"Review of potential of Regenerative Hybrid Suspension System as a future technology for suspension"

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1. Introduction

With the increasing quantity of possessed automobiles, it has received a great deal of attention from automobile manufacturers and government for the energy conservation and environmental protection both at home and abroad. To protect the environment and reduce vehicle emissions and fuel consumption of vehicles, it is necessary to recover the energy wasted by the car, such as the braking energy, engine exhaust emissions energy and vibration energy of suspension, etc. Usually the vibration energy caused by road roughness when car runs has not been paid attention to and it is wasted through conversion to thermal energy. If the vibration energy can be recovered and converted to other form of energy such as electric or hydraulic power so to supply for other devices, then the aim of eco-friendly energy-saving is reached. Research shows that the vibrational energy can convert to electric energy through the innovative electromagnetic shock absorber. [7]

Green energy is one of the most popular topics nowadays. The future of clean Energy technology is foreseeable, especially on vehicle industry. The vehicle manufacturers have made costly strides to improve fuel economy. Car designers also spend Great deal of effort to reduce wind drag so as to improve fuel economy through streamlined low drag Vehicle body design. Manufacturers also use lighter material to reduce the weight of vehicle and ultimately to reduce fuel consumption. It is pointed out that only 16% of energy is actually used for driving. If only 16% of energy is actually used to drive, where does the rest amount of energy go? It is well known that automobiles are inefficient, wasting over74% of energy stored in fuel as a heat. Major energy losses are engine losses (62.5%), idle & standby(17.2%), braking losses (5.8%), rolling resistance (4.2%) & drive line losses (5.2%), accessory usage(2.5%), aerodynamic drag (2.6%).To recovers energy from 5.8 % braking losses, regenerative braking systems are developed and successfully implemented in electric vehicles. One important energy loss in automobiles is the dissipation of vibration energy in vehicle suspension system. When a vehicle travels on rough road, the vibrations are produced. These vibrations have not been yet considered for energy recovery and are wasted through conversion into thermal energy. Experiments have shown that at 90 kmph on good and average roads, 100-400 watts average power is available to recover in the suspension system of amiddle-size vehicle Middle-size passenger vehicle requires 180 watt power to operate continuous loads like ignition, fuel injection and 260 watt power to operate prolonged loads like side & tail lights, head light main lamp etc. Total power requirement of vehicle to operate its electrical components sum out to be 180 to 440 watts. If all the available vibration energy is recovered, it is possible to use regenerative shock absorber to charge the battery of vehicle, instead of alternator. Thus alternator load on vehicle engine can be decreased or removed completely. Theoretical results show a maximum of 10 % fuel efficiency can be recovered from vehicle suspension system by implementing regenerative shock absorbers. Therefore, if the amount of energy wasted by all four shock absorbers is harvested for driving, we can increase the fuel efficiency by 1-8%.If say 3% of fuel efficiency of vehicle is improved by this energy recovery scheme, by considering number of vehicles in world (value app. in millions), huge amount of fuel can be saved. Thus energy recovery from suspension system is necessary to reduces fuel consumption.The potential of regenerative shock absorber is foreseeable and is the motivation for this research. [1, 3]

Considering fewer parts for successful operation of energy generation, piezoelectric method is superior than other two methods. Furthermore it requires less maintenance. With more than 200 watts of power output, hydraulic system is most efficient out of three methods. Linear design of electromagnetic energyharvester system makes it possible to implement in vehicle suspension with minimum design changes.Hydraulic system is most expensive as it requires number of additional components for successful operation like turbine, hose pipes, flow meter etc. Main advantage of electromagnetic regenerative shock absorber is that possible integration with active or semi active suspension system called Electromagnetic suspension. Based on above points of comparison, it is clear that electromagnetic energy harvesting system is best suited alternative for suspension system. [3]

The goal of regenerative suspensions is to recover the vibrational energy, converting it into electrical energy that can be used to recharge the battery. This can lead to a larger driving range, if electric vehicles are considered, or to a reduction in carbon dioxide emissions, due to the lower usage of the alternator, if conventional internal combustion engine vehicles are taken into account. Moreover, electromagnetic shock absorbers show several advantages compared to the standard hydraulic solution, for instance, small sensitivity to environmental parameters such as temperature and ageing, and larger bandwidth. In addition, due to the electromagnetic nature of these devices, they allow a relatively easy implementation of active control. Although it is a promising solution, there are still many challenges that must be faced before considering its introduction in mass production vehicles. The obstacles are mostly related to the fact that conventional shock absorbers guarantee good performance while having low cost. As regenerative shock absorbers have a higher cost when compared to traditional ones, the gain in terms of harvested power has to be sufficient to justify the on-vehicle implementation of this kind of system. Moreover, another concern that emerges from the literature is related to the weight to performance ratio of electromagnetic shock absorbers, which in most of the cases exceeds the range of acceptable values. The results suggest that road roughness, tire stiffness, and vehicle driving speed have great influence on the harvesting power potential, where the suspension stiffness, absorber damping, and vehicle masses are insensitive.[5,16]

Electromagnetic regenerative shock absorbers convert kinetic energy of vibrations into useful electricity depending on their structural configuration these systems are broadly classified in three types as,

1) Electromagnetic shock absorber with linear generator.

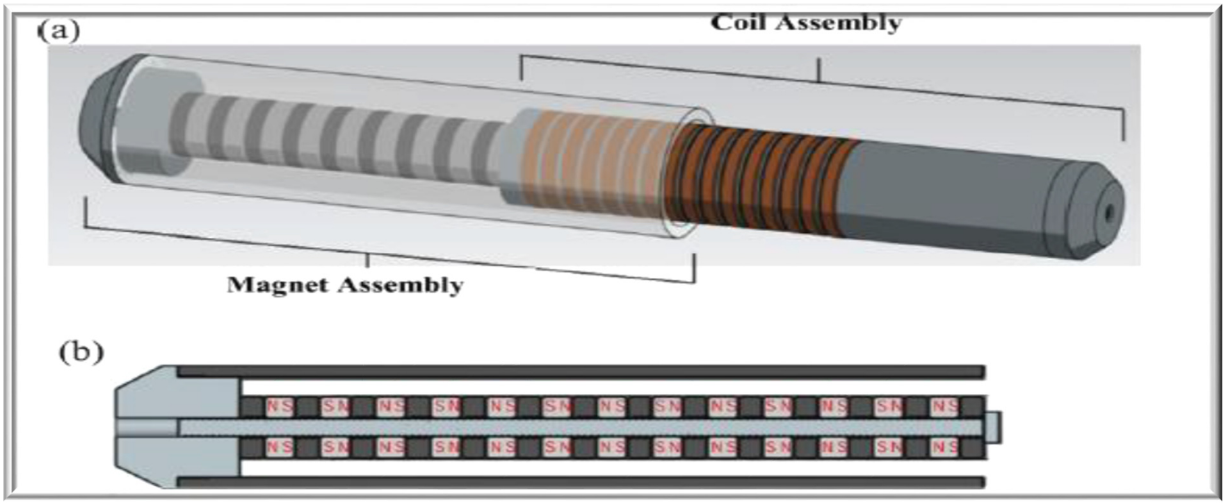

Figure 1.1: LINEAR ELECTROMAGNETIC HARVESTER DESIGN OVERVIEW [1]

Linear regenerative damper can be designed the same size of actual shock absorber. The friction loss is significantly small since there is no contact between wire and magnets. The orientation of the axial magnets alternates and are divided by iron space. Electricitywill be generated when the wire coil cut the magnetic flux. Zuo claimed the steel shell will guide the flux and greatly increase the power density [1]

2) Electromagnetic shock absorber with rotary generator

A rotary generator can be used in an energy harvesting shock absorber. Ballscrew or rack-pinion arrangement with bevel gears, which convert reciprocating motion into rotary, can be used to drive the generator. Number of helical gears may also be incorporated to increase rotational speed of the generator. In comparison to direct drive linear generators, rotary harvesters operate with amplified velocity, which results in greater power output this type of arrangement is favored in self-powered active vibration controllers. Ball screw-nut and bevel gear arrangements used in regenerative suspensions are illustrated in Figure.

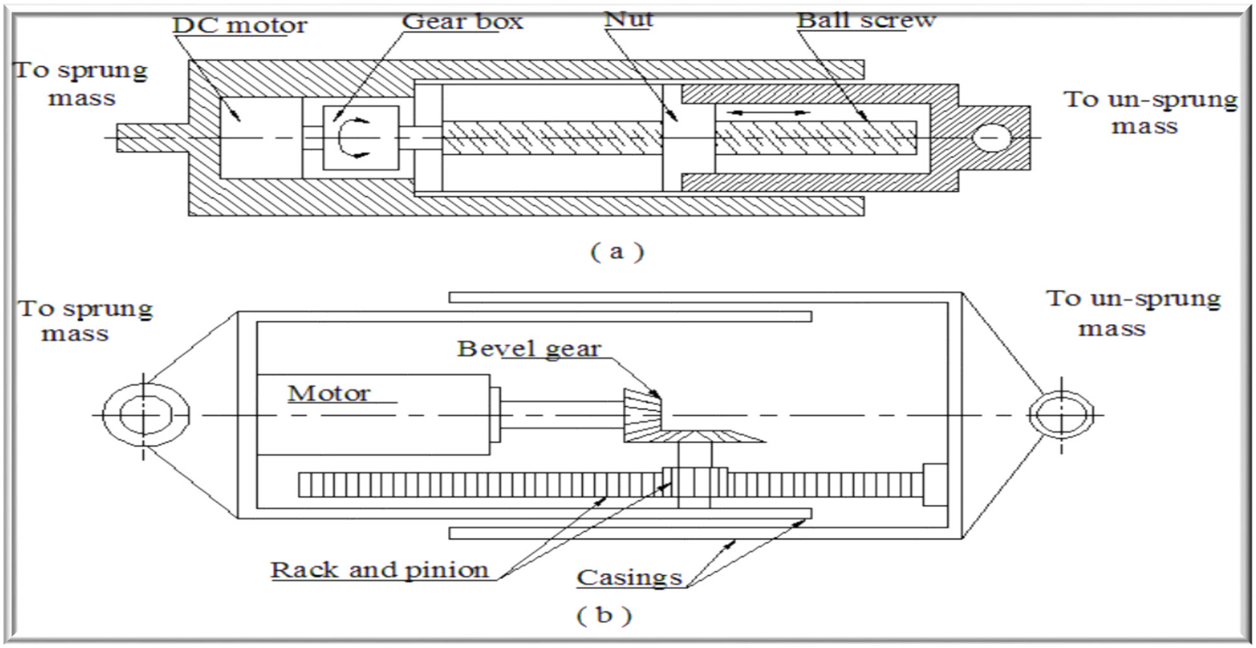

Figure 1.2: Regenerative shock absorbers
(a) Ball screw arrangement (b) Bevel gears arrangement.[7]

3) Hybrid systems with hydraulic transmission.

The energy harvesting system contained the hydraulic and electromagnetic (EM) mechanisms, and electric circuits. The external circuit was integrated to the system to observe the harvested energy properties of shock absorbers. To obtain the optimum harvesting energy from the regenerative shock absorber, the value of external resistors of system was chosen as equal to the internal resistors of the coil and generator. The constant resistors were used as the load of the energy harvesting system. [14]

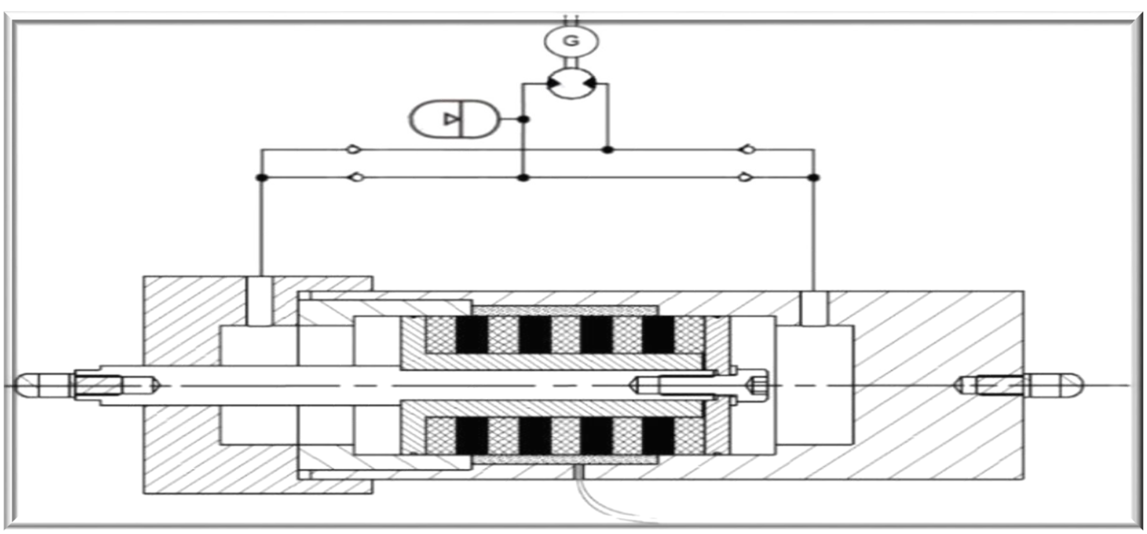

Figure 1.3: Schematic of the hybrid energy-harvesting shock absorber. [14]

Hybrid electromagnetic dampers, which are proposed in recent studies, are potential solutions to high weight, high cost, and fail-safety issues of an active suspension system. The hybrid electromagnetic damper utilizes the high performance of an active electromagnetic damper with the reliability of passive dampers in a single package, offering a fail-safe damper while decreasing weight and cost. [10]

It can be said that the harvesting energy from vibration is still in the beginning. Such as, taking into concern that the vibrations and movements which create vibrations are always present in the environment, this dimension of the renewable energy can be a main factor of interest for the future. So, this main propose of this research is to study the harvesting potential of the energy from vibrations. Below fig.-1 gives the basic block diagram of vibration energy harvesting system.

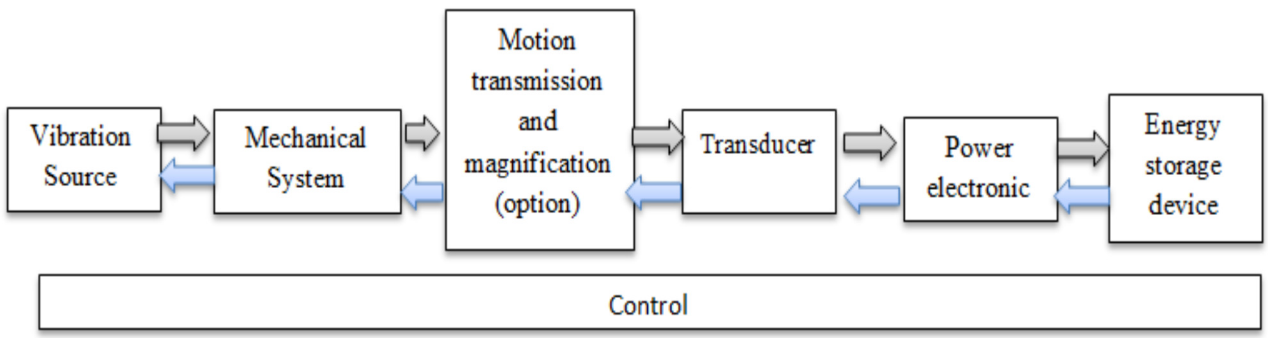

Figure-1.4:Block diagram of vibration energy harvesting system [22]

Although much initial work has been done in regenerative vehicle suspension regarding the power potential, the fundamental questions are still not clear: (1) what is the potential of harvestable power? The number in literature varies in a very largerange, from 46W to 7500 W. (2) what is the relation of the power and the road roughness and driving speed? (3) How sensitive isthe harvestable power to the changes of the vehicle parameters? (4) Will the ride quality (vibration intensity) and road handling(tire-ground contact force) be better if we extract more energy from the suspension system? These unanswered questions arevery critical to understand the regenerative suspension and to guide the design of the regenerative shock absorbers. It is the purpose of this research to address the above questions by creating a mathematical model for road-vehicle-suspension system and bysystematically analyzing the vehicle dynamics, ride comfort, road handling, and potential power at the same time.

2. LITERATURE REVIEW

In this chapter, a brief review of the past research work carried out in the field of regenerative electromagnetic shock absorber has been discussed in brief, for identification of the gaps, and for proposal of the new research work listed in the present study.

2.1. Review of literature on regenerative suspension system

1. Pei Sheng Zhang (2010)"Design of Electromagnetic Shock Absorbers for Energy Harvesting from Vehicle Suspensions".
Pei Sheng Zhanginvestigated the conflictions between power generation and comfort or safety numerically, the tradeoffs between vehicle's performances were well studied and the effects of vehiclehardware parameters on performance were also compared. Design and modeling of Linear, Rack and pinion and ball screw harvester and their comparison was done. This thesis shows experimentally validated numericalresults on shock dissipative energy on different ISO classed roads at various speeds. Author clearly stated the need of actual model of ball screw and rack and pinion harvester to understand the limit of rotational harvester by considering inertia, backlash, torsion, motor parameters, frictions and transmission along with optimal circuit design and Vibration and self-power suspension control.

2. Rahul U.Patil, Dr. S. S. Gawade (2013) "Design and static magnetic analysis of electromagnetic regenerative shock absorber".

Rahul U.Patil and Dr. S. S. Gawade created two dimensional model of energy harvester in MagNet software and solved statically to get flux function plot or contour plots showing flux distribution in coils. Also the full scale electromagnetic regenerative shock absorber was fabricated to find out the variation in regenerated voltage against in excitation frequency& amplitude. It was also found that the frequency of the regenerated voltage does not necessarily have the same frequency as the excitation. Instead, the wave shapes of the regenerated voltage will depend on excitation frequency, amplitude and equilibrium position.

3. Zhang Jin-qiu, PengZhi-zhao (2013)"A Review on Energy-Regenerative Suspension Systems for Vehicles"

Zhang Jin-qiu, Peng Zhi-zhao et al.reviewed different types of mechanical, electromagnetic and hybrid regenerative suspension system stated need of balance between regenerated and consumed energies and study on reliability of Hydraulic transmission and Self-powered MR damper.

4. Fabio Tarantini (2015), "Simulation of a Regenerative Electromagnetic Vehicle Suspension"

Fabio Tarantiniduring his master workevaluated CO2 emission reduction and Dynamic performance of the electromagnetic generator using matlab model and proposed modeling of the friction occurring in the ball screw mechanism, accurate analysis of the electrical charging circuit along with an active control and construction of prototype.

5.Zhen Longxin, Wei Xiaogang (2010), **"**Structure and Performance Analysis of Regenerative Electromagnetic Shock Absorber".

Zhen Longxin and Wei Xiaogangintroduced the structure and principle of a regenerative electromagnetic shock absorber in detail and Used ANSYS software to analyze the magnetic flux density of the permanent magnet array of the electromagnetic shock absorber also calculated the performance parameters. For special structure the max magnetic flux density in the place where coils come through reaches as high as 2.6T. It is found that when the car runs at 20m/s on the c-level road, the recovery efficiency reaches 39% and it still has margin to be increased by improvement of the structure. For example to substitute permeability material with high permeability Alloy.

6.Istvan Zador (2008) **"**Rear earth and high temperature superconducting permanent magnet synchronous tube motor/generator optimization for the components of the car suspension system".
Istvan Zadorin his doctoral thesis discussed about the analytical and a FEM designer and optimization model, which was validated by prototypes measurements. The models can calculate the electric, Magnetic and shock-absorber specific optimal (maximum energy) geometrical parameters of a PM synchronous tube motor/generator fitted into the possible shock absorber space. The parameters, which can be studied, are the ferromagnetic environment, and the quantity of the magnets. It is possible to use a tube machine stator as a drive unit for the magnets, so we can damp the oscillation of the vehicle with the coils and parallel realize the spring unit.

7. Nitin V. Satpute, Dr. Shankar Singh (2013), **"**Design and analysis of energy-harvesting shock absorber with electromagnetic and fluid damping".
Nitin V. Satpute and Dr. Shankar Singh carried out design, optimization and analysis of a linear generator for use in automobile shock absorber. While designing the linear generator damping factor, efficiency of the generator and weight of the structure has been considered. Full scale linear generator will be able to harvest electrical energy of 60-100W for suspension velocities of 0.1 to 0.2 m/sec, which were normally encountered on the road. Full scale electromagnetic Shock Absorber will offer damping force of 250- 500N for the above velocities. Frequency of the generated voltage depends on input frequency of excitation, thickness of magnets and pole pieces. Electromagnetic damping force shows On-Off effect, which needs to be further, investigated, for its effect on safety and comfort of the vehicle.

8. A. Gupta, J.A .Jendrzejczyk ,T.M.Mulacahy,J.R.Hull (2006), "Design of electromagnetic shock absorber"
A. Gupta et.al fabricated and tested two different electromagnetic shock absorbers. Peak power generated during the traversing of the ATV increased from a meager 7.4–88.8 W when the Mark 2 shock design was replaced the Mark 1 design. Research was conducted with a larger DC motor and a rack-and-pinion system. Because increasing demand on vehicle fuel efficiency necessitates exploring concepts like electromagnetic shock absorber.

9. UrszulaFerdek, Jan Łuczko (2012) "Modeling and Analysis of a twin-tube hydraulic shock absorber"

UrszulaFerdek and Jan Łuczkocreatedphysical and mathematical model for a twin-tube hydraulic shock absorber, using oil as the working medium. To analyze the model, methods of numerical integration were incorporated. The effect of the amplitude and frequency of the excitation, as well as the parameters describing the flow rate of oil through the valves, were examined. The basic characteristics of the damping force were obtained. This paper provides basic guidelines for creating mathematical model and numerical integration methods applications in regenerative shock absorbers.

10.S. P. Beeby, R. N. Torah, M. J. Tudor (2008),“Kinetic Energy Harvesting”

Beeby et al.reviewed vibration energy harvesting used to provide a localized power supply for Wireless applications. Three transduction mechanisms employed to convert mechanical energy into electrical were presented along the characterizing equations that highlight the important design parameters. Suitability of the technology in space applications will be determined by the nature of the available kinetic energy and the required Level of output power.

11. Jun Yin, Xinbo Chen, Jianqin Li, and LixinWu (2015), “Investigation of Equivalent Unsprung Mass and Nonlinear Features of Electromagnetic Actuated Active Suspension”

Jun Yin et al. (2015) introduced the magnitude of the unsprung mass based on a gearbox and ball screw type actuator. The geometry of the suspension and the actuator also influence the equivalent unsprung mass significantly. This research is based on two examples of the rotating type electromagnetic actuated active suspension. The discovery of this paper provides a fundamental for evaluating the rotary type electromagnetic actuated active suspension performance and control strategy derived.

12. Liew Hui Fang, Syed Idris Syed Hassan, Rozemizi Bin Abd Rahim, and MohdFareqAbdMalek (2016),“Study of vibration energy harvester”

Liew Hui Fang et al. investigated various designs of vibration energy harvesting from ambient vibrations using electrostatics, piezoelectric and Electromagnetic concept. Most of the harvesting circuits were developed based on the periodic or harmonic excitations. The future challenges to be addressed in the research field include improving the conversion efficiency and energy harvesting and storing circuits. Actually, one of the possibilities to recharge such batteries is to use energy harvested from the surrounding.

13. Zhigang Fang, XuexunGuo, Lin Xu, and Han Zhang (2013)**,** “Experimental Study of Damping and Energy Regeneration Characteristics of a Hydraulic Electromagnetic Shock Absorber”

Zhigang Fang et al.developed anOptimal Algorithm for Energy Recovery of Hydraulic Electromagnetic Energy-Regenerative Shock Absorber. They carried out optimal energy recovery analysis and active control of HESA based on a quarter-car model combined with simulation results. The feasibility of active control of HESA is confirmed by the experiments, although there still need much further study. They concluded that the energy-recyclable power is more sensitive to excitation frequency than to damping ratio, and the requirements of ride comfort and safety can be met by changing the damping ratio properly without reducing energy-recyclable power.

14.Mustafa Demetgul, Ismail Guney(2017), “Design of the Hybrid Regenerative Shock Absorber and Energy Harvesting from Linear Movement”

Mustafa Demetgul and Ismail Guney proposeda new type of hybrid energy-regenerative suspension system and examined at three different velocities by using tensile test machine. This new hybrid system includes the combined hydraulic and electromagnetic structures. Different experimental conditions, including higher speed excitations, Structural analysis and parameter optimization of this hybrid system can be studied further.

15. Bohaung(2016), “An energy-regenerative vehicle suspensionsystem –development, optimization, and improvement”

Bo Huangcarried out research to include design and development novel regenerative system, fabrication of a proof-of-concept prototype and its experimental verification, optimization of the system parameters design for the best control and power regeneration performance, and improvement of the system such as bandwidth. The explicit relationship between RMS results for the harmonic excitation and results for the stochastic excitation should be investigated. Some advanced optimization strategies should be investigated to deal with the trade-off between power regeneration and ride comfort/road handling of the nonlinear suspension system using perturbation methods. The experimental test on the regenerative Skyhook control strategy should be implemented

16.BabakEbrahimi(2009), “Development of Hybrid Electromagnetic Dampers for Vehicle Suspension Systems”

BabakEbrahimideveloped Hybrid Electromagnetic Dampers for Vehicle Suspension Systems.Hybrid electromagnetic dampers, which are proposed in this research work, are potential solutions to high weight, high cost, and fail-safety issues of an active suspension system. The hybrid electromagnetic damper utilizes the high performance of an active electromagnetic damper with the reliability of passive dampers in a single package, offering a fail-safe damper while decreasing weight and cost. Two hybrid damper designs are proposed in this thesis. The first one operates based on hydraulic damping as a source of passive damping, while the second design employs the eddy current damping effect to provide the passive damping part of the system. It is demonstrated that the introduction of the passive damping can reduce power consumption and weight in an active automotive suspension system.

It is suggested that a fluid analysis is performed to model this effect so the characteristics ofthe reservoir chamber will be designed in a way that the damper potentially exhibits thedesired asymmetric damping behavior in compression/extension stages. As a part of future work, the effect of the moving fluid in the steady-state working temperature of the system could be analyzed. Althoughthe operating temperature is influenced by the operating and road conditions as well as theenvironmental temperature, the hydraulic hybrid damper design could be modified based on amore accurate operating temperature.

17. Zhigang Fang, XuexunGuo, Lin Xu and Han Zhang (2013), “An Optimal Algorithm for Energy Recovery of Hydraulic Electromagnetic Energy-Regenerative Shock Absorber”.

Zhigang Fang et al.developed a new kind of shock absorber. The energy recovery scheme was put forward, and the HESA prototype as well as the bench was trial manufactured. The damping characteristic of the HESA prototype was tested, and its performance was good under low cracking pressure and small excitation amplitude without taking the requirement that damping force in compression Stroke is greater than that in extension stroke into account .It was found that the rectifying efficiency of the hydraulic rectifier decreases with the excitation frequency increase because of the time delay of the opening and closing of the check valves, which eventually leads to a reduction in energy recovery efficiency. This is difficult to be settled, because the presence of hydraulic rectifier affects not only the damping characteristic of HESA but also the energy-regenerative characteristic of HESA. And further work is required to deal with the problem. The linear loss of oil accounts for the largest share of the energy distribution of the HESA prototype, and it can be decreased effectively by increasing the inner diameter of pipe line based on our proposed mathematical model of linear loss

18. H.B.Arsem(1971), “Electric Shock Absorber”

H.B.Arsem inventedelectric shock absorber .The principal object of this invention was to convert the mechanical energy applied to automotive shock absorbers into useful energy.More specifically, invention presented a shock absorber in the form of an electric generator which converts the mechanical energy applied there into electrical energy for charging an automobile storage battery. This invention gives basic concept but not exact idea about energy conversion, electric circuit design and amount of energy can be harvested from such regenerative shock absorber.

19. Christopher Paul cox (2014)“Methods and apparatus for position sensitive suspension damping”

Christopher Paul cox invented method and apparatus for position sensitive suspension damping use in vehicle suspension. Particularly relate to methods and apparatus useful for variable and position sensitive dampening rate in vehicle shock absorbers. In one aspect fluid damper is provided Comprising a damper Chamber divided by a piston into a primary Compression and a primary rebound chamber; a secondary compression chamber in fluid communication with the damper chamber; and an adjustable fluid meter controlling fluid flow out of the secondary compression chamber. This invention gives new design of hydraulic shock absorber which may be consider for further developments in field of hybrid shock absorber for energy harvesting

20. John A. Konotchlck (2014) **“**Linear motion electric power generator”

John A. Konotchlckinvented a linear motion electric power generator. A rare earth magnet and a coil are positioned to move linearly back and forth relative to each other. The movement of the coil in the field of the Magnet generates a current in the coil. Spring less orientation means were provided to maintain a neutral position about which the relative motion occurs. The current application could provide a potentially more cost effective method of supplying remote power. For many applications where batteries were used to power small devices mechanical energy is available, for example walkers or joggers using portable radios. For some of these applications use of batteries could be replaced by the devices described in this invention.

21. Ronald B. Goldner (2005) “Electromagnetic linear generator and shock absorber”

Ronald B. Goldnerinvented a regenerative shock absorber which is capable of converting parasitic displacement motion and vibrations encountered under normal urban driving conditions to a useful electrical energy for powering vehicles and accessories or charging batteries in electric and fossil fuel powered vehicles. The disclosed device is capable of high power generation capacity and energy conversion efficiency with minimal Weight Penalty for improved fuel efficiency. This invention was utilized in any power generating application where recovery and generation of electric power is desired with compact and efficient power source.

22. NimaEslaminasab (2008), “Development of a Semi-active Intelligent Suspension System for Heavy Vehicles”

Nima Eslaminasab carried out the research to advances the state of knowledge in the semi-active suspension design system while making new contributions in many related areas such as the manufacture and design of semi-active dampers, mathematical modeling, control, and non-linear dynamics application. Development of an industrial final version of the prototyped internal solenoid-valve semi-active damper, development of a microcontroller for each of the proposed control methods and commercialization process of this product is an important aspect of future work. More research on the nonlinear system response to a general random input can be studied further.

23. Jorge de-J. Lozoya-Santos, Damián Cervantes-Muñoz(2015), “Off-Road Motorbike Performance Analysis Using a Rear Semiactive EH Suspension”

Jorge de-J. Lozoya-Santos et al. analyzed a control system for a semi active rear suspension in an off-road two-wheeled vehicle. Several control methods as well as the recently proposed Frequency Estimation Based (FEB) algorithm were studied. The motorcycle dynamics, as well as the passive, and semi active dampers, and the algorithm controlled shock absorber models are loaded into BikeSim, professional two-wheeled vehicle simulation software, and tested in several road conditions .The results show a detailed comparison of the theoretical performance of the different control approaches in a novel environment for semi active dampers. The results confirm that a performance increase can be obtained by using this technology, but at the same time it is limited to selected events due to the dependency of the vehicle suspension behavior on road frequencies and speed Conditions.

24. Lei Zuo, Pei-Sheng Zhang(2013),"Energy Harvesting, Ride Comfort, and Road Handling of Regenerative Vehicle Suspensions"
Lei Zuo, Pei-Sheng Zhangpresented a comprehensive assessment of the power that is available for harvesting in the vehicle suspension system and the tradeoff among energy harvesting, ride comfort, and road handing with analysis, simulations, and experiments. The excitation from road irregularity was modeled as a stationary random process with road roughness suggested in the ISO standard. The concept of system H2 norm was used to obtain the mean value of power generation and the root mean square values of vehicle body acceleration (ride quality) and dynamic tire-ground contact force (road handling). For a quarter car model, an analytical solution of the mean power was obtained. The influence of road roughness, vehicle speed, suspension stiffness, shock absorber damping, tire stiffness, and the wheel and chasses masses to the vehicle performances and harvestable power were studied. Experiments were carried out to verify the theoretical analysis. The results suggest that road roughness, tire stiffness, and vehicle driving speed have great influence on the harvesting power potential, where the suspension stiffness, absorber damping, and vehicle masses are insensitive.
It was clearly stated that more power harvesting does not mean better vibration reduction or better road handling, in additional the influence of tire stiffness to the road rolling resistance should be considered too to fully evaluate the fuel efficiency of the vehicle

25. W. GAO, N. Zhang and H. P. Du (2007),"A half-car model for dynamic analysis of vehicles with random parameters".
W.Gao et al.presented a half-car model for dynamic analysis of vehicles with random parameters which was suggested by many researchers working on regenerative suspension. The effect of uncertainty in the vehicle's parameters on the randomness of the natural frequencies and vehicle's random responses are presented by using the MCSM. The dynamic characteristics and random response of stochastic vehicles are obtained expediently. This method will also be applied to the dynamic analysis of random vehicles by using stochastic full-car models.

26. Brian Clancy (1996),"Motor simulation of a shock absorber"
Brian Clancydeveloped an electrical fully active motor cycle front suspension. Formula 1 motor-cycle front suspension shock absorber was simulated using a Permanent Magnet DC motor and digital controller. Methodical approach to choosing coupling ratio was introduced and sample calculations were made for the permanent magnet. There is however steps that should be taken to improve the accuracy of simulation and also to bring this research further towards realizing the electrical active suspension concept. Adaptive control of a motor simulated shock absorber is a logical step towards an electrical active suspension and is recommended by this author as the control approach to be considered next.

27. Musa Mohammed Bello, Adamu Y. Babawuro andSadoFatai(2015),"Active suspension force control with electro-hydraulic actuator dynamics"

Musa Mohammed Bello et al.designed a double loop PID control of generated force and vehicle suspension parameters using a four degree of freedom, nonlinear, half vehicle active suspension system model with hydraulic actuator. Comparisons were made between the nonlinear active PID base suspension systems with a nonlinear passive system. Results obtained show a better performance improvement in the active system when compared to the passive System at the expense of cost and power consuming. In this work, author intend to deal with the real system model perhaps could help in reducing the possibility of poor performance on implementation due to nonlinearity of system and at the same time developed a control system which is less complex and also less expensive to utilize.

28. KoenDeprez (2009), “Assessment and improvement of the lowfrequency vibrational comfort on agricultural machinery by optimized cabin suspension”.

KoenDeprezdeveloped a commercially viable cab suspension system to improve the low frequency vibrational comfort of the operators on mobile agricultural machines. A combine harvester was used as a case study and since this machine can be considered to be a mobile agricultural machine of average size, most of the conclusions found here are transferable to other mobile agricultural machines. Minor changes to the comfort values found in this thesis are expected because the evaluation platform, the hydraulic shaker, had a margin of error when reproducing the measured in-situ vibrations. Also the effect of not being able to evaluate the suspension by using a real cabin will come into play.

29. Andronic Florin , Manolache-RusuIoan-Cozmin , PătuleanuLiliana(2013),“Pasive suspension modeling using matlab, quarter car model, input signal step type ”

Andronic Florinsimulated a passive suspension system using State Space and Transfer Function. Results obtained, using the three methods with the same parameters of the suspension system, are identical. A step type signal was used for a broad application of the suspension system. This signal can be modified, for example, a sinusoidal or a required signal.

2.2. ResearchGaps identified

Through entire literature we studied design, analysis, and testing of regenerative electromagnetic regenerative shock absorber. Based on literature surveyed following research gaps are identified.

1. Energy-recyclable power is more sensitive to excitation frequency than to damping ratio, and the requirements of ride comfort and safety can be met by changing the damping ratio properly without reducing energy-recyclable power Primary purpose of vehicle shock absorber is better vehicle comfort and handling rather than energy harvesting.There is conflict between suspension performance and energy harvested. Some advanced optimization strategies should be investigated to deal with the trade-off between power regeneration and ride comfort/road handling of the suspension system.
2. Damping force of electromagnetic devices significantly depends on the electrical load. Thus with change in load resistance damping will also varies which may result in bad damping.In case of failure of electrical components such as armature winding damping force will become zero if only electromagnetic system is used which states need of fluid damper along with electromagnetic linear generator which was not discussed by researchers.

3. Different experimental conditions, including higher speed excitations, Structural analysis and parameter optimization of this hybrid system can be studied further.
4. The design and modeling of other hybrid damper with the goal of minimizing the weight and size, and enhancing the damping performance configurations is another key future work.
5. Most of the harvesting circuits were developed based on the periodic or harmonic excitations. The future challenges to be addressed in this research field include improving the conversion efficiency and energy harvesting by optimal design of electrical circuits.
6. With use of linear generator as the harvesting/dissipative element in vehicle shock absorber, frequency of the generated voltage waveform is different from the excitation frequency .This leads electromagnetic damping force frequency to differ from the excitation frequency, which gives ON-OFF effect on the electromagnetic damping force However many authors have not investigated its effect on comfort and handling of the vehicle.
7. Electromagnetic rotary generators with rack and pinion and ball screw arrangement are proposed in order to reduce overall weight and size of linear generators. But still there is need of theoretical and experimental study by considering inertia, backlash, torsion, motor parameters, friction and transmission elements along with its effect on increase cost and harvesting efficiency.
8. Much research has been carried out on development of self-sustaining active suspension system. However, these systems are complex and involve costly sensors and supporting electronics hardware. Moreover, most of the harvested energy is consumed in applying active force by the actuator.

3. Scope of Research Work

Scope of the research work is outlined as:

1. As discussed in the literature review, a regenerative shock absorber combining electromagnetic and fluid damping has not been studied. Hence, the proposed work deals with design and development of new hybrid electromagnetic hydraulic shock absorber.
2. Generator will be use as the harvesting element in proposed shock absorbers in order to increase the power output from the system velocity amplification is also proposed.
3. Generator will be connected to the battery through a control circuit, which will contribute to energy harvesting efficiency hence efficient electrical circuit will be design.
4. A quarter car dynamic model of the proposed regenerative shock will be develop using FE analysis and numerical simulations.
5. Experimentationwill be performed on a prototype which validates the theoretical model.
6. Comparison of results obtained from prototype testing will be done with the conventional system for weight and costalong with harvested power to check its feasibility on-vehicle implementation of this kind of system.

4. Conclusion

1. It is possible to convert vibration/kinetic energy to electric energy by using regenerative shock absorber effectively. The harvested energy from automotive shock absorbers will result in a much more economical vehicle performance in terms of fuel consumption as well as it will decrease the amount of CO2 emission in case of conventional internal combustion engine vehicles. Thus aim of eco-friendly energy-saving is reached.
2. It is also possible that generated electric energy can be used to charge the batteries of electrical vehicle which will increase driving the range of electrical vehicles.
3. Main advantage of electromagnetic regenerative shock absorber is that possible integration with active or semi active suspension system is feasible.
4. Moreover, electromagnetic shock absorbers show several advantages compared to the standard hydraulic solution, for instance, small sensitivity to environmental parameters such as temperature and ageing, and larger bandwidth.

5. REFERENCES

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