SUSPENSION BASED KINETIC ENERGY RECOVERY SYSTEM

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ABSTRACT

Automobiles and trucks have shock absorbers to damp out the vibration experienced due to roughness of the roads. However, energy in conventional shock absorbers gets dissipated as heat and is not used in any way. Suspension Based Kinetic Energy Recovery System provides a means for recovering the energy dissipated in shock absorbers. A device for recovering the kinetic energy relating to the vertical motion of a vehicle suspension relative to the frame of the vehicle when the vehicle is traveling on a roadway, the device comprising: energy conversion means for converting the energy relating to the vertical motion of the vehicle frame relative to the vehicle suspension to a form of energy which can be stored on the vehicle for later use in powering vehicle systems. Road vehicles can expend a significant amount of energy in undesirable vertical motions that are induced by road bumps and much of that is dissipated in conventional shock absorbers as they dampen the vertical motions. This project aimed at determining the effectiveness of efficiently transforming that energy into electrical power by using optimally designed regenerative electromechanical system. In turn, the electrical power can be used to recharge batteries or other efficient energy storage devices rather than be dissipated.

Key words: Shock absorbers, Kinetic Energy Recovery System, Regenerative Electromechanical system.


1. INTRODUCTION

World-wide demand for oil increasingly strains the available supply. The need for more oil means higher prices and more pollution. With gas prices on the rise, people and businesses are looking for environmentally sound solutions. New technologies have emerged to combat rising gas prices and decrease pollution. Fuel cell vehicles run on hydrogen and emit only water vapor. Biofuel vehicles run on fuel made from plants. Electric vehicles can run on rechargeable batteries, and hybrid vehicles use a combination of a gasoline engine and another type of power source. A hybrid pairing a gasoline engine with an electric motor powered by lithium ion batteries results in increased fuel economy and reduced pollution. A process called regenerative braking charges the batteries when the car brakes, thereby converting friction energy, which is normally lost in conventional vehicles, to electrical energy stored within the lithium ion batteries. The lithium ion batteries then power the electric motor. The electric motor in most cars generally is sufficiently powerful only to move the car at slow speeds. In most gas/electric hybrids, the gas engine...
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takes over once the car reaches a speed of 20-30 miles per hour. Thereafter, the car operates like a conventional gasoline powered vehicle.

The job of a car suspension is to maximize the friction between the tires and the road surface, to provide steering stability with good handling, and to ensure the comfort of the passengers. If a road were perfectly flat, with no irregularities, suspensions wouldn't be necessary. But roads are far from flat. Even freshly paved highways have subtle imperfections that can interact with the wheels of a car. These imperfections apply forces to the wheels. According to Newton's laws of motion, all forces have both magnitude and direction. A bump in the road causes the wheel to move up and down perpendicular to the road surface. The magnitude, of course, depends on whether the wheel is striking a giant bump or a tiny speck. Either way, the car wheel experiences a vertical acceleration as it passes over any roadway imperfection. Without an intervening structure, all of wheel's vertical energy is transferred to the frame, which moves in the same direction. In such a situation, the wheels can lose contact with the road completely. Then, under the downward force of gravity, the wheels can slam back into the road surface. The study of the forces at work on a moving car is called vehicle dynamics, and most automobile engineers consider the dynamics of a moving car from two perspectives—Ride and Handling. Ride is a car's ability to smooth out a bumpy road. Handling is a car's ability to safely accelerate, brake and corner. These two characteristics can be further described in three important principles—road isolation, road holding, and cornering.

The three fundamental components of any suspension are springs, dampers and anti-sway bars. Today's springing systems are based on one of four basic designs. Suspension coil springs are, essentially, a heavy-duty torsion bar coiled around an axis. Suspension coil springs compress and expand to absorb the motion of the wheels. Leaf springs consist of several layers of metal (called “leaves”) bound together to act as a single unit. They are still used today on most trucks and heavy-duty vehicles. Torsion bars use the twisting properties of a steel bar to provide coil-spring-like performance. One end of a bar is anchored to the vehicle frame. The other end is attached to a wishbone, which acts like a lever that moves perpendicular to the torsion bar. When the wheel hits a bump, vertical motion is transferred to the wishbone and then, through the levering action, to the torsion bar. The torsion bar then twists along its axis to provide the spring force. Air springs, which consist of a cylindrical chamber of air positioned between the wheel and the car's body, use the compressive qualities of air to absorb wheel vibrations. Shock absorbers work in two cycles—the compression cycle and the extension cycle. The compression cycle occurs as the piston moves downward, compressing the hydraulic fluid in the chamber below the piston. The extension cycle occurs as the piston moves toward the top of the pressure tube, compressing the fluid in the chamber above the piston. A typical car or light truck will have more resistance during its extension cycle than its compression cycle. With that in mind, the compression cycle controls the motion of the vehicle's unprung weight, while extension controls the heavier, sprung weight. All modern shock absorbers are velocity-sensitive—the faster the suspension moves, the more resistance the shock absorber provides. This enables shocks to adjust to road conditions and to control all of the unwanted motions that can occur in a moving vehicle, including bounce, sway, brake dive and acceleration squat. Anti-sway bars (also known as anti-roll bars) are used along with shock absorbers or struts to give a moving automobile additional stability. An anti-sway bar is a metal rod that spans the entire axle and effectively joins each side of the suspension together. When the suspension at one wheel moves up and down, the anti-sway bar transfers movement to the other wheel. This creates a more level ride and reduces vehicle sway. In particular, it combats the roll of a car on its suspension as it corners. Almost all cars today are fitted with anti-sway bars as standard equipment. The stopping and starting requirement for regenerative braking on which current electric hybrids and hydraulic hybrids are based is unavailable at highway speeds. What is needed is a device which will capture the kinetic energy of suspension movement and generate power at highway speeds when regenerative braking is not available.

A device for recovering the kinetic energy relating to the vertical motion of a vehicle suspension relative to the frame of the vehicle when the vehicle is traveling on a roadway, the device comprising:
energy conversion means for converting the energy relating to the vertical motion of the vehicle frame relative to the vehicle suspension to a form of energy which can be stored on the vehicle for later use in powering vehicle systems; and mounting means for mounting the energy conversion means between the frame and the suspension of the vehicle. A vehicle suspension kinetic energy recovery system generates useful energy from the up-and-down motion of a vehicle suspension caused by roadway irregularities as the vehicle travels down the roadway. In one embodiment, a piston-type pump is mounted between the frame and the suspension. As the vehicle frame moves towards the vehicle suspension in response to roadway irregularities, the piston pumps fluid from a low-pressure reservoir to a high-pressure accumulator, thus increasing the pressure of the fluid. This energy stored in the high-pressure accumulator is available to power the vehicle. The energy thus made available can also be used to drive hydraulic motors, e.g., power windows, power seats, etc. In addition, the high pressure fluid can power an alternator which produces electricity for storage in a conventional automobile battery. In another embodiment, electricity is generated directly by a conductor moving with respect to magnetic field as a result of the up-and-down motion of the vehicle suspension.

Based on where springs are located on a car i.e., between the wheels and the frame engineers often find it convenient to talk about the sprung mass and the unsprung mass. The sprung mass is the mass of the vehicle supported on the springs, while the unsprung mass is loosely defined as the mass between the road and the suspension springs. The stiffness of the springs affects how the sprung mass responds while the car is being driven. Loosely sprung cars, such as luxury cars, can swallow bumps and provide a super-smooth ride, but loosely sprung cars are prone to dive and squat during braking and acceleration and tends to experience body sway or roll during cornering. Tightly sprung cars, such as sports cars, are less forgiving on bumpy roads, but they minimize body motion well. Tightly sprung cars can be driven aggressively, even around corners. Whether loosely sprung or tightly sprung, the suspension of any vehicle is constantly moving relative to the frame.

Figure 1 General Phase layout for Suspension Based Kinetic Energy Recovery System
2. CALCULATIONS

Average Initial Displacement = 0.5563 inches/sec
So average attainable velocity = 0.5663 inches/sec = 14.13 mm/sec
System is designed according to the following parameters:

Average rack velocity = 14.13 m/s
Average rpm required = 24 rpm

Gear 1:
Angular velocity = $\omega_1$
Pitch circle diameter = 2$r_1$

Gear 2:
Angular velocity = $\omega_2$
Pitch circle diameter = 2$r_2$

Gear 3:
Angular velocity = $\omega_3$
Pitch circle diameter = 2$r_3$

Specification of alternator: 12 Volt D.C @ 24 rpm

$V_1$ = 14.13 mm/s : $r_1$ = 26 mm
Since $V_1$ = $\omega_1$ $r_1$

$\omega_1$ = 0.54 rad/sec
$\omega_1$ = $\omega_2$  \hspace{1cm} (1)
$\omega_2$ $r_2$ = $\omega_3$ $r_3$  \hspace{1cm} (2)

$\omega_3$ = $\frac{(2 \times 3.14 \times 24)}{60}$ = 2.512 rad/sec
$\therefore$ $r_2$/$r_3$ = 2.512/0.54 = 4.65
Let $d_2$ = 108.5 mm
$\therefore$ $d_2$ = 23.4 mm

Now according to the available data:

Gear 1:
PCD = 52 mm
Module = 2
Number of teeth = 26
Width = 20 mm
Material = En-8 (steel)

Gear 2:
PCD = 108.5 mm
Module = 1.6
Number of teeth = 67
3. DESIGN

The various parts that had been designed and then manufactured are shown below.

1) This is a single unit in which gears are made on one side. These gears mesh with the rack and this convert the linear motion into the rotational motion.

![Figure 2 Gear 1 drawing](image)

2) This part is a simple ring. The function of this ring is to hold the freewheel with the pinion gear. It becomes one assembly thereafter. Two such assemblies are required.

The bottom figure is the shaft on which the above mentioned assembly is mounted. After mounting the assembly, this shaft rotates in one direction only, no matter what direction the rack moves.
The final assembly is shown below:
The final assembly of the above parts is shown below:

**Figure 5** Gear assembly after welding operation on MS plates

This assembly when fitted on the bike used, gave the final look to the project as shown below:

**Figure 6** Final project with the assembly
4. ELECTRONIC PARTS OF THE PROJECT

The electronics part is one of the core elements of the project. This portion is important because the power production actually depend upon how well the electronics portion is equipped with. The electronics can be further divided into two categories.

1. Power producing unit
2. Data acquisition

4.1. Power Producing Unit

![DC Geared motor (Alternator)](image)

The power is produced from a simple geared motor which is used as DC generator in this case. The motor has the following specifications.

- Generator output: 6V – 20
- Current output: ~ 0.5-1 amp
- Rpm usage: 20-30 rpm

Motor selection:

- As the rpm of the mechanism is very low, so in order to utilize the maximum of the energy available in the suspension movement, such an rpm is selected that can easily give a decent output voltages level, say 15-20 volts.
- The size should be as small as possible.
- It should have the facility of mounting additional accessories such as gears or belts on the shaft.

The next important part in the power generation is the storage or usage. Since the power produced is always varying with time, so using those small values of power doesn’t prove to be useful nor does that make any sense. Hence, a system has to be developed that can accumulate such power and thereafter it can be used. It’s just like filling a tank with small drops of water and then as the tank is filled up to brim, the water is again utilized for heavy purposes.

The system uses capacitor bank for that. Very large capacity capacitor ~15000uF 63 V are used for this. The capacitors are very big because:

- It can hold a large amount of charge
- The rate of discharging is small so that all the power is not dissipated in a spur of time.
The overall circuit can be summarized as below:

4.2. Data Acquisition Circuit
The whole project started with mere observations, observation being watching the suspension going up and down movement. As the idea of utilizing that power available in the suspension system clicked, there starts the process of data acquisition. It means that if the observation really meant anything. In this system data is acquired about

- How much movement of suspension is possible.
- How fast that movement can be.

For that real time data acquisition system which makes use of PC interfacing is used. Below is the circuit showing this.
This circuit was not made at the first attempt. First another ADC converter was used named ADC 0808. However it did not work successfully. Next simulation of the new circuit (shown below) was done using the software. The new circuit consists of an ADC 0804 which has an inbuilt clock and is rather easy to use.

**4.3. Working**

The circuit here works by picking up the signals from the suspension movement. This is done by connecting somehow the potentiometer, rather linear potentiometer with the actual mechanical system. Now as the system acquires to and fro motion, potentiometer varies in voltage. This analog voltage is sent to the ADC 0804 which converts it into the digital form. The analog to digital converter gives digital output as 8 bit output. The 8 bit output is sent to the parallel port which has to be BIDIRECTIONAL in nature. The pins numbered from 2-9 are the pins for either output or input. By default they are set for the output purposes only. This can be tweaked to set them into input mode which is required. This is explained later in the program in C++. The C program acquires the data input in digital format and accordingly plots a graph of the movements of the suspension in excel sheet. Thus data is acquired about much movement is available and from this circuit itself conclusion about feasibility of the project is made.
Figure 11 Data Acquisition circuit
5. PROGRAMMING

The following program has been used for manipulating the data of the suspension movement.

```cpp
#include<iostream.h>
#include<conio.h>
#include<fstream.h>
#include<dos.h>
#define port 0x378
void main()
{
    clrscr();
    int i,x,y,j,k,m,p,g,c=0,l,var;
    textcolor(2);
    cout<"\t\\t";
    cprintf(" WELCOME TO THE WORLD OF SMART ENERGY\n");

textcolor(123);
    cout<"\\t\\t\\t";
    cprintf("KINETIC ENERGY RECOVERY SYSTEM IN SUSPENSION\n ");
    cout<"\\t ";
    ofstream energy;
    x = inportb(0x37A);
    y = x | 0x20;
    outportb(0x37A,y);
    energy.open("C:/graph.xls");
    for(i=1;i<=60;i++)
    {
        j=inportb(port);
        delay(500);
        k=j*0.196;
        if(i<=1)
        {
            l=k;
        } else
        {
            g=p;
        }
        c=c+g;
    } if(p<0)
    {
        g=-1*p;
    } else
    {
        g=p;
    }
    c=c+g;
```
if(k<=34)
{
    m=34-k;
    cout<<m<<"\t\t"<<g<<"\t\t"<<c<<"\n";
    energy<<m<<"\t\t"<<g<<"\t\t"<<c<<"\n";
}
else
{
    m=34-k;
    cout<<m<<"\t\t"<<g<<"\t\t"<<c<<"\n";
    energy<<m<<"\t\t"<<g<<"\t\t"<<c<<"\n";
    l=k;
}
cout<<"\n Total rate of change of flux calibrated as mm/s ="<<c;

energy.close();
getch();
}

Running the program gives results in the form shown in the next page.
But before going to the result lets see, how can this interfacing be made possible as there are quite a large number of difficulties in doing so.

- The system having windows XP can’t run this program to have results because of some securities reasons that do not allow the parallel port to easily interface. The problem is solved by using an earlier version of operating system that do not have such security issues such as win 98se. Hence The above program used that operating system and the programming was done in turbo c v3.0.

- Another problem that occurred in the meanwhile was that of interfacing the data pins which by default are in output mode. This is done by using the following 2 steps:
  - Setting the bios option of parallel port to BIDIRECTIONAL.
  - Thereafter a code is inserted into the c program as shown in the program.

\[
x = inportb(0x37A);
\]
\[
y = x | 0x20;
\]
\[
outportb(0x37A,y);
\]

6. RESULT AND DISCUSSIONS
A suspension based kinetic energy recovery system generates useful energy from the up-and-down motion of a vehicle suspension caused by roadway irregularities as the vehicle travels down the roadway.

![Figure 12 Damping force and Relative velocity Relationship in suspension](image_url)
A conventional hydraulic damper has a cylinder filled with a viscous fluid and a piston with holes or other passages by which the fluid can flow one side of the piston to the other. The mechanical energy is converted into heat due to the movement of the damping fluid through the damper. For a conventional viscous damper the power dissipated is given by:

\[ P_{\text{dissipated}} = FDX \text{ (in W)} \]
\[ P_{\text{dissipated}} = CX^2 \text{ (in W)} \]

where:  
\( C = \text{damping coefficient} \)
\( X = \text{relative damper velocity} \)
\( F = \text{damper force} \).

**Efficiency of regeneration** can be found out using following equation:

\[ \eta_{\text{regeneration}} = \frac{P_{\text{regenerated}}}{P_{\text{regenerated}} + P_{\text{dissipated}}} \]

The overall findings from literature survey indicated that typical dissipation rates in a vehicle suspension were approximately 5 to 20 (W) per vehicle damper, however, approximately 50 (W) could be dissipated for a vehicle traversing a road classified as 'poor'. Overall, it appeared that the power dissipation generally increased for an increase in vehicle velocity, and increased for an increasingly degraded road surface condition.

### 7. PROGRAM OUTPUT

**Figure 13** Generated graph showing suspension movement

- The graph shows the movement of the suspension in absolute terms in millimeter.
- The time axis is of half second interval so that it can give better results.
- The portion above the zero line shows the suspension has been compressed and accordingly the amount of movement as well from defined zero on the zero of potentiometer.
- The portion below the zero shows the suspension being expanded. Hence it can be inferred that the suspension has more of upper movement than lower or expansion movement.
- The second graph is actually related to amount of energy produced. Although it is not exactly the energy but gives an idea of how much energy can be saved.
- We know that energy produced is proportional to rate of change of flux which is then dependent on the speed of the generator. Hence faster the movement of the suspension, more will be the electricity produced. The graph below shows cumulative sum of all such flux change per unit time as the time passes which give a fair idea of the electricity produced.
8. FUTURE SCOPE

And now when it is practically shown that energy can be recovered from the up and down movement of suspension which otherwise gets lost to the surrounding as heat and sound or any other form of energy, much scope of this concept can be visualized. It is shown in this project in a motor bike. This can as well be used in other vehicles where the weight is much more and hence much inertia is available which can be utilized to produce energy.

However this small attempt is not the end of the project, it’s a mere start. Much work can be done in using the best generator and power producing circuits. In this project a simple motor is used which can act as generator as well. Moreover instead of using the cycle freewheel, there is an option of using the clutch bearing which can give better performance. This project is made as compact as possible, but improvement in the design is still possible.

Many problems in mounting the whole system on the motor bike were faced. This is because it is difficult to modify already existing system than to make a new one. Hence much work needs to be done in this area.

REFERENCE


[9] www.electronics4u.com
