

# Review on Regenerative Vehicle Suspension

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**Abstract**— *Hydraulic shock absorbers have get widespread use in vehicle suspensions since decades past to effectively reduce the acceleration of auto bodies and maintain sensible contact between tires and ground underneath road irregularities. though energy potency has been a serious concern within the automotive trade since the mass production within the decennary, researchers accomplished that the energy dissipated in ancient hydraulic shock absorbers is worthy of being recovered only in the middle of 1990s. Since then, many different types of energy harvesting based shock absorbers were conceptualized and prototyped. Unlike ancient suspension systems that suppress the vibrations by dissipating the vibration energy into waste heat, the regenerative suspension with energy harvesting shock absorbers will convert the historically wasted energy into electricity. This paper may be a comprehensive review on energy gathering based mostly vehicle suspensions.*

**Keywords**— *Hydraulic shock absorber, suspension, energy harvesting.*

## I. INTRODUCTION

Traveling on roads, vehicles are subjected to different disturbances such as road irregularities, braking forces, acceleration forces, and centrifugal forces on a curved road which cause discomfort to the driver and passengers and influence maneuverability. Passive suspensions, composed of viscous hydraulic shock absorbers and springs in parallel, have been widely used to suppress the vibration by dissipating the undesired mechanical energy into heat waste. The active and semi-active suspensions have been investigated extensively in the past 40 year showing improved vehicle dynamic performances at the cost of complexity and additional energy consumption. However, the passive suspension system is still dominating in the automotive industry because of its simple structure, high reliability, and low cost. Reducing vehicle energy losses is necessary for improving fuel economy, reducing emissions, and supplying other systems power demand. In addition to improving engine and powertrain efficiency, we may also harvest the energy wasted in vehicles including the recovery of wasted heat energy, regenerative braking energy, and vibrational energy on shock absorbers. Regenerative suspensions with the energy harvesting shock absorber have gained tremendous attention in the past two decades as promising directions in vehicle research because of its potential to enable the suspension system not only providing enhanced dynamic performance but also converting the wasted vibration energy to electricity. After the early trial in the middle of 1990s, the number of publications per year on regenerative energy suspensions has been exponentially increased over the last decade, as illustrated in rotary based electromagnetic harvesters, there are two common kinds of linear-to-rotary motion transmissions, the mechanical based transmission and the hydraulic based transmission. The mechanical transmission based harvester has been developed rapidly because of its simple construction, greater efficiency, and considerable average power. Many proposed designs of the mechanical regenerative shock absorber have been introduced including ball screw mechanism, rack-pinion mechanism and other mechanisms. The second category of the rotary electromagnetic harvesters is the hydraulic regenerative shock absorbers which harvest the vibration energy by employing oscillatory motion from hydraulic absorbers to drive the generator. Many researchers have implemented the hydraulic energy harvesters in vehicle suspensions and studied their performances theoretically and experimentally. This review tends to provide updates and state-of-the-art concerning energy harvesting from vehicle suspension as a large-scale vibration source. The energy harvesting potentiality from vehicle suspensions is addressed in this review paper to answer the question of how much energy is available for being harvested in vehicle suspensions. The principal motivation of this study focuses on reviewing the energy harvesting based suspension technologies and exploring the concept, structure and properties of the different harvesters as regenerative dampers. This state-of-the-art also presents a comprehensive, analytical and statistical survey on the vehicle energy harvesting suspension systems including the conducted theoretical simulations, experimental bench tests, and real road tests. Further, a technical comparison between the most popular vibration energy harvesting schemes used in automotive suspensions is given. The research gaps that remain unresolved are addressed and some recommendations regarding such challenges are stated for further research and real scale applications.

## II. PROBLEM DEFINITION

Ordinarily, the vehicle rolls on uneven roads in which the harvesting-based damper can convert the linear oscillation of the suspension into electricity based on an electromagnetic circuit. Regenerative suspension based on electromagnetic harvesting method is one of the most popular harvesting technologies used in automotive energy harvesting suspension as issued in the literature. The electromagnetic based harvester has been put forward and become increasingly attractive because of its high-energy conversion efficiency, design simplicity, quick response, strong controllability and capability in energy recovery. As the energy harvesting mechanisms are categorized based on how the perpendicular vibrations are translated into electricity. According to the electromagnetic motor modulator, the harvesting mechanisms can be categorized into linear electromagnetic harvesters (direct energy harvesters) and rotary electromagnetic harvesters (indirect energy harvesters). Both the linear and rotary electromagnetic based energy harvesting suspensions were investigated by many scholars. This section presents the implemented energy regenerative absorber configurations and their working principles and mechanisms. Besides, a comparison of the findings with those of other studies conducted on energy harvesting shock absorbers is addressed.

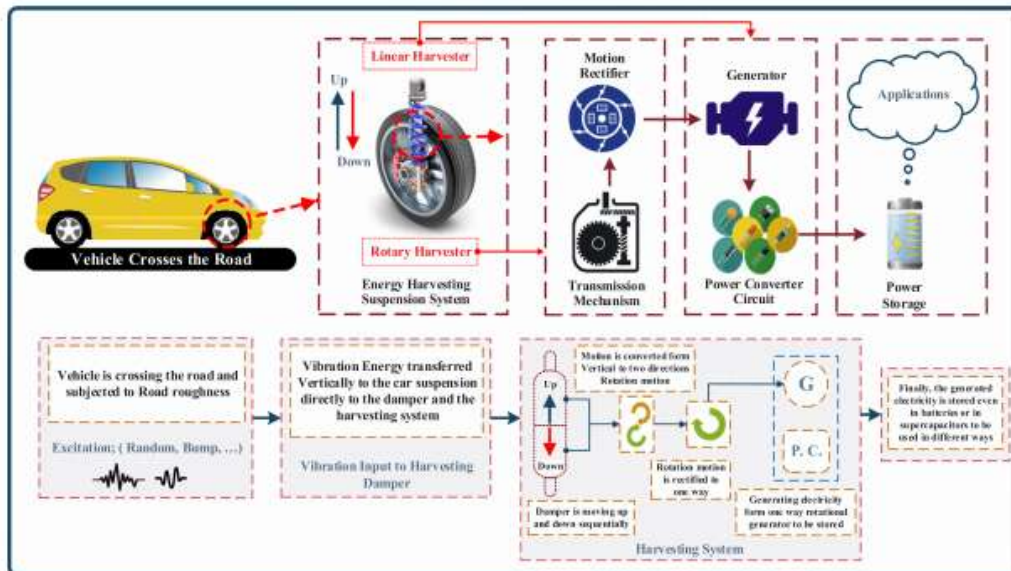


Fig 1. Scheme of the vehicle energy harvesting suspension system layout.

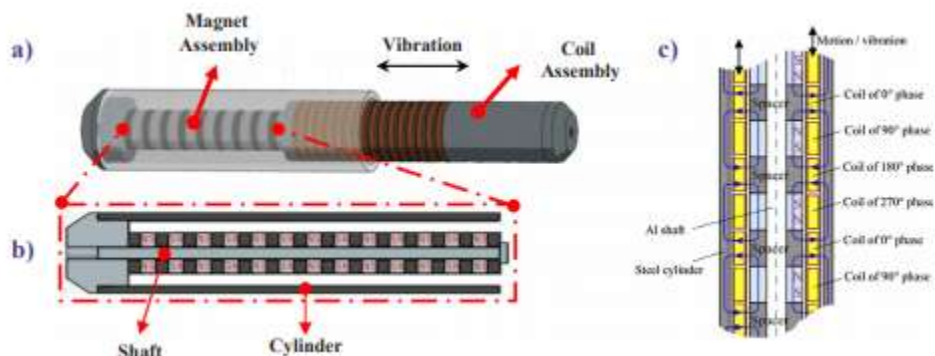


Fig 2. Linear electromagnetic based energy harvesting shock absorber; (a) 3D model of the linear motor-based damper; (b) cross-section of the magnet assembly; (c) diagram of the four-phase generator.

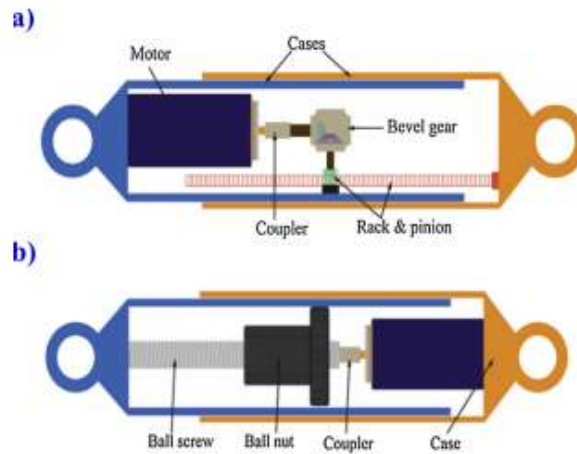
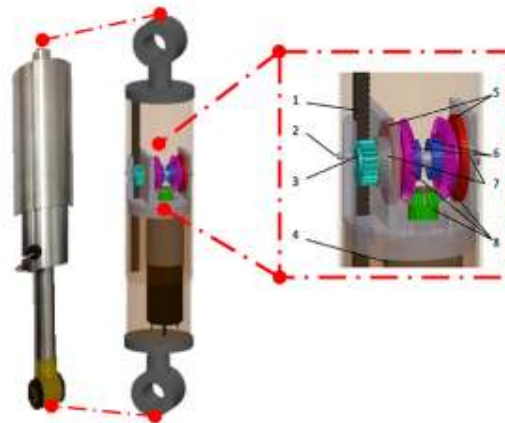


Fig 3. Rack-pinion energy regeneration mechanism, (b) Ball-screw energy regeneration mechanism.



- |                              |                   |                    |                  |
|------------------------------|-------------------|--------------------|------------------|
| 1. Rack                      | 2. Roller         | 3. Pinion          | 4. Ball bearings |
| 5. Planetary gears and motor | 6. Thrust bearing | 7. Roller clutches | 8. Bevel gears   |

Regenerative shock absorber based on rack and pinion mechanism

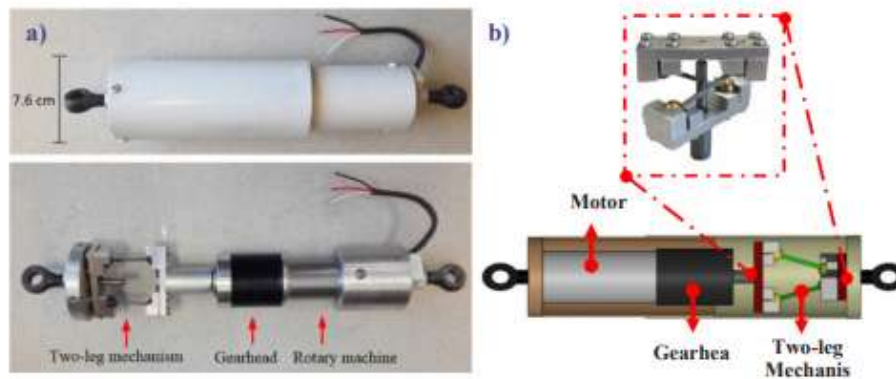


Fig 5. Regenerative shock absorber based on the two-leg mechanism; (a) prototype of the two-leg mechanism-based damper; (b) CAD assembly of the proposed prototype

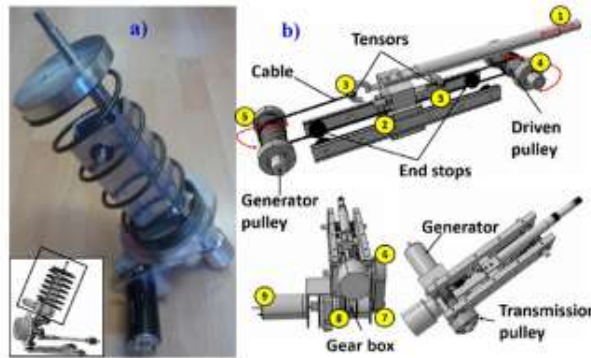


Fig 6. Cable/pulleys transmission based rotary electromagnetic regenerative shock absorber; (a) prototype assembly of the CD-EHSA; (b) CAD assembly, structure and components of the CD-EHSA

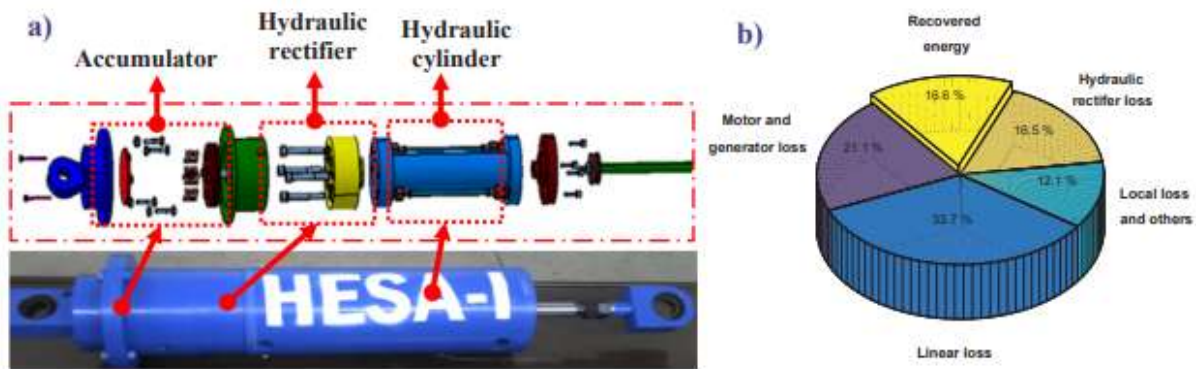


Fig 7. Hydraulic harvesting absorber with HMR; (a) HESA prototype; (b) Energy distribution of the HESA

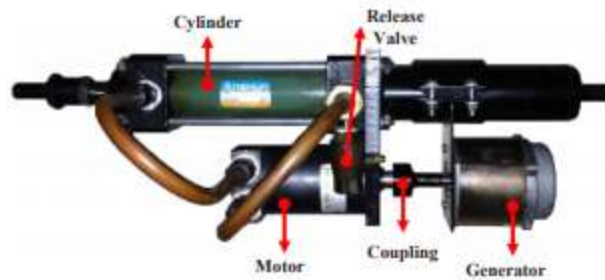


Fig 8. A full-scale prototype of a hydraulic regenerative based shock absorber without HMR

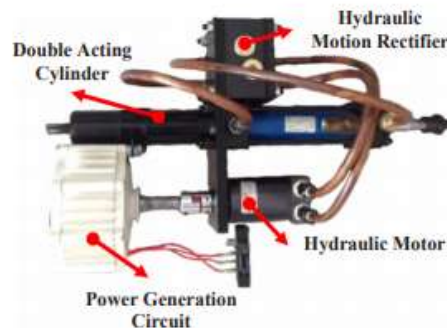


Fig 9. A full-scale prototype of a hydraulic transmission based regenerative shock absorber

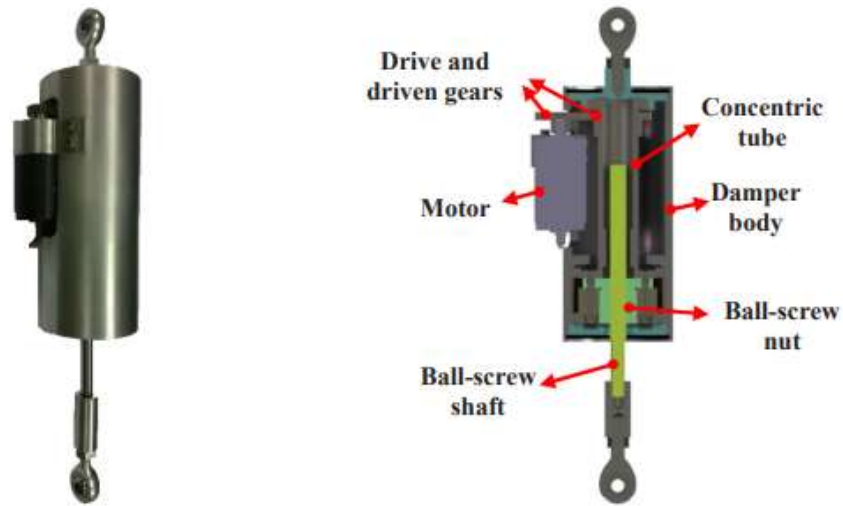


Fig 10. Regenerative shock absorber with ball screw shaft; (a) proposed prototype; (b) CAD model sectional view with major components.

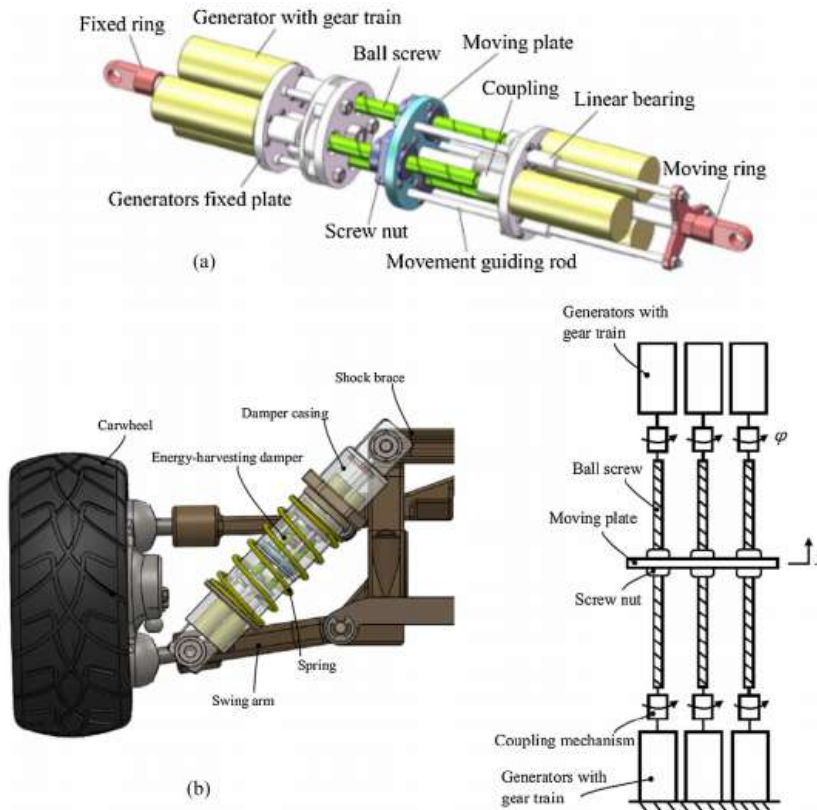


Fig 11. Ball-screw transmission-based energy-harvesting damper; (a) 3D model, (b) the damper in suspension, (c) diagram of the transmission mechanism

### III. CONCLUSION

The aim of this paper was to present a comprehensive review on automobile energy harvesting. The present research challenges were discussed and future work was suggested regarding real applications in wheeled vehicles. Unlike small-scale energy-harvesting systems (e.g., wireless sensors and electronic devices), automobile energy harvesting based suspensions have not been sufficiently investigated. Automobile energy harvesting technologies have attracted more attention in which a harvested average power of 350 W could be achieved for a medium-size sedan (four energy-harvesting dampers). For heavy-duty and off-road vehicles, the regenerative suspension can effectively provide a wide range of the harvestable power over 1 kW which is worthy of being recovered regarding improvements in fuel efficiency.

There are some essential questions remaining under investigation towards enhancing our understanding of the real application based energy harvesting suspensions in practice. According to the literature, no attempt has been made to investigate the actual vehicle fuel savings using an energy harvesting suspension in terms of litter/100 km. In the mobility of the future, developing a smart suspension based energy-harvesting function would be interesting that can work efficaciously during the car trip on different real roads. Meaning while, as for real applications, the investigations regarding an integrated energy-harvesting based damper in a wheeled vehicle has not been considered enough yet.

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