Active hybrid suspension system: A review

Dr. Rajnish Katarne¹, Dr. Satyendra Sharma²

¹Assistant professor, Mechanical Engineering Department, NMIMS University, Mukesh Patel School of Technology Management and Engineering, Shirpur-425405, India, ²Associate professor, Mechanical Engineering Department, SIRT, Sage University, kailod kartal, Rau-pass road, Indore- 452020, India,

rajnish.katarne@gmail.com

Abstract. In the current research paper, researcher has tried to give a review on hybrid/active suspension system. The primary purpose of a suspension system in an automobile is to sustain vehicle's stability and maneuverability during irregular and uneven road surfaces. Owing to the fast changing technology, conventional suspension systems limit the performance necessary. However, the modern suspension systems lack the practicality of implementation. The objective of this research is to highlight the various damping systems available and thereby, taking into account the best feasible option for further research in the area. An attempt has been made by the researcher to review significant papers in this area and focus on considered parameters like performance, feasibility, capacity, safety etc.

1. Introduction

Conventional suspension systems, such as, hydraulic dampers with coil springs are outdated and lack the recent innovations and progress. In spite of much technological advancement in the automotive industries, the task of the providing comfort and safety along with meeting the design constraints has not yet been effectively solved. There is a potential need for an active hybrid suspension system with controlled damping actions that utilizes the unused energy dissipated during damping action as well as it provides better ride comfort and vehicle handling abilities to the driver. Excitations from wide range of frequencies restrict the performance of the conventional passive systems.

2. Review on Suspension

Propose a concept of active control of hybrid suspension system is discussed by Suda (1996) et al. In this systems researcher has talked about passive dissipate heat in suspension. By numerical simulations and basic experiments, author explained and found that the proposed hybrid control mechanism provides a satisfactory performance in reducing the vibrations as well as in energy regeneration [1]. Actively controlling the vibrations could be depicted with the help of regenerated vibration energy. The energy required for the active control of the system is provided by the damper that regenerates the vibration energy. In this Yoshihiro (1998) et al. proposes less energy consuming active control law using the concept of skyhook control [2]. Martins (1999) et al. proposed the idea of combining both the passive damper and electromagnetic actuation mechanism. The author also concluded that the use of smaller, lighter actuator results in the same performance as that of the active suspension system. They also suggested that the energy required for the system to run is powered by the suspension system which results in the active force when compared to the conventional hydraulic
active system where the source provides both the passive and active forces [3]. Various predictive control techniques to magnetically control mass-spring-damper system could be use.

S. Di Cairano (2007) et al. developed two algorithms, one based on mechanical and other on electronic sub systems. Model Predictive Controllers (MPC) only controls the mechanical behavior of the chosen subsystem whereas, electromagnetic subsystems provides a dynamics through an inner-loop controller [4]. Z Li (2013) et al. presents an electromagnetic shock absorber which can also regenerate power. Their test results indicated that the stiffness of the spring is a major characteristic in vibration energy harvester. The excess bounce can be easily managed by controlling the electric load on shock absorber. Their design consists of a rack and pinion mechanism which generates power from the irregular surfaces and converts vibration energy to electrical energy [5]. The experimental study on Magneto-rheological (MR) dampers, indicating the variety range in allowable damping force under the acting magnetic field. GZ Yao (2002) et al. also suggested that the saturation of MR damper takes place as the current in the system reaches a definite value. During the MATLAB simulation, the response time was assumed to be very fast and the time delay was neglected. As a result, graphs of acceleration of sprung mass, suspension travel and tire deflections vs frequency were plotted and it became evident that the response was satisfactory for all three parameters around body resonance. Hence, performance characteristics of the MR dampers are very high [6].

Rashid (2007) et al. talked about magneto-rheological dampers and their characteristics. In this researcher conducted a deep and intense study on the controller’s performance (graphically) and the simulations of a MR damper with fuzzy PID controller and a hybrid fuzzy PID controller are plotted. Adhering to the simulation results, they found that performance of the MR damper (in terms of amplitude of displacement) with a hybrid fuzzy controller reduces the disturbance considerably (90% to 92%) when compared to fuzzy controlled damper. Hence, they concluded that hybrid fuzzy controller was better in performance than the fuzzy controller [7]. The high speed ON/OFF valves, hydro-pneumatic cylinder (actuator) and sensors are used in the suspension system. Shaojun & Liu(1996) et al. The system was analyzed with the help of simulation to examine the dynamic performance by designing a quarter car model experiment setup. Skyhook damper control and optimal control was adopted for the simulation of the model. Results indicated that optimal regulator gave vibration isolation nearly 13% whereas the skyhook control gives about 23%. A solenoid ON/OFF valve use confirmed better performance of designed optimal regulator [8]. For the riding comfortableness and traveling safety of automobile , control strategy of automobile magneto-rheological semi-active suspension was proposed by Wang(2008) et al. to progress . In addition the application and research status quo of automobile damper were introduced as well as the principle of magneto-rheological effect and the composition of the magneto-rheological fluid. Working principles and models of the automobile magneto-rheological damper was analysed and the future focus was discussed after summarizing the simulation models, control method and testing technology of automobile magneto-rheological damper of automobile suspension [9].

The Eddy Current Damper (ECD) virtual model is developed by Babak (2008) et al. By using appropriate equations and a prototype was developed for testing the magnetic flux density and the damping force. The performance of the ECD is compared with the readily available dampers. However, the authors also concluded that the failure of such system is high as they rely on the use of permanent magnets which eventually gets demagnetized. Use of rare magnets can ensure the desired reliability and durability of the system [10]. The feasibility of a smart passive control system using a MR based damper system. The newly developed system uses conventional passive system (that is, without sensors, controllers or any other power sources) that includes an Electromagnetic Induction device which is capable of generating electrical energy that is further used to change the damping properties of the MR damper. After analysing the result, author was certain that it is feasible to implement a smart passive control with an MR damper reducing the complexity of the circuit and the cost of production [11]. Gysen (2010) et al. has proposed the idea of a tubular Permanent-Magnet actuator with a spring attached to it. The author has tried to compare the proposed model with the readily available suspension system such as hydraulic, MR, electromagnetic etc. Specific
magnetizations were employed to develop the analytical model and of a quarter car model and conclusions were drawn [12]. Halbach magnetization topology to obtain the highest force generation in system. The research showed that exterior halbach magnetized topology is not capable to hold axial magnetization. The system is suitable when the voltage is low and large currents are necessary which in turn require expensive converters [13].

Hybrid suspension system that exhibited the same simulations results as that of a fully active suspension system proposed by Guido Koch 2010 et.al. An adaptive controller was designed for a quarter car model that consisted of a low bandwidth actuator and a damper. Lyapunov function approach ensured the stability of the adaptive controller, this concept proved to be beneficial as it decreased the power demand, made the system asymptotically stable and easy to implement [14]. The use of a hybrid magnet to reduce the vibration amplitudes over a wide range of frequencies. A quarter car model with single degree of freedom was analyzed with and without the use of hybrid magnet. An actuator which contained a cylindrical magnet was placed between the ends of the springs to suppress vibrations. MATLAB Simulink tool was used for modeling the quarter car model and the theoretical results obtained were verified experimentally using LABVIEW and FAST FOURIER TRANSFORM analyzer [15]. A hybrid energy harvester that uses two power generating mechanism that is piezoelectric and electromagnetic. The finite element and coupling mathematical models were developed and the experimental results depicted that the combination of both the energy harvesting devices had thrice the bandwidth of that a single harvesting mode device. The work presented proved to be effective in increasing the frequency bandwidth and energy output of a harvester [16]. The use of Magneto Rheological dampers in front bumpers of car to reduce the impact of collisions discussed by T.Imthiyaz Ahamed (2014) et al. The damper assembly included a chamber filled with MR fluid covered inside coil spring. This was intended to reduce the impact of vibrations by the combine action of the spring and MR fluid. The proposed model suggested that MR fluid accounts for absorbing 50-60 % vibrations during the event of a collision and the rest as absorbed by spring [17].

The numerous remote sensors embedded in a vehicle and harvest the energy to power. This power was to be obtained by piezoelectric conversion of vibrations transferred through uneven surfaces. Bond graph model was adapted to identify the power recovering areas when the car hit a bump at a speed of 30km/hr. The results suggested that around 0.5mW was recovered during the process. The paper suggested that increase in the number of piezoelectric harvesters resulted in more power recovery [18]. The effects of various control strategies on semi active dampers like skyhook, ground hook and hybrid on a quarter car simulation on MATLAB was analysed. The results obtained are further compared with the results of a commercially available passive system. It was concluded that for a distance of 0.01 meter, skyhook control proved to the most optimal choice in reference of ride comfort and stability [19]. The key purpose of a suspension system is to provide the shock absorption in automobiles. Besides carrying the weight of the vehicle it attempts to minimize/eliminate vibrations that may be induced by different sources like road surface irregularities, aerodynamics forces and non-uniformity of the tire/wheel assembly [20]. Abroon Jamal qazi (2013) discussed successful application of hybrid artificial intelligence techniques in designing a semi-active suspension system. Both passive and semi-active suspension systems have been shown in Simulink [21].

Y.M. Halde et.al.(2015) show active hybrid suspension system and focused on performance of dampers in the suspension system by using smaller electrically powered actuator increasing the performance of system. As per road conditions suspension system synchronize the performance. Few Researchers also suggested three degree of freedom vibration isolation system using active zero power controlled magnetic suspension is presented in order to isolated vibrations transmitted. With the help of experiments studies research has demonstrated the effectiveness of the isolator for dynamic vibration [22]. Zhang Jin-qiu, et.al.(2013)development of regenerative suspension is reviewed, and the energy harvesting schemes and their characteristics are remarked/summarized. In the regenerative suspensions combination of performance and energy harvesting efficiency is having scope in this type of system. The vibration generated by road roughness is controlled by robust artificial neural network control system scheme [23]. This is proposed by Ikbal Eski et.al. (2009). He designed active
suspension by using neural network based control system. The performance is compared to both the proposed RNN control system and the PID controller for fortuitous in road bumpiness [24]. With the help of neural networks K N Spentzas et.al (2002) has presented a design method for non-linear hybrid suspension systems. When the roughness of road is exceeded up to certain limit then active suspension system gives best performance. Irregular action of the controller helps to minimize the energy consumed by the actuator. The target of the design is to give more comfort ride to the passenger by minimization of the vertical acceleration effects [25].

Kinetics simulation model/ working theories by applying the interdisciplinary software AMESim for hydraulic transmission electromagnetic energy-regenerative suspension are discussed by the Lin Xu (2011). Comparison of hydraulic transmission electromagnetic energy-regenerative suspension/ passive suspension, of the energy-regenerative suspension of this structure leads to improve the ride comfort /fuel economy [26]. Due to high energy consumption Active suspension has limited use in automobiles. Long Chen et.al (2016) has discussed the concept of different type of suspension in this linear motor is used in adjustable shock absorber to form the hybrid active semi active suspension (HASAS). Its energy consumption and regeneration mechanisms are revealed. And the system controller which is composed of linear quadratic regulator (LQR) controller, mode decision and switch controller, and the sliding mode control based thrust controller is developed. LQR controller is designed to maintain the suspension control objectives, while mode decision and switch controller decides the optimal damping level to tune motor thrust [27]. The modelling and force tracking control of non-linear hydraulic actuator system is used in a quarter-car active suspension system. The two loops namely inner loop and outer loop controllers are developed for the active suspension system. The function of outer loop controller is absorbing the effects of road disturbances and the inner loop controller is used to keep the actual force close to this desired force. Both the loop show significant improvement in the performance of the suspension system [28]. In hybrid electric vehicles active suspension system with simultaneous simulation of power train shown by Seyedmohsen Hosseini et.al (2008). Both the system is integrated and the exchange of power and data between two systems is simulated by the authors. Variations due to road roughness are generated and are applied to the suspension system [29].

Now days demand in on road and off road is increasing comfort and handling performance is vital. When we focus on suspensions performance, it’s a trade of between various parameters like suspension travel, vibration reduction, actuator effort, road holding capability, noise and fatigue. Stratis Kanarachos et.al.(2015) proposed design of intelligent suspension system which focuses on all these permanent with the help of actuators. An algorithm continuously monitors the real time data of suspension travel and adapts accordingly [30]. A mathematical model for three axis active suspension system is proposed by Takeshi Mizuno et.al (2003). In this he shown the three motions could be treated separately in this zero-power control system is used this characteristic was confirmed experimentally [31]. Neural scheme is used with PD, PI and PID controllers to control the suspension system. This control system always works in closed loop which leads to better performance S. Yildirim (2003) [32]. Some researchers also used semi-active control methods by using commercial magneto rheological damper in a suspension system. With the help of experimental test bed Y. SHEN et.al.(2006) study the three control methods under sinusoidal and random excitations. This experimental result verified with analytical results also. Both the methods show significance improvements in the system [33].

Use of Magneto rheological dampers proposed by Ali Fellah Jahromi,(2012) in suspension systems of passenger cars. This system provides comfortable ride by considering various parameters like rolling, vertical movement of four tyres [34]. Babak Assadsangabi, (2009) designed controller which takes consideration of ride comfort and road holding for this he suggested hybrid model reference sliding mode controller. This controller is having two stages control system [35]. By the use of MATLAB/SIMULINK Ansar Mulla et.al. (2014) analyze effect of vibration on suspension system in quarter-car model [36]. Magneto rheological damper system is presented for semi-active control system by G Z. Yao et.al. (2002) [37]. Luis C. Félix-Herrán (2008) magneto rheological damper
system including the dynamics of the semi-active suspension. This leads to more comfortable ride for passengers [38]. Yechen Qin et.al. (2017) has compared analysis the time delay in semi-active suspension control systems. In this paper five systems has been compared and suggested increase in delay time could increase ride comfort [39]. Multi-objective microgenetic algorithm is used for semi-active suspension systems in MATLAB. This result shown it is helping to increase ride comfort [40].

3. Conclusion
In this paper, a hybrid suspension machine which mixes a passive damper with an electromagnetic actuator is proposed. The objective of the research is to reap a better performing suspension system without compromising the protection of the automobile. Literature review furnished an informational technique closer to the controlling systems for dampers. The following table 1 is the optimization of damper controlling structures on the premise of 4 parameters. If the cost parameter is considered, Electromagnetic damping device is a superb choice than Magneto-rheological or Electro-rheological systems. Although, if the performance is given a more credit score, the MR machine is a great choice and Electromagnetic damping system comes subsequent. Reviewing the desk similarly, Permanent Magnet structures show to be less green being highly-priced. Reviewing the desk similarly, Permanent Magnet systems prove to be much less efficient being steeply-priced. It may be without problems concluded that Electromagnetic Damping device may be an apt desire for further evaluation in this region.

| Controlling system                | Cost    | Feasibility | Performance | Implementation |
|-----------------------------------|---------|-------------|-------------|----------------|
| Magneto-Rheological Damper System | High    | Medium      | High        | Low            |
| Electro-Rheological Damper System | Very High | Less        | High        | Low            |
| Electromagnetic Damping system    | Medium  | Medium      | High        | High           |
| Permanent Magnets                | Medium  | Less        | Low         | Medium         |
| Hydraulic Damping System         | Low     | More        | Low         | High           |
| Eddy Current Damping system      | Medium  | Less        | Medium      | Medium         |

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