Output Power (W)
20	10	0.6
30	15	0.9
40	20	1.2
50	25	1.5
60	30	1.8
70	35	2.1
100	50	3

Table 4.1

V.GENERATOR SIMULATION

We have used MATLAB - Simulink software to simulate and obtain the values of output power and voltage given by the generator. In this section, we have determined simulated output power and later compared it with calculated power.

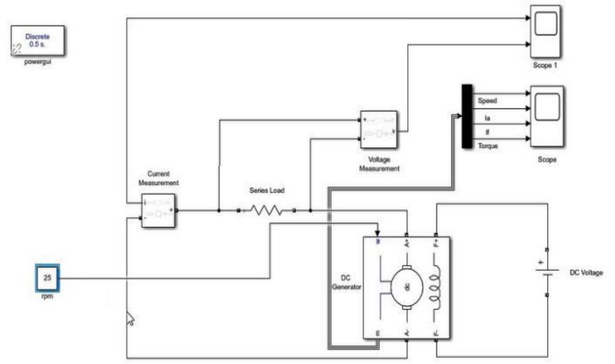

Fig 5.1 Generator Circuit in Simulink

In the circuit above, the field coil of the DC Generator is externally excited using a DC Voltage. An Ammeter is connected in series with the Armature in order to measure the current generated. To measure the voltage generated, a Voltmeter is connected in parallel with the Armature. The output current and voltage graphs are displayed on Scope 1. Field current, Armature current , speed and torque of the generator can be obtained from Scope 2. Input to the generator is given in the form of number of rotations of shaft per minute.

Graphs for Scope 1 are generated in order to get the voltage and power for each displacement.

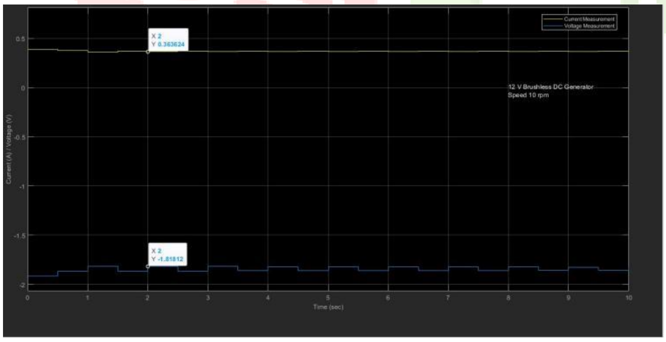

Fig 5.2 Generator Simulation for Speed = 10 rpm

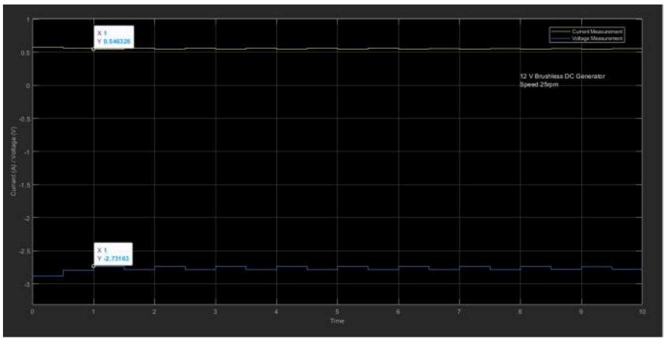

Fig 5.3 Generator Simulation for Speed = 20 rpm

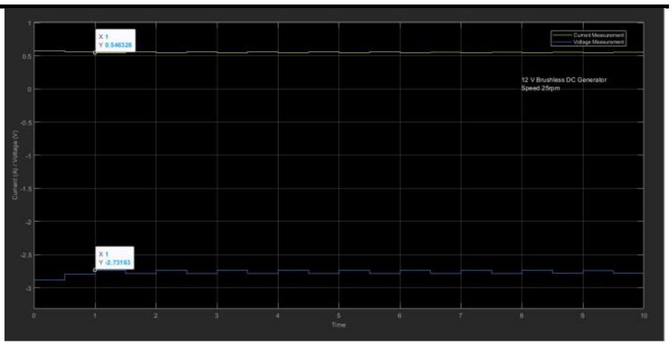

Fig 5.4 Generator Simulation for Speed = 25 rpm

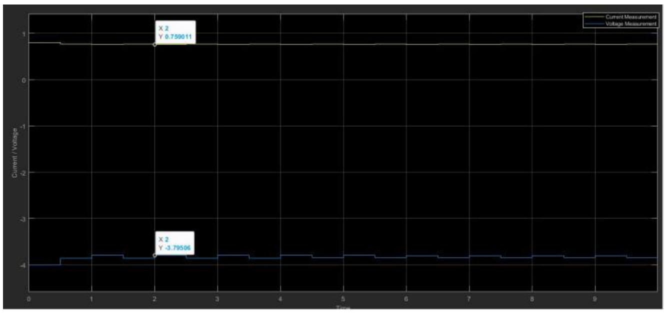

Fig 5.5 Generator Simulation for Speed = 50 rpm

VI.STATIC ANALYSIS AND DESIGN VALIDATION

ANSYS software to carry out static analysis of both the shafts and validate the design.

- Analysis of Shaft 1:

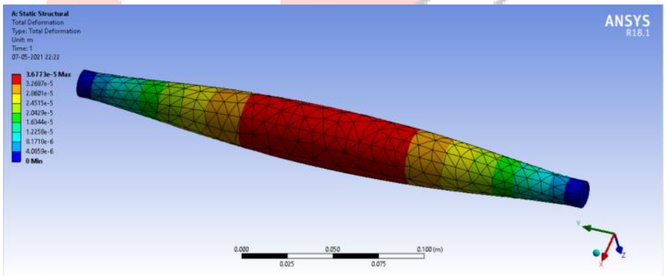

Fig 6.1 Total Deformation of Shaft 1

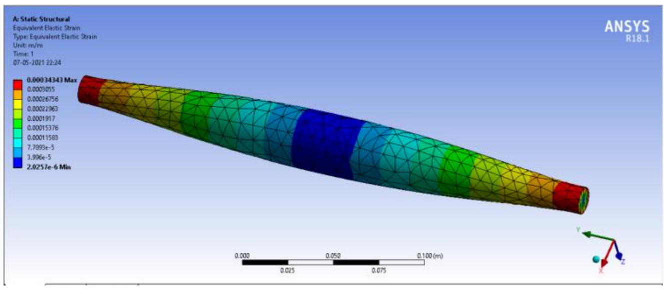

Fig 6.2 Equivalent Strain of Shaft 1

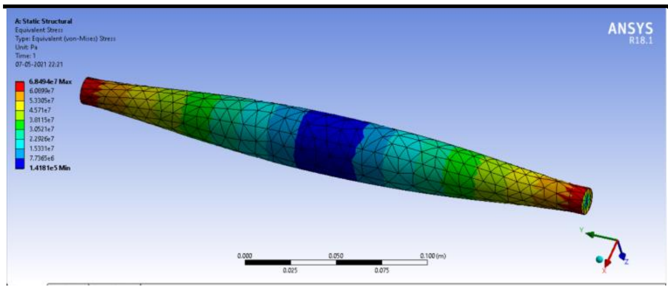

Fig 6.3 Equivalent Stress of Shaft 1

From this analysis,

Maximum stress = 68MPa

But, Maximum Allowable Stress on Shaft 1 = 140MPa

Therefore, Factor of Safety = 140/68 = 2.05

- Analysis of Shaft 2:

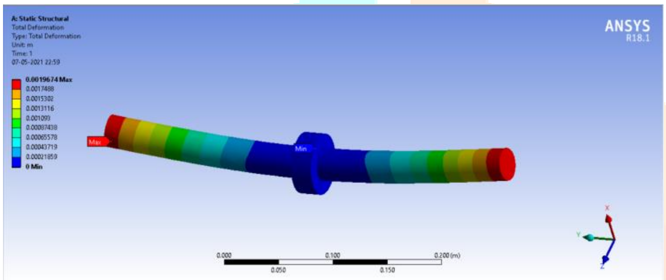

Fig 6.4 Total Deformation of Shaft 1

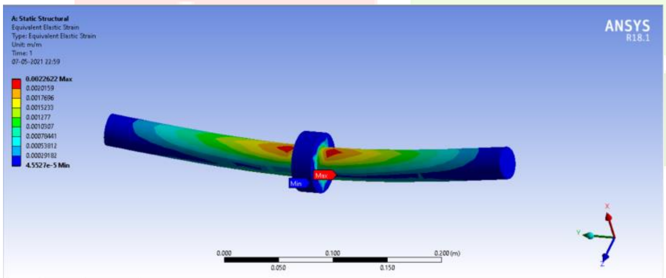

Fig 6.5 Equivalent Strain of Shaft 2

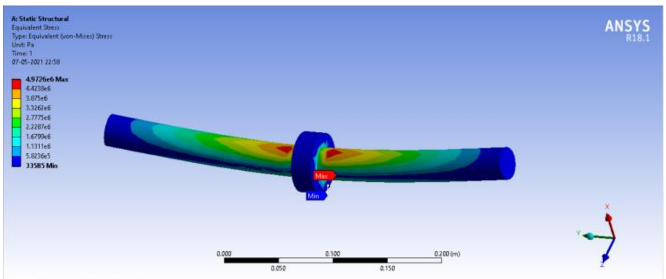

Fig 6.6 Equivalent Stress of Shaft 2

From this analysis,

Maximum stress = 5MPa

But, Maximum Allowable Stress on Shaft 1 = 11MPa

Therefore, Factor of Safety = 11/5 = 2.2

VII.OUTCOMES

Comparing the calculated and simulated parameters:

Displacement (mm)	RPM of generator (rpm)	Calculated Output Power (W)	Simulated Output Voltage (V)	Simulated Output Power (W)
20	10	0.6	1.82	0.66
30	15	0.9	2.04	0.84
40	20	1.2	2.37	1.11
50	25	1.5	2.73	1.5
60	30	1.8	2.93	1.7
70	35	2.1	3.16	2
100	40	3	3.8	2.9

Table 7.1

Graphs for Simulated and calculated parameters

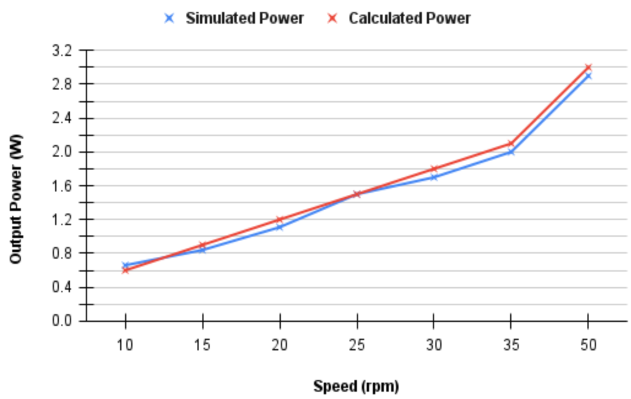

Fig 7.1 Speed vs Output Power Graph

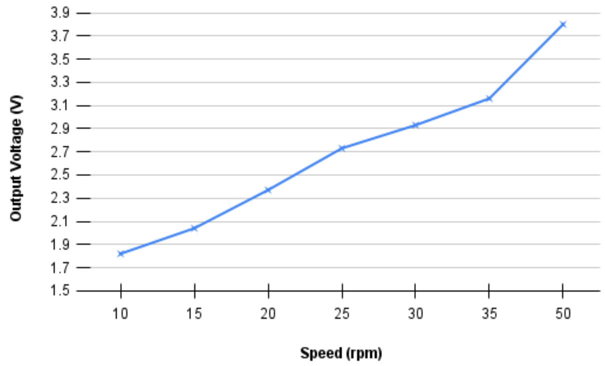

Fig 7.2 Speed vs Output Voltage Graph

VIII.CONCLUSION

A simulation of a combined system of regenerative suspension unit and electromagnetic braking unit, incorporating a 3D model was presented. From the simulation carried out, we have determined the amount of voltage produced and power recovered due to road irregularities. From graphs it can be observed that simulated output power is less than calculated output power. As generator shaft speed increases, output power and output voltage increases. Additionally, from static analysis of the shafts, it can be concluded that design for both the shafts is safe with optimum factor of safety. These observations can be the basis of our future work, which aims at improving this system to outmatch the current results, and ultimately control depletion of energy resources.

ACKNOWLEDGEMENT

Any accomplishment involves the efforts of many people. This research is no different. It is a result of the combined efforts of all the team members and our guide.

Taking this opportunity to express our gratitude, we thank our guide Prof Gaffar G.. Momin for his guidance and support at various stages during the course of our experiment. It was due to his patient guidance that this endeavour of ours could be materialised.

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