A Study of Regenerative Shock Absorber

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Abstract

The whole world is dependent on conventional energy sources like coal, petroleum products, etc. for energy, which are rapidly depleting. Nowadays, people are exploring new energy alternatives. People today are actively seeking new energy alternatives for their daily activities. In this context, renewable energy sources represent a viable option.

An innovative solution involves capturing the energy that is typically wasted in a vehicle's shock absorber and converting it into useful electrical power for the vehicle. This technology is referred to as an energy-regenerative shock absorber..

In this context, the automobile industry is also leaving no stone unturned to make a significant contribution. Modern vehicles dissipate a considerable amount of vibration energy through conventional hydraulic shock absorbers in the form of heat. Regenerative Shock Absorbers (RSAs) have emerged as an innovative technology that converts this wasted vibration energy into useful electrical energy while simultaneously providing suspension damping. This technology has significant potential in improving fuel economy, extending the driving range of electric vehicles, and reducing carbon emissions. Various energy conversion mechanisms, including electromagnetic, hydraulic-electromagnetic, piezoelectric, rack-and-pinion, ball-screw, and linear generator systems, have been proposed by researchers worldwide.

The paper discuss about the characteristics feature of regenerative shock absorber, it's working principle and it/s design.

Keywords: Regenerative Shock absorber, energy harvesting, Suspension system, Vibration Energy

I. INTRODUCTION

The suspension system is one of the most important components of a vehicle, responsible for maintaining ride comfort, vehicle stability, and road handling. Conventional hydraulic shock absorbers dissipate the kinetic energy generated by road irregularities as heat. This energy is permanently lost.

Since the early 1980s, researchers have investigated methods for recovering the energy dissipated by vehicle shock absorbers. The regenerative shock absorber was proposed to capture the kinetic energy generated by suspension vibrations and convert it into electrical energy. Electromagnetic damping technology has been widely studied because of its effectiveness in energy harvesting applications [1]. A regenerative electromechanical suspension based on a quarter-car model was investigated through simulation, revealing a peak energy recovery of about **150 W** at a vehicle speed of **90 km/h**. The proposed system achieved better energy harvesting efficiency while maintaining improved ride comfort over conventional suspension designs. Another regenerative shock absorber configuration was capable of producing **100–400 W** of electrical power at **100 km/h**, with the generated power influenced by the road profile [2]

Huang et al. introduced an analytical design methodology for energy-regenerative suspensions that combines ground–tire interface analysis and a ride comfort optimization cost function. A regenerative suspension system addresses this inefficiency by recovering part of the vibration energy and converting it into usable electrical power. The generated electricity can be used to charge the vehicle battery, power onboard electronics, or improve the efficiency of electric and hybrid vehicles.

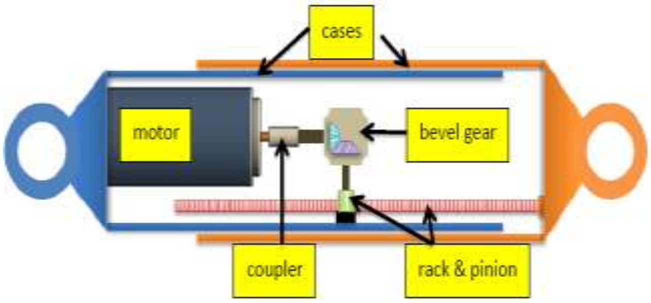


Fig. 1: Overall Scheme of Vehicle Regenerative Shock absorber

The Fig.10. shows the activity of this regenerative shock absorber. Using two roller holds the rotational movement can be made unidirectional.

Objectives

- Recover energy normally lost in conventional shock absorbers.
- Improve vehicle fuel economy and battery efficiency.
- Maintain ride comfort and vehicle stability.
- Reduce overall energy consumption.
- Develop an eco-friendly suspension system.
- Integrate renewable energy recovery into modern vehicles.

. *Problem Statement*

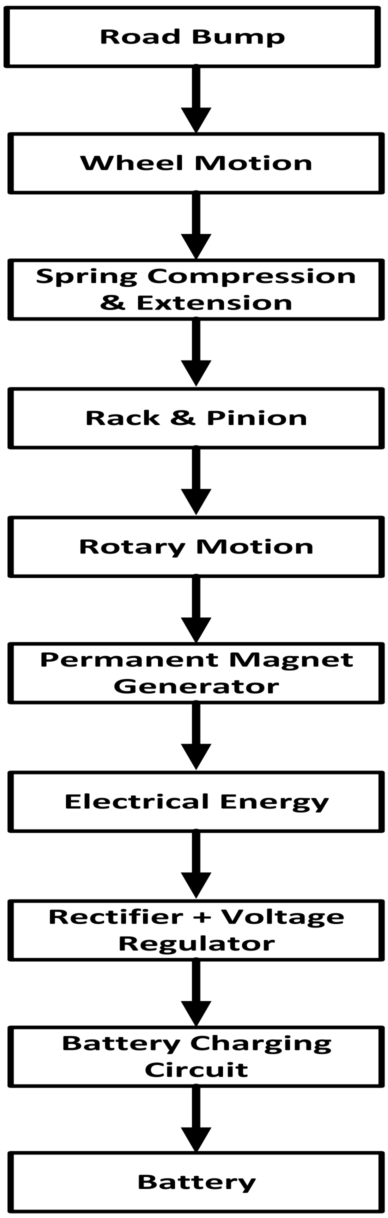
Conventional vehicle suspension systems waste vibration energy in the form of heat through hydraulic dampers. Modern vehicles, especially electric vehicles (EVs), require efficient energy utilization to extend driving range. A regenerative suspension system aims to convert otherwise wasted mechanical vibration into electrical energy while maintaining suspension performance.

Working Principle

Step 1: Vehicle moves over an uneven road

Step 2: Suspension spring compresses and extends.

1) *Step 3:* Linear motion drives a rack-and-pinion mechanism (or linear generator).
2) Step 4: Pinion rotates the shaft of a DC generator.
3) Step 5: The generator converts the mechanical energy produced by suspension vibrations into electrical energy, which can be stored or used to power the vehicle's electrical systems.
4) Step 6: Rectifier and charging circuit regulate the output.
5) Step 7: Electrical energy is stored in a battery or super capacitor.



Block diagram

Over the last decade, regenerative shock absorber technology has gained significant interest in both academic research and industrial applications. Road surface irregularities induce vibrations in the vehicle suspension system during operation. In conventional suspension systems, this vibration energy is lost as heat through the damping mechanism. Regenerative shock absorbers recover a portion of this wasted energy and convert it into usable electrical power.

With the increasing emphasis on energy conservation and sustainable transportation, regenerative shock absorbers have emerged as a promising technology for recovering wasted vibration energy and improving overall vehicle energy efficiency.

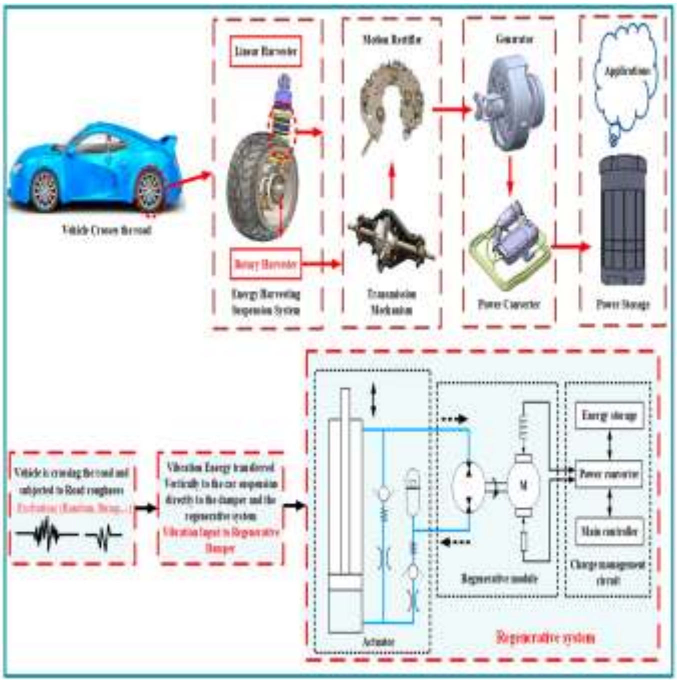
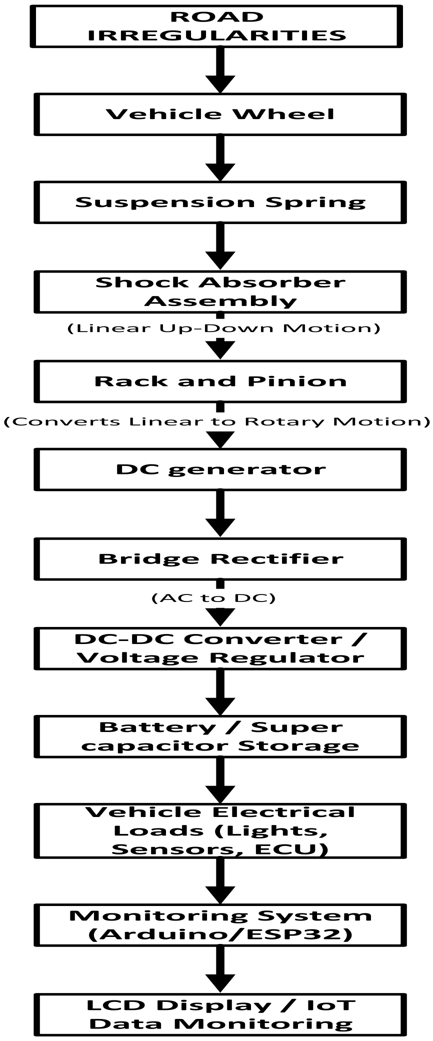
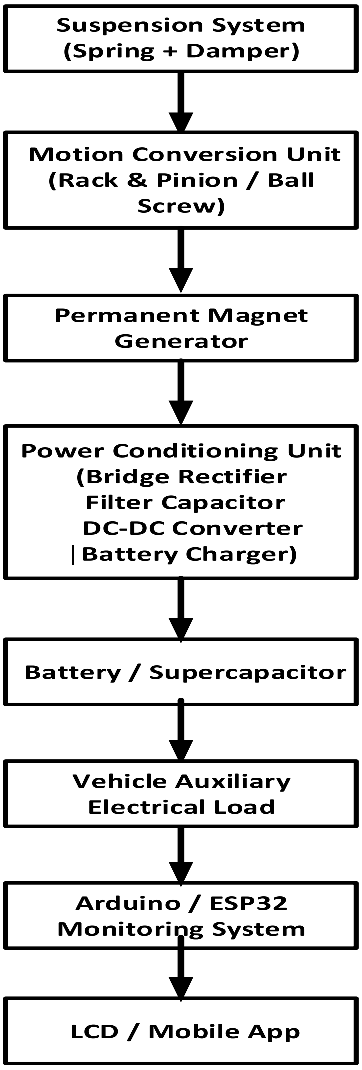


Fig. 02: the complete layout of a regenerative shock absorber or regenerative suspension system.



Functional Block Diagram



System Architecture

Vehicle motion over rough roads causes the suspension system to oscillate, resulting in the compression and extension of the suspension spring. A rack-and-pinion or ball-screw assembly converts this reciprocating linear motion into rotary motion. The rotary motion is then used to operate an electrical generator, converting mechanical energy into electrical energy. A bridge rectifier and DC–DC converter process the generated output to provide a regulated DC supply, which is stored in a battery or supercapacitor. The entire system is supervised by an Arduino or ESP32 controller that records voltage, current, and power generation data and communicates the information through a local display or an IoT-enabled monitoring system.Electrical System

Components:

- DC Generator
- Bridge Rectifier
- Capacitor Filter
- Buck Converter
- Battery Charging Module
- Battery
- Arduino
- LCD

Control System

Sensors:

- Voltage Sensor
- Current Sensor
- Speed Sensor
- Suspension Displacement Sensor

Microcontroller:

- Arduino Uno or ESP32

Functions:

- Measure generated voltage.
- Display current and power.
- Log data.
- Protect against overcharging.

DESIGN COMPONENTS

Typical Regenerative Shock Absorber includes

- Spring
- Linear guide
- Gear mechanism
- Generator
- Flywheel
- Battery
- Power converter
- Rectifier
- Voltage regulator

APPLICATIONS

- Passenger cars
- Electric vehicles
- Hybrid vehicles
- Heavy trucks
- Military vehicles
- Railway suspension
- Off-road vehicles
- Industrial machinery
- Agricultural vehicles
- Autonomous vehicles

Advantages

- Energy recovery
- Reduced fuel consumption
- Improved battery charging
- Reduced CO_2 emissions
- Longer EV driving range
- Smart suspension compatibility
- Low maintenance
- High reliability
- Environment friendly

LIMITATIONS

- High manufacturing cost
- Complex control system
- Additional weight
- Generator heating
- Power fluctuation
- Packaging constraints
- Higher initial investment

Recent Research Developments

- Recent studies focus on
- Electromagnetic linear generators
- Magnetorheological regenerative dampers
- AI-based damping control
- Adaptive suspension
- IoT monitoring
- Machine learning optimization
- Wireless energy management
- Hybrid hydraulic-electromagnetic systems
- High-efficiency permanent magnets
- Active-regenerative suspension

Conclusion

Regenerative shock absorbers represent a promising advancement in sustainable automotive engineering by simultaneously improving ride comfort and recovering energy otherwise dissipated as heat. Various designs, including electromagnetic, rack-and-pinion, ball-screw, hydraulic-electromagnetic, and piezoelectric systems, have demonstrated the feasibility of energy harvesting from vehicle suspensions. Electromagnetic and ball-screw-based systems generally offer the highest efficiency and power output, making them suitable for electric and hybrid vehicles. However, challenges remain in terms of cost, packaging, durability, and control complexity. Future developments integrating artificial intelligence, adaptive control algorithms, advanced magnetic materials, and smart energy management are expected to enhance the commercial viability of regenerative suspension systems. Continued research and real-world validation will be essential to optimize the balance between ride comfort, vehicle handling, and energy recovery.

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