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# A Design Analysis of Suspension Energy Regenerative System Using Dynamo Damping

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**Abstract:** The ordinary vehicle suspension system scatters the mechanical vibration vitality as a considerable amount of waste heat. In recent times the regenerative suspension systems have pulled in much consideration for the augmentation of vibration attenuating performance as well as the reduction of energy dissipation or harvesting the same. The main objective is to fabricate a prototype of *Suspension Energy Regeneration System (S.E.R.S.)* at a convenient cost for the automobile industry, further conduct the experiments, and analyse the power output. Also, to raise the fuel efficiency of the engine by decreasing the consumption of electrical energy produced by the I.C. engine by harvesting the same energy from S.E.R.S. Thus, reducing the fuel energy wastage and promote sustainable development. The main focus is to evaluate the possibility of using dynamo as a damping module in the Suspension system. The performance analysis was done to observe the differences between the operations of the conventional suspension system and S.E.R.S. After carrying out the necessary study, the simplified design of S.E.R.S. was made and fabricated which was cost-efficient as well as had enough power regeneration to support auxiliary electronic system in vehicles like audio system, headlights, etc.

## 1. Introduction

In India, Automotive Vehicles experience a great deal of rough street and speed breakers. The suspension framework utilized in autos chiefly hoses these vibrations [1]. This is a significant zone where the squandered vitality could be utilized [2-4]. The vehicle suspension framework can help the heaviness of the vehicle anatomy, to disconnect the vehicle skeleton from street aggravations, and to empower the wheels to grasp the street surface. Two main components in suspension are spring and damper. Expectedly, the damper is intended to disseminate vibration vitality into heat to weaken the vibration, which is disseminated from street excitation. In any case, the dispersed heat is by implication from fuel or electrical vitality because of the drive of the vehicle. Besides all the advances, this technology has a notable drawback, and it is shown that comfort and stability drastically decrease due to the increase in the unsprung-to-sprung mass ratio [5]. Although in-wheel motors allow the degree of freedom to control traction and brake forces [6] independently, the enhancement of comfort is complicated. Therefore, an active suspension system will be necessary for the successful mitigation of the above concerns and also for the overall improvement of the performance of the vehicle [7-9].



Green manufacturing also called environmentally conscious manufacturing, is one of the most sought-after subjects these days. Since the suspension is a significant wellspring of vitality scattering, it is plausible to collect its vibration vitality and convert it into regenerative vitality to improve the vehicle eco-friendliness [10-11]. This paper deals with the S.E.R.S module as shown in figure 1, which is an Electromagnetic Regenerative Suspensions. It harnesses energy from the bumps. It also provides resistance to motion, thus functioning as a damper. Therefore, so-called regenerative suspensions arise as time requires. Instead of losing the vibration energy into waste heat, the damper in regenerative suspension will transform the kinetic energy into electricity or other potential energy and store it for later use. The stored energy can be used to power vehicle electronics

## 2. S.E.R.S. Module: Manufacturing and Physical Details

A Baja ATV was considered as a test vehicle for the initiation of S.E.R.S. design. Various parameters were taken from the ATV as shown in table 1 and 2 used for calculation and simulations.

Table 1. Test Vehicle physical parameters details.

Vehicle			Dynamo			Gears		
Weight	Weight on Front Axle	Weight per wheel	Torque	Max. Voltage develop	Max. Current generated	Module	Face width	Reduction ratio
350 kg (Off-road Baja)	150 kg (43% weight distribution front-rear)	75 kg	1 N-m	12-14 V	300-500 mA	1mm	10 mm	1:3.5

Table 2. Dimensions and Manufacturing modes of components in S.E.R.S.

S. No	Part Name	Parameter 1	Parameter 2	Parameter 3	Material	Manufacturing Method
1	Connector Rod (Long)	Length - 224mm	OD - 12mm	I.D. - 8mm	MS	Lathe + Tapping
2	Rocker Arm	Holes O.D. - 8mm	Thickness - 3mm	-	EN 24	Water Jet cutting
3	Connector Rod (Short)	Length - 48mm	O.D. - 12mm	I.D. - 8mm	MS	Lathe + Tapping
4	Wheel Gear Linkage	Length - 79mm	Thickness - 3mm	-	EN 24	Water Jet cutting
5	Wheel Gear	Teeth - 63	Face Width - 10mm	Module - 1mm	EN 24	Gear Hobbing + Lathe
6	Pinion Gear	Teeth - 18	Face Width - 10mm	Module - 1mm	EN24	Gear Hobbing + Lathe
7	S.E.R.S. Housing	Thickness - 3 mm	Max Length - 245mm	Max Width - 212mm	MS	Gas cutting + Welding

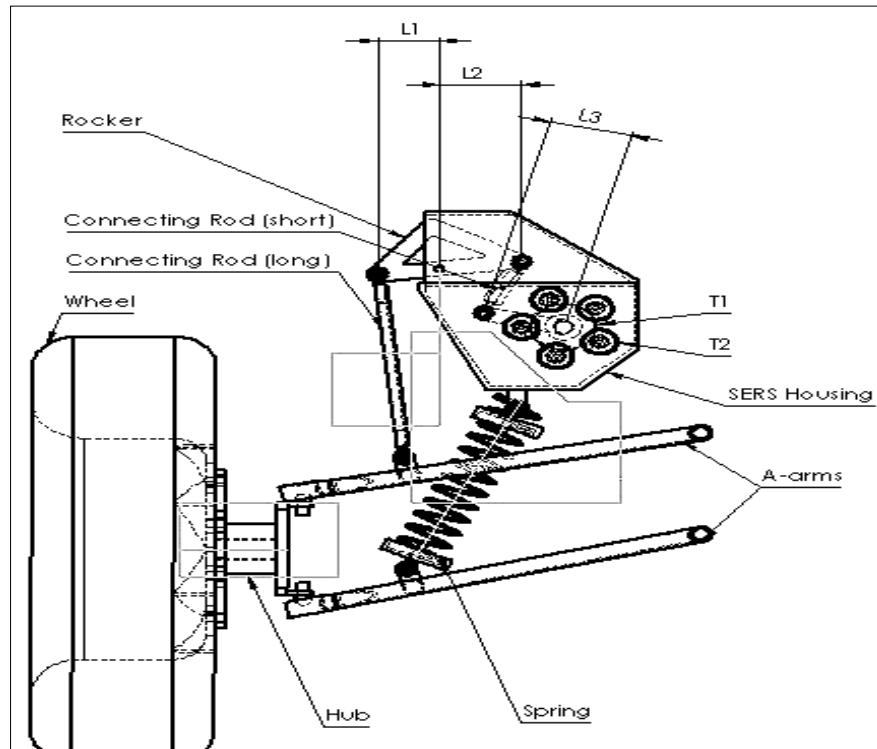


Figure 1: Nomenclature of S.E.R.S

### 2.1. S.E.R.S. Housing

The S.E.R.S. Housing was cut to the required dimensions and then welded together. A hinge was provided to ensure ease of assembly and hence better serviceability as shown in Figure 2.

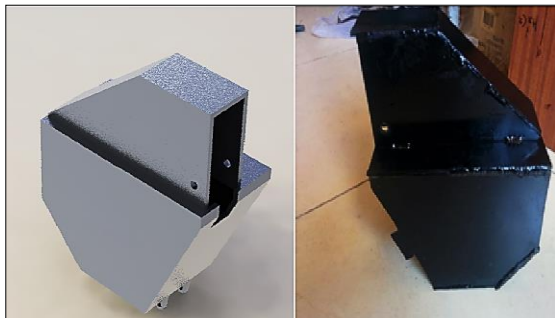


Figure 2: S.E.R.S. Housing - CAD model and the manufacturing component.



Figure 3: Rocker Arm - CAD model and the manufacturing component

### 2.2. Rocker Arm

The Rocker arm was designed to transmit the force from the bump to the Wheel Gear. It was manufactured by Water Jet Machining for a high accuracy. The Rocker Arm was then assembled into the S.E.R.S. module as shown in above Figure 3.

### 2.3. Wheel Gear Assembly

Using Gear Hobbing, Lathe Machining, and Water Jet Cutting were used to manufacture the Wheel Gear, Shaft, and the Wheel Gear Linkage, respectively as shown in Figure 4.



Figure 4: Wheel Gear Assembly - CAD model and the manufacturing component.



Figure 5: Pinion Gear - CAD model and the manufacturing component

#### 2.4. Pinion Gear

The Pinion Gear was manufactured by Gear Hobbing, it was machined to mate with the Wheel Gear and to fit on the dynamos. Five Pinion Gears were manufactured to incorporate five dynamos as shown in Figure 5.

#### 2.5. Wheel Gear Assembly

To check for packaging, a Wheel Assembly which included the A-arms, the Wheel, the Upright, the Spring, and the S.E.R.S. module was designed. After a few iterations, a good position for the S.E.R.S. mounts were decided as shown in Figure 6.

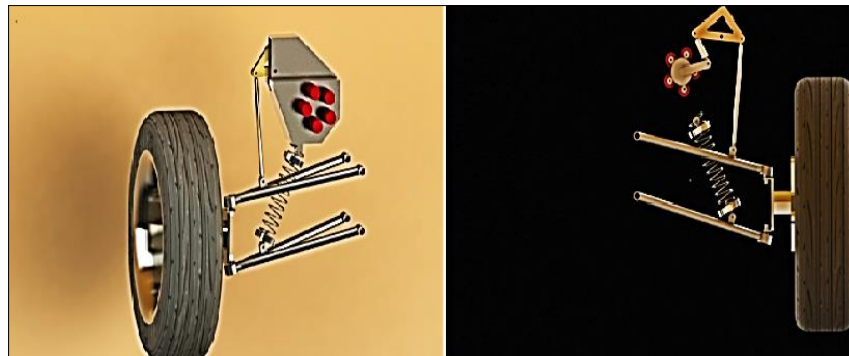


Figure 6: CAD model of the S.E.R.S. Assembly with and without the Housing

### 3. Bump Force and Torque Calculation

Let  $F$  be the force transmitted from the bump. Due to the Rocker arm, the force will be reduced by a factor of  $L1/L2$  (Fig. 1). Now, the torque at the Wheel gear would be a product of the force and perpendicular distance, which is  $L3$  (Fig. 1). This torque reduces by a factor of  $T2/T1$  (Fig. 1) after gear reduction. So, the formula for the relationship between Bump Force and Torque is given using the literature studied [12] as: -

$$T = \frac{F \times L1 \times L3 \times T2}{L2 \times T1} \quad (1)$$

The speed bumps are designed at an angle of incidence =  $30^\circ$ . So, the capable bump force would be  $F \times \sin(30^\circ)$ , which gives us the final relationship:-

$$T = \frac{F \times L1 \times L3 \times T2 \times \sin(30)}{L2 \times T1} \quad (2)$$

$$W \times v = F \sin(30) \times t \quad (3)$$

where,

W = weight per wheel

V = velocity of the car

t = Impact time whose value varied between 0.1-0.2 second.

#### 4. Experimental Details

To test the S.E.R.S. system, a testing rig was designed. A high torque low rpm motor was used to simulate the bumps on the road. The S.E.R.S. and the motor were mounted on the testing rig. An eccentric hub was designed to simulate two bumps of 2 inches and 4 inches' amplitudes. The hub was attached to the motor, and the hub and the rocker in S.E.R.S. were connected via a connecting rod. AISI 1020 square tubes of 1inch side lengths and 1mm wall thickness were chosen to manufacture the Test Rig as can be seen in Figure 7.

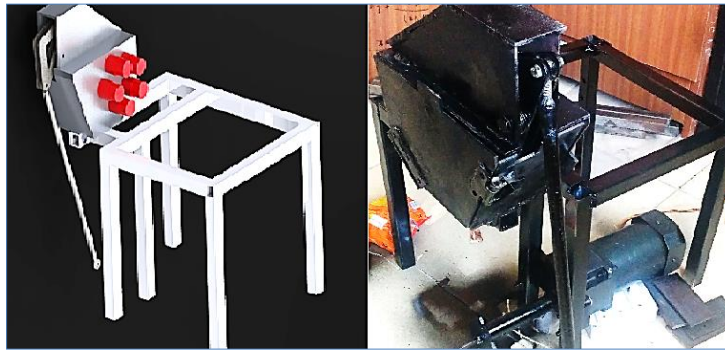


Figure 7: Test Rig with S.E.R.S. mounted on top - CAD model and the manufactured system

##### 4.1. Low Bump Testing

The low bump testing mode was done for a bump amplitude of 2 inches, which meant a wheel up-travel of 1 inch and a down-travel of 1 inch. This mode corresponds to either a low bump or a low vehicle velocity. A multimeter was used to measure the current generated, and the voltage developed. Low Bump mode gave an output of 400 mA at 3 V.

##### 4.2. High Bump Testing

The High bump testing mode was done for a bump amplitude of 4 inches, which meant a wheel up-travel of 2 inches and a down-travel of 2 inches. This mode corresponds to either a low bump or a high vehicle velocity. A multimeter was used to measure the current generated, and the voltage developed. High Bump mode gave an output of 750 mA at 7.5 V.

#### 5. Results and Discussions

##### 5.1. Finite Element Analysis (F.E.A.)

**5.1.1. Rocker:** Based on the theoretical calculations, a force of 2200N (max. calculated force to get exerted on rocker) was applied on the input side. The centre hole was fixed for all motions except rotation, and the output hole was fixed. Figure 8 shows the stresses developed and confirms that the design is safe.



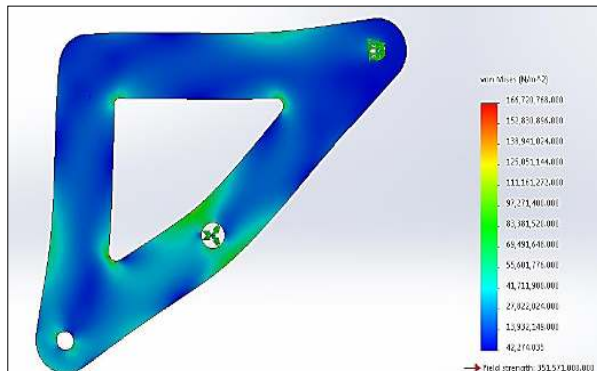


Figure 8: F.E.A. of Rocker (Stresses developed)

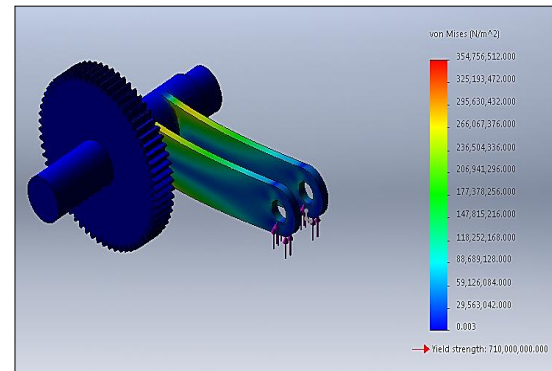


Figure 9: F.E.A. of Wheel Gear and Wheel Gear Linkages (Stresses developed)

**5.1.2. Wheel Gear:** Based on the theoretical calculations, a force of 1650 N (max. calculated force to get exerted on gears) was applied to the wheel gear linkage. The shaft was fixed for all motions. Figure 9 above shows the stresses developed and confirms that the design is safe.

**5.1.3. Pinion Gear:** Based on the theoretical calculations, a force of 900 N (max. calculated force to get exerted on pinion) was applied to the pinion tooth. The bore was fixed for all motions. Figure 10 shows the stresses developed and confirms that the design is safe.

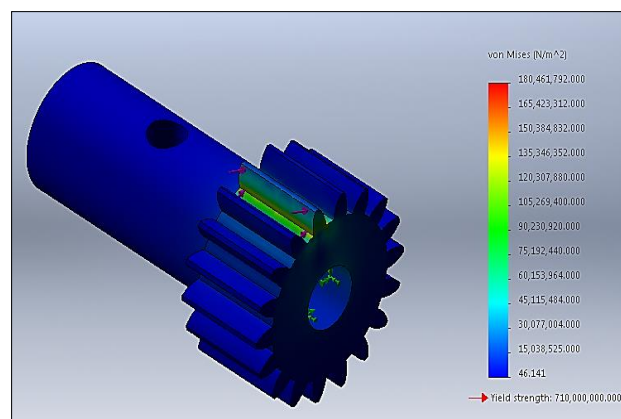


Figure 10: F.E.A. of Pinion Gear (Stresses developed)

**5.1.4. Connecting Rod - Long:** Based on the theoretical calculations, a force of 2200 N (max. calculated force to get exerted on rod) was applied on the input end. The output end was fixed for all motions. Figure 11 shows the stresses developed and confirms that the design is safe.

**5.1.5. Connecting Rod - Short:** Based on the theoretical calculations, a force of 1650 N (max. calculated force to get exerted on rod) was applied to the input end. The output end was fixed for all motions. Figure 12 shows the stresses developed and confirms that the design is safe.

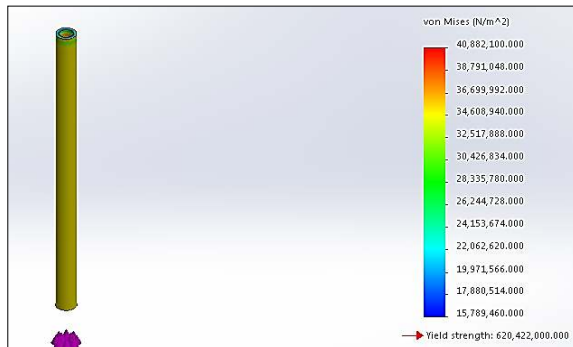


Figure 11: F.E.A. of Connecting Rod - Long (Stresses developed)

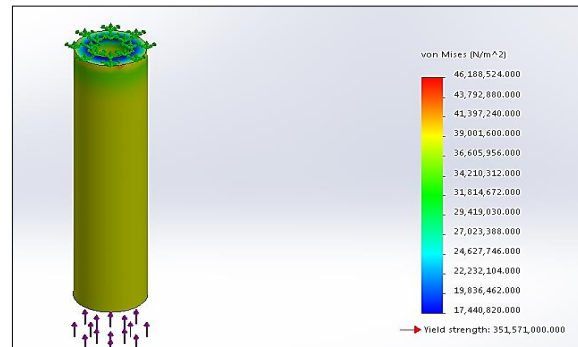


Figure 12: F.E.A. of Connecting Rod – Short (Stresses developed)

## 5.2. Results Based on Experiments

- 1) From Figure 13, it is observed that the bump force increases with the velocity of the vehicle linearly which verifies equation 3 and also gives positive due effect onto the power generated by the S.E.R.S module.
- 2) Current generated, the power generated, and the velocity of the damper (Long Connecting Rod in S.E.R.S.) with respect to the bump amplitude simulated in the testing. On a Baja terrain, there could be any number of bumps in a kilometre, ranging from 1 to 10 or even more as shown in Figure 14.

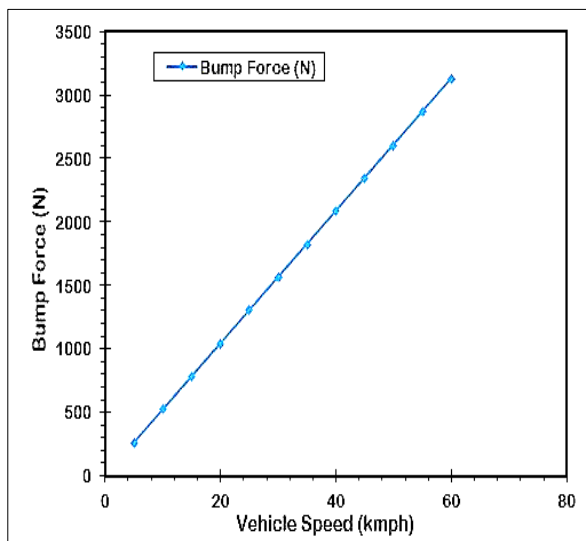


Figure 13: Bump Force vs. Vehicle Speed

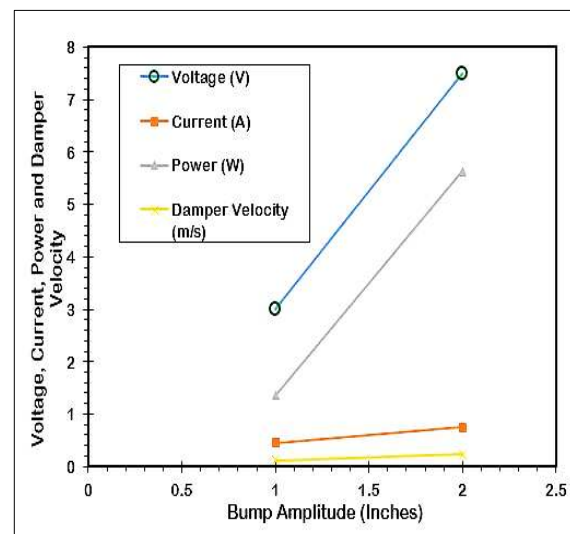


Figure 14: Voltage, Current, Power & Damper Velocity Vs Bump Amplitude

- 3) By increasing the number of S.E.R.S. systems in the car up to 4, it is observed that the maximum power generated increases thus increase the sustained energy storage capacity, as shown in Figure 15.
- 4) While testing the S.E.R.S. system, a range of Current and Voltage values were recorded. A relationship between these values and the simulated bump amplitude is shown in Figure 16. It's evident that as the bump amplitude increases the voltage and current also increases linearly. So, we can imply that if the bump amplitude is high the power generated by the S.E.R.S. will also be high. But this relation between the bump force and the power generated



is limited by the structural integrity of the system and the vehicle i.e. any force beyond the structural limit of the system will not generate high power but rather lead to the failure of the system and the vehicle.

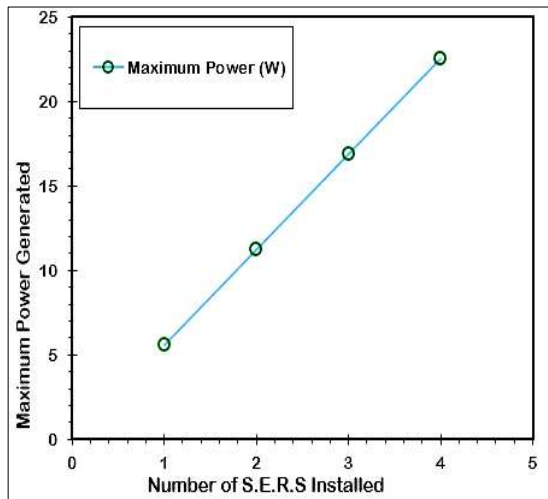


Figure 15: Maximum power generated vs Number of S.E.R.S. installed

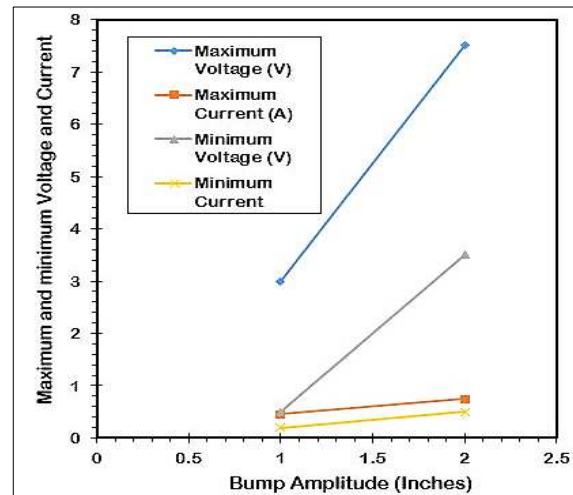


Figure 16: Range of Voltage and Current vs Bump Amplitude

## 6. Conclusions

The S.E.R.S. system, along with the testing rig, was successfully designed, manufactured, assembled, and tested. The system performed well and gave a sound output. It provides a resistance to motion, acting as a damper as well as generated electricity. Before testing the system practically, Finite element analysis simulation was done on each part which marked the system safe to test. The testing was performed in two modes: Low and High Bump modes. The results of both the modes are as follows:

- 1) Low Bump Mode: The S.E.R.S. generated a maximum of 400 mA current at 3 V. This mode corresponds to either a low amplitude bump or the vehicle traveling at low speeds.
- 2) High Bump Mode: The S.E.R.S. generated a maximum of 750 mA current at 7.5 V. This mode corresponds to either a high amplitude bump or the vehicle traveling at high speeds.

A maximum of 5.625 W of power was generated for one Bump. This means that having four S.E.R.S. systems in the car for four wheels would generate 22.5 W of power for one bump. In a Baja event, which is mainly off-road, there may be as many as 10 bumps in a kilometre, or even more. By assuming 10 bumps per kilometre, a Baja car traveling at 30 kmph would generate 6.75 kWh of energy. By implementing the S.E.R.S. system in passenger cars, higher torque dynamos may be used, thus generating a higher output. The generated output is sufficient to power auxiliary electrical components or charge the battery. Also, the more massive the vehicle, the more the amount of energy regenerated from S.E.R.S.

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