

# **Design of an Electromagnetic Suspension and Regenerative Braking System for Electricity Generation**

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## **Abstract**

This research aim was to design an electromagnetic suspension and regenerative braking system for power generation. It looks at ways in which the heat dissipated into the environment from the brakes and suspension can be reused by converting it into another form of electrical energy stored in batteries. My research findings indicate how the braking efficiencies vary with a number of factors. These include road geography (slopes), braking velocities and traffic volumes. The results of this research then helped to narrow down which types of road geography would lead to an optimum amount of energy being recovered. Journals of past researches on the topic were reviewed in order to help determine how best to design a system that will integrate regenerative braking and the electromagnetic suspension. Calculations on determining the optimum braking force needed were done which has led to the final chosen concept. This project focused on Electrical Vehicles.

## **Keywords**

Electric vehicles, power generation, electromagnetic suspension and regenerative braking system

## **1. Introduction**

In the case of brakes or suspensions, kinetic energy is often released as heat. Friction brakes, which convert kinetic energy to heat, are used in the majority of automobiles. This basically means that when you apply the brakes, a lot of energy is released as heat (Lakshmi, 2017). Regenerative braking is the conversion of kinetic energy generated during braking into a form that can be used right away or stored till later. For most convectional vehicles, the majority of the Kinetic energy converted during friction braking, between the brake pads & wheels turns into heat which then gets emitted unused into the environment as waste but not when driving a hybrid model or electrical vehicle. Using electric motors, a portion of Kinetic energy can be recovered for reuse. This means using a regenerative braking system, all the Kinetic energy that would have been lost can partially be put right back into the battery.

Every automotive suspension has two goals: passenger comfort and vehicle control. Electromagnetic suspension is a system that converts vehicle bump into electrical energy. Its primary function is to reduce effects of vibrations and irregularities on roads. This is achieved with the help of shock absorbers that emit vibrational energy in the form of heat. This heat is the one that this project aims to harvest and convert into electrical power that can then charge the battery. This research proposes a design of a system where the heat lost in the suspension system and brakes combined is extracted, converted into a usable form of electrical energy which can charge batteries. In 1967, the American Motor Car Company (AMC) created an electrical energy regeneration brake for their concept electric car, the AMC Amitron. Toyota was the first car manufacturer to commercialize RBS technology in their Prius series hybrid cars (Clark, et al., 2011). Since then there has been an evolution in the regenerative braking systems. Modern

hybrid cars and EVs make use of an electrical engine to power the car which makes applying regenerative braking very simple and efficient.

ZERA launched the first electric car to accelerate adoption of clean energy, it is in sync with Zimbabwe's aspirations of a modernized and mechanised country by 2030. The intent to adopt more electric cars in the country means the need to charge those cars grows. This is a great opportunity to invest in the design of the electromagnetic suspension and the regenerative braking system as it solves the problem of not having enough charging ports by utilizing the wasted energy in order to charge the car batteries. The major issue is the battery time and the need to reduce the frequency in charging. The amount of energy wasted by braking and suspension system coupled by shorter charging intervals is as a result of convectional braking. ZERA launched the first electric car to accelerate adoption of clean energy in Zimbabwe. Introduction of more electric cars means a lot of energy is wasted as a result of braking and suspension systems.

### 1.1. Objectives

The objective was to design a mechanical system that harvests and utilizes the energy lost during regenerative braking and in the electromagnetic suspension system combined as a result of linear motion and vibration. This was achieved through the design an energy optimization system that will integrate energy from regenerative braking and electromagnetic suspension, determination the optimum amount of braking force needed for maximum energy, analysis of maximum energy recovered due to road irregularities and braking and the design a system that is not only efficient but affordable.

## 2. Literature Review

Regenerative braking is used in cars with electric motors, such as electric automobiles and hybrid electric vehicles. When an electric motor rotates in one direction, it converts electrical energy into mechanical energy that may be used to perform tasks such as spinning the wheels of a car, but when it rotates in the opposite direction, it becomes an electric generator. (Unnewehr & Nasar, 1982). There are two types of regenerative braking which are serial and parallel regenerative braking. Serial regenerative braking combines a friction-based adaptive braking system with a regenerative braking system that converts electrical energy to the electric motors and batteries as part of an integrated control strategy. A friction-based and a regenerative braking system work together without the need of an appropriate control in the parallel braking system. Suspensions are catergorised into their construction and ways of energy generation. Examples based on paths of generation are piezoelectric, hydraulic, pneumatic, electromagnetic and hybrid [hydraulic + electromagnetic]. BEVs [battery electric vehicles], PHEVs [plug-in hybrid electrical vehicles], and HEVs [hybrid electrical vehicles] are the three primary kinds of electric vehicles, which are characterized by the amount to which electricity is employed as an energy source. HEVs use both an electric motor and fuel to power them. The Battery is charged as the vehicle runs on gas. PHEVs are plugged in in order to recharge the battery. They are similar to the convectional hybrids. BEVs are powered 100% by battery and an electric motor. (Plugndrive, 2021).

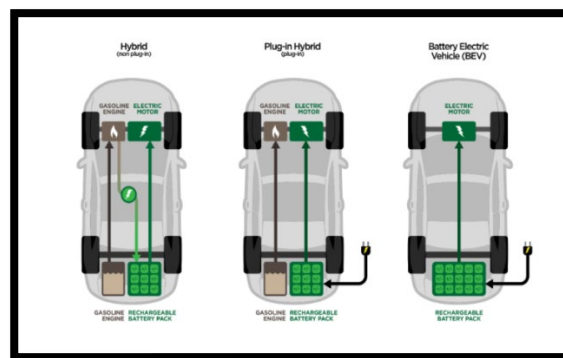


Figure 1. Types of EVs (source: [www.nspower.ca](http://www.nspower.ca))

A research was done by Salinas and Cajamarca (2021) which was an analysis of regenerative braking efficiency in an electric vehicle through experimental tests. The main significant values were initial and final braking velocities and the weight of the vehicle. Three routes were investigated which had different types of road geography, slopes, and

looked at how initial braking speeds had an impact on the variability of the obtained efficiencies. Due to the general above-mentioned parameters tested, the average efficiency in the specific sample for route 1 was 23%, indicating that the brake pedal was not utilized frequently. Due to the high vehicle flow, low driving speeds, and heavy use of the brake pedal on route 2, the figures fluctuated. As a result, the regenerative system's efficiency improved, and the efficiency tended to stabilize, resulting in increased energy recovery. The efficiency of Route 3 varied depending on the road terrain, typical braking velocities, and traffic volume. With a maximum value of 77 percent, the average efficiency was 22 percent (Table 1, table 2 and table 3).

Table 1. Route 1

| <b>SPEED (km/h)</b> | <b>RECOVERY BRAKING ENERGY <math>E_m</math> (J)</b> | <b>ENERGY LOSS OF BRAKING <math>E_b</math> (J)</b> | <b>EFFICIENCY (%)</b> |
|---------------------|---|--|-----------------------|
| 9                   | 3053.40   | 409842.90  | 0.07                  |
| 44                  | 6930.63   | 19275.92   | 36                    |
| 74                  | 444720  | 55819.86   | 79                    |

Table 2. Route 2

| <b>SPEED (km/h)</b> | <b>RECOVERY BRAKING ENERGY <math>E_m</math> (J)</b> | <b>ENERGY LOSS OF BRAKING <math>E_b</math> (J)</b> | <b>EFFICIENCY (%)</b> |
|---------------------|---|--|-----------------------|
| 9                   | 111.72  | 8261.11  | 1.35                  |
| 22                  | 6346.10   | 17210.64   | 37                    |
| 44                  | 8030.25   | 10326.39   | 78                    |

Table 3. Route 3

| <b>SPEED (km/h)</b> | <b>RECOVERY BRAKING ENERGY <math>E_m</math> (J)</b> | <b>ENERGY LOSS OF BRAKING <math>E_b</math> (J)</b> | <b>EFFICIENCY (%)</b> |
|---------------------|---|--|-----------------------|
| 9                   | 346.96  | 569041.39  | 0.06                  |
| 22                  | 1748.81   | 4818.98  | 36                    |
| 52                  | 34224   | 44059.25   | 78                    |

Each route's regenerative braking efficiency is demonstrated to be dependent on the amount of energy lost and recovered by the vehicle. Table 4 for route two values showed that there was an improvement by the extended use of the brake pedal even though its velocity values were lower due to intense traffic. As there is no need for a large power demand, energy consumption is reduced. A lack of significant alterations in the route favored energy recovery and high efficiency. Due to the geology of the road, high power when overcoming slopes, and modest usage of the brake pedal, the vehicle had a large energy loss compared to route 2, resulting in lower recovery compared to route 2.

## 2.1 Factors limiting the braking power generated during regenerative braking

- Braking power is limited by the charging power limit of the battery pack. This limit depends on the chemical composition (battery type) and this changed with temperature.
- When a car is moving slowly, the kinetic energy is low enough such that very little energy is put back into the battery as the car comes to a stop. In most cases the small amount of energy generated as the car slows down does not even cover the fixed losses in the inverter and motor.
- Additional charge from regenerative braking would cause the voltage of a full battery to rise above safe level, the motor controller unit will limit regen torque in this case.

## 2.2 Efficiency calculations

In order to evaluate our regenerative braking system performance we use Overall efficiency and Powertrain efficiency. In order to perform efficiency calculations two elements are considered; energy available and energy collected.

#### *Wheel power/energy*

In order to get the total force on the vehicle, the derivative of vehicle speed is taken to get the vehicles acceleration/ deceleration. The Newton's second law with the test vehicle weight is used.

$$F_{Total} = M_{veh} \cdot \frac{dv_{m/s}}{dt}$$

The drive force based on road load force and total force is obtained. With the vehicle speed in m/s, the wheel power;

$$F_{Wheel} = F_{Total} - F_{roadload}$$

$$P_{wheel} = F_{wheel} \cdot v_{m/s}$$

$$E_{wheel} = \int_{t_{start}}^{t_{end}} P_{wheel} \cdot dt$$

#### *Battery power/ energy*

For battery power calculation, the battery current and battery voltage are multiplied to get the battery power.

$$P_{battery} = I_{wheel} \cdot V_{wheel}$$

If an engine is running on regenerative event and is charging the battery, a portion of power would have to be removed from the battery power.

$$P_{battery} = I_{battery} \cdot V_{battery} - P_{engine} \times E_{motor}$$

Where;

$P_{engine}$ -engine power

$E_{motor}$ -motor efficiency

Integrating the battery power using start and end time, the amount of battery energy can be obtained by

$$E_{battery} = \int_{t_{start}}^{t_{end}} P_{battery} \cdot dt$$

The overall efficiency then becomes

$$Eff_{Overall} = \frac{E_{battery}}{E_{Wheel}}$$

The recovery of energy from vibrations due to road bumps and irregularities as well as braking is the target. The concept of Electromagnetic induction achieves the energy recovery system. Regenerative braking is a good way to increase the range of an electric car. It can save anywhere from 8% to 25% of the total energy used by the vehicle, depending on the driving cycle and how it was driven (Chen, & Guo, 2005). Regenerative braking reduces the use or duration of the main brake, prevents the main brake from overheating, improves the safety of continuous braking, and achieves smart energy management (Feng, 2019) , which happens to be one of the main goals of this project.

### **3. Methods**

#### **3.1. Literature Review**

Through the use of credible sources online, textbooks, articles and researches that have been done prior on the topic of Regenerative braking systems and electromagnetic suspension systems, the researcher conducted a theoretical study to obtain a better understanding of the topic, in order to understand the current system being used, learn its advantages and be able to improve it by making use of authentic articles online and from the library.

Existing models of electromagnetic suspension systems and regenerative braking systems were revealed throughout the project as a foundation of the intended design which aims to improve on the current existing ideas. With the use of reputable articles on the internet and library visit, that is how the information was obtained to aid in the best way to combine the two systems. Concepts were generated and compared against each other according to design criteria and requirements towards the selection of the final desired design.

#### **3.2. Design Procedure**

The researcher made use of software like AutoCAD and Solid works for the modelling and simulation of the final design. Cost analysis was done for all the designs. Data collection and data analysis was done with aid of existing models and the use of credible research sources online and in the library.

Three possible solutions were prepared and analysis so as to be able to select the best possible solution was done. The generation of concept ideas were generated taking into account cost, customer's needs, components to be used and general size.

#### **3.3. Selection of Best Concept, Design Analysis and Optimization**

A decision matrix was prepared in order to choose the best concept from the three possible solutions. The chosen solution was analysed and designed to meet the objectives and requirements of chosen solution. The working principle of three possible techniques was analysed to come up with the matrix.

#### **3.4. Expansion of The Concept**

Research of the current advancements in electromagnetic suspensions and regenerative braking systems was taken into account. Innovation using research techniques like the internet and currently published books and journals were all taken into consideration mainly focusing on the experimental details and the numerical analysis.

#### **3.5. Detailed Design Calculations, Drawings and Analysis**

Calculations were brought down, from the braking torque necessary for optimum energy harvest as well as the braking force required to achieve an optimum result. Other frictional forces caused by the motor due to the torque produced were also considered. AutoCAD was used for the detailed drawings of the three options. Due to the wide scope of different motors used, different designs amongst other components, the decision matrix was used to choose the best concept.

#### **3.6. Evaluation and Analysis**

##### ***Feasibility Analysis***

The design of the regenerative braking system and electromagnetic suspension was expected to increase efficiency of existing models. The outcome was expected to come up with advancements of the existing systems. The drawings and modelling proved to be the best for the expected prediction of the result.

##### ***Economic Analysis***

A breakdown of the cost budget of the components needed was done. The costing took into consideration the manufacturing costs, cost of design, cost of assembly, cost of parts and all manufacturing processes to be done.

#### **3.7. Development of Chosen Solution**

The development of the optimum chosen concept was done. Actual drawings were made using the CAD software. The entire design was exploded and each component analyzed in order to fulfil the major aim and objectives of the project. The full structure of the regenerative braking system was drawn which shows all connections.

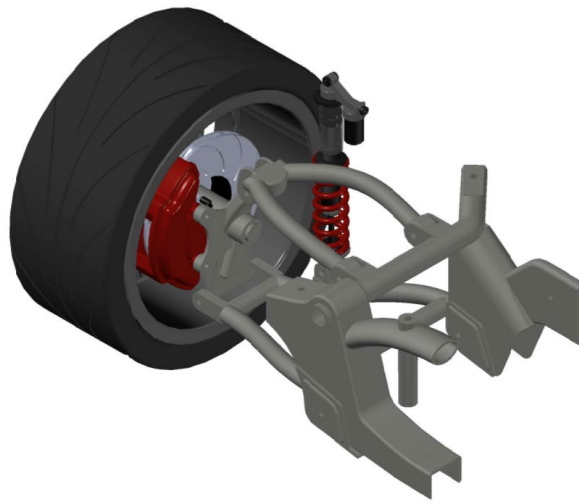


Figure 2- Regenerative braking mechanism and electromagnetic suspension assembly with disc braking mechanism

The regenerative braking system is connected to a rotating disc in the wheel system with electric motors attached to it (Figure 2). A connecting mechanism joins the spring system, shock absorber and the magnets which are the foundation of the electromagnetism concept in the suspension. The energy generated by these two concepts combined is then used to charge the battery and other features in the electrical vehicle that need electric energy. This model does not make use of the braking drum and friction lining but rather the metal disc is used to achieve the desired results.

#### ***Working concept***

This concept makes use of a regenerative braking system where motors are attached to a disc brake. When the brakes are applied the motors touch the surface/lining of the brake and automatically run thus harvesting the heat energy, changing it into electrical energy and making use of connecting cables to transfer that energy to the batteries.

The electric motor is engaged when an electric current is sent through it. When an external force is applied to engage the motor, it acts like a generator, creating electricity. When the motor rotates in one way, electric energy is transformed to mechanical energy, which is utilized to accelerate the vehicle; when the motor rotates in the opposite direction, the inverse is true (motor runs in the opposite direction performing functions of a generator). The generator then converts mechanical energy into electrical energy, allowing the rotational force that turns the electric motors to be more easily achieved. With the regenerative resistance of the electric motors, this results in the regeneration of electric energy for storage in batteries and a reduction in vehicle speed. The electromagnets found in the suspension system, facilitates the concept of electromagnetism that way harvesting energy from the suspension and combining it with the energy from the regenerative braking system to then charge the battery.

The electromagnetic suspension system turns all types of vehicle bumps into electricity, including linear motion and vibration. The energy is absorbed without being converted into electrical energy by the shock absorber enclosed within the casing and spring system. To generate electricity from this motion, the electromagnetic principle is applied. A metal shaft, spring, magnet coils, base with screws, and joints make up the shock absorber. Cylindrical supports are utilized to reduce friction and provide a smooth generation process. The spring is precisely fitted to obtain the appropriate motion and magnet overlap, allowing electricity to be generated using the electromagnetism principle. The electromagnetic suspension system is used to generate smart electricity.

### *Components used*



Figure 3. Exploded view of chosen concept

1. Shaft made of metal (Figure 3)
2. Spring
3. The inner rod
4. Magnets
5. Coils made of copper
6. The foundation of the frame
7. Joints and screws
8. Dc motors
9. Linking mechanism
10. Metal disc

### *Advantages*

1. Free energy generation
2. Low maintenance
3. Energy conservation

### *Modifications*

To avoid a problem of overheating on the motor, routine maintenance is to be done that way temperature and performance for signs of overheating or deterioration can be observed and fixed on time. In order to alert the owner of the vehicle if there is overheating, a thermostat is to be placed on the surface of the motor. Motors generally need

room to breathe to perform at their optimal therefore, small fans are to be placed on the sides of the motor which will carry away heat from the surface of the motor.

#### ***Additional features***

##### **1. Voltage regulator**

The device contains a voltage regulator linked to the motor to prevent overheating or burning of the motor. When the motor is under low load, less work has to be done, resulting in less voltage being permitted to go to the motor. As a result, the amount of voltage allowed to reach the motor is proportional to the load. This prevents the motor from overworking or consuming too much energy when there is no load, while also increasing the amount of energy used when there is more load.

##### **2. Sensors**

A number of sensors are used with various parts of the electromagnetic suspension framework to make it keen and quick responsive. These sensors sense the ride's requirements and send signals to the vehicle's ECU (electronic control unit) to control the suspension as needed, and they are in charge of the electromagnetic suspension framework's strength.

## **4. Results and Discussion**

The regenerative braking system is designed so as to utilize the mechanical energy which is usually dissipated when brakes are applied. It converts the mechanical energy into electrical energy which is used to charge the battery and other components in the vehicle that need the energy. The design was mainly focused not on heavy duty vehicles but vehicles with respect to a certain weight. Hence if the mechanism applied and design procedures here are done on vehicles larger or smaller, the same concept will work the same only if the parameters are adjusted in accordance to the size of that particular vehicle (Table 4 and table 5).

Table 4. list of parameters to be used

| <b>PARAMETER</b>                        | <b>VALUE</b>            |
|---|-------------------------|
| Vehicle mass                            | 1500kg                  |
| DC motor speed                          | 1800rpm                 |
| Approximate diameter of a vehicle wheel | 20.823inches=0.5289042m |

### **4.1. Brake calculations**

Table 5. Disc brake standard measurements

|                                |                       |
|--------------------------------|-----------------------|
| Rotor disc dimension           | 240mm                 |
| Rotor disc material            | Carbon ceramic matrix |
| Pad brake area                 | 2000mm <sup>2</sup>   |
| Pad brake material             | Asbestos              |
| Coefficient of friction (wet)  | 0.07-0.13             |
| Coefficient of friction ( dry) | 0.3-0.5               |
| Maximum temperature            | 350°C                 |
| Maximum pressure               | 1MPa                  |



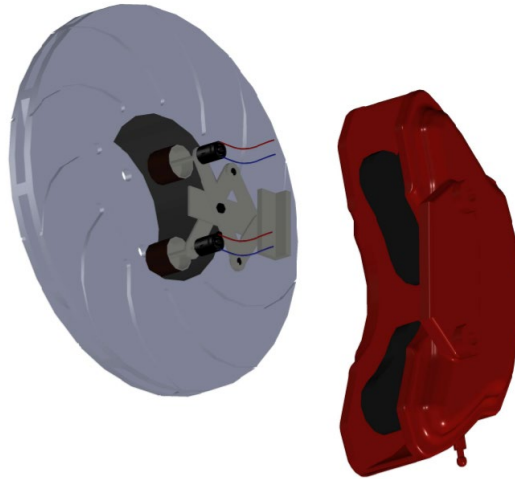


Figure 4. Braking system

Tangential force between brake pad and motor ( $F_t$ )

Where:

$\mu$ -coefficient of friction

$P_{max}$  –maximum pressure

A –pad brake area

$$F_t = 0.5 \times \left( \frac{10^6}{2} \times 2000 \times 10^{-6} \right) = 500N$$

NB: Total force is the tangential force between the pad and rotor in the outer and the inner face. Since the material is the same that means the tangential force in the inner face is the same as the tangential force in the outer face (Figure 4).

Brake torque ( $T_b$ )

*Assumption: the coefficient of friction between the inner face and outer face is equal*

$$T_b = F_{t(total)} \times R$$

$$T_b = (500 + 500) \times (120 \times 10^{-3}) = 120Nm$$

#### 4.2. Choosing the right motor to use

Let:

L-load of the vehicle

g -acceleration due to gravity (9.81m/s)

*[For the calculation of rpm for a motor, the frequency in hertz is multiplied by 60(for the number of seconds in a minute) also multiplied by 2 for the negative and positive cycles in a cycle. Solution is then divided by the number of poles the motor has.]*

Assuming a motor of approximately 60Hz frequency is used with 4poles.

$$N = \frac{60 \times 60 \times 2}{4} = 1800rpm$$

$$T = (1500 \times 9.81) \times \left( \frac{0.5289042}{2} \right) = 3891.412652 Nm$$

Power needed for the motor to move the system

$$P = \frac{2 \times \pi \times 1800 \times 3891.412652}{60} = 733514.0039 Watts$$

$$P = 983.6583129 \text{ horsepower}$$

NB: therefore a 984 horsepower brushless DC motor is the best choice considering cost and efficiency. A DC motor of that horsepower can also be used though the advantages of an induction motor outweigh those of the DC motor.

#### 4.3. Spring design

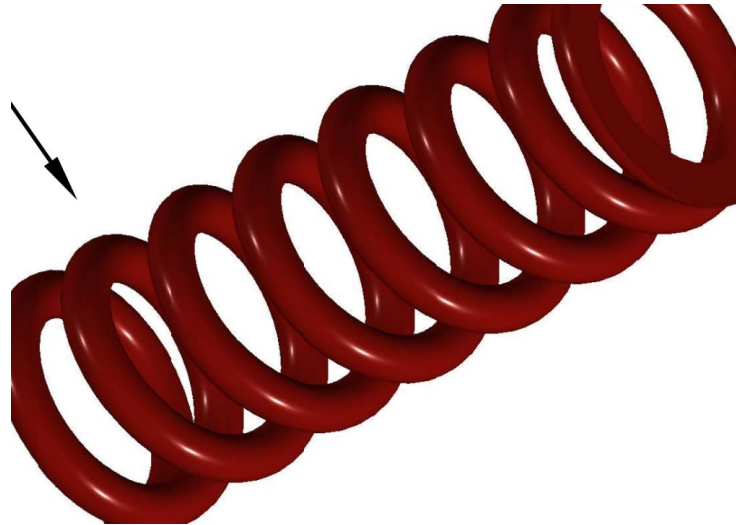


Figure 5. Helical spring

Let:

D = Mean diameter of the spring coil

d = Diameter of the spring wire

n = Number of active coils

G = Modulus of rigidity for the spring material

W = Axial load on the spring

$\tau$  = Maximum shear stress induced in the wire

C = spring index = D/d

p = Pitch of the coils

$\delta$  = Deflection of the spring, as a result of an axial load W

Since the spring does not support the full load of the car but rather a certain mass. Assumption made is that the spring is subjected to approximately 60kg (588.6N) which will be used in design calculations (Figure 5).

Table 6. Values of allowable shear stress, modulus of elasticity and modulus of rigidity for various spring materials

| MATERIAL        |                   | ALLOWABLE<br>SHEAR STRESS<br>(MPa) |                  | MODULUS<br>OF<br>RIGIDITY<br>(G) | MODULUS OF<br>ELASTICITY<br>(E) |
|-----------------|-------------------|------------------------------------|------------------|----------------------------------|---------------------------------|
|                 | SEVERE<br>SERVICE | AVERAGE<br>SERVICE                 | LIGHT<br>SERVICE |                                  |                                 |
| 1. Carbon steel |                   |                                    |                  |                                  |                                 |

|                           |     |     |       |    |     |
|---------------------------|-----|-----|-------|----|-----|
| a) Up to 2.125mm          | 420 | 525 | 651   |    |     |
| b) 2.125-4.625mm          | 385 | 483 | 595   |    |     |
| c) 4.625-8mm              | 336 | 420 | 525   |    |     |
| d) 8-13.25mm              | 294 | 364 | 455   |    |     |
| e) 13.25-24.25mm          | 252 | 315 | 392   |    |     |
| f) 24.25-38mm             | 224 | 280 | 350   |    |     |
|                           |     |     |       | 80 | 210 |
| 2. Music wire             | 392 | 490 | 612   |    |     |
| 3. Oil tempered wire      | 336 | 420 | 525   |    |     |
| 4. Hard drawn spring wire | 240 | 350 | 437.5 |    |     |
| 5. Stainless steel wire   | 280 | 350 | 437.5 | 70 | 196 |
| 6. Nonel metal            | 196 | 245 | 306   | 44 | 105 |
| 7. Phosphor bronze        | 196 | 245 | 306   | 44 | 105 |
| 8. brass                  | 140 | 175 | 219   | 35 | 100 |

Making use of carbon steel, the modulus of rigidity is therefore 80kN/mm<sup>2</sup> and 210kN/mm<sup>2</sup> for modulus of elasticity

$$\text{Mean Wire Diameter}(D) = \text{inner diameter} + d \text{ mm}$$

Assuming wire diameter of standard wire gauge (SWG) 5.9mm and inner diameter 50mm  
 $n = 9.6 = 10 \text{ turns}$

Since spring is grounded on both ends

$$n = 10 + 2 = 12 \text{ effective turns}$$

Assuming the free length is 70mm, the pitch is

$$L_F = np + 2d$$

$$p = \frac{(L_F - 2d)}{n} = \frac{(70 - 2 \times 5.9)}{12} = 4.85 \text{ mm}$$

Assuming maximum deflection is 70mm, the deflection load will be

$$\tau_{ind} = \frac{KWC}{\pi d^2} = \left( \frac{4C - 1}{4C - 4} + \frac{0.615}{C} \right) \times \frac{8WC}{\pi d^2} = \left( \frac{4(8.97) - 1}{4(8.97) - 4} + \frac{0.615}{8.97} \right) \left( \frac{8 \times 476.86 \times 8.97}{\pi \times 5.9^2} \right)$$

$$\tau_{ind} = 363.8 \text{ MPa}$$

Surging which is the application of many cycles on load per second at a frequency higher than natural frequency of spring causes unequal deflections and propagation of waves and resonance resulting in spring failure (Table 6). In order to avoid this failure, springs of frequency higher than the frequency of loading are to be used. Where spring frequency is to be given by

$$\text{Natural frequency } (f_n) = \frac{w_n}{2\pi} = \frac{\sqrt{\frac{k}{m}}}{2\pi} = \frac{\sqrt{\frac{8530.4}{60}}}{2\pi} = 1.898\text{hz}$$

Car wheels drive at a frequency of 0.33cycles per second, therefore the designed spring is safe from surge failure.

#### 4.4. Braking force calculation

*(Braking force is affected by mass of the vehicle, velocity at which the vehicle is moving and the braking distance. The speeds and distances will be adjusted in order to the effect they may have on the braking force)*

Where

- m is the mass of the car
- v is the velocity of the car before braking
- d is the stopping distance

Case 1

m=1500kg

v=25m/s

d=25m

$$\text{braking force} = \frac{\frac{1}{2} \times 1500 \times 25^2}{25} = 18750N$$

Case 2

m=1500kg

v=25m/s

d=80m

$$\text{braking force} = \frac{\frac{1}{2} \times 1500 \times 25^2}{80} = 5859N$$

The greater the braking distance, the smaller the braking force which proves that the two are inversely proportional. From the formula above, it shows that braking force is directly proportional to the braking force.

## 5. Conclusions and Future Research

An electromagnetic suspension and regenerative braking system approach was proposed. The electromagnetic suspension system is capable of providing a substantially smoother ride than any luxury sedan, as well as significantly less roll and pitch than any sports vehicle. Vehicle Suspension Energy Generation is a very efficient and practical method of turning kinetic energy from vehicle movement, particularly the suspension, which is generally wasted, into electric energy that may be utilized to power auxiliaries in the vehicle as well as charging the battery. The two systems combined ensure that an optimum amount of energy is recovered by making use of clean energy which would otherwise be lost into the environment. As technology advances this combined system may become one of the promising trends in the vehicle industry.

To achieve maximum efficiency throughout the process, some areas that could be investigated further in future work in order to improve the mechanization of the braking system and electromagnetic suspension were identified. The following are some suggestions for future work

- a) The findings of simulations are not always accurate representations of real-world scenarios. It only serves to give a rough notion of whether the chosen approach has enough potential to be implemented in the actual world. As a result, it is recommended that the simulation tactics be tested on a real vehicle to fine-tune the recovery values.
- b) In this project brushless DC motors were used due to the availability, characteristics like high starting torque, high efficiency and cost. Induction motors can also be used due to their ability to withstand rugged.

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