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# Analysis of Automotive Suspension System

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***Abstract*— In the advent of technology, the automotive industry is focusing more on the passenger safety and comfort. The vehicle suspension system has a vital role to play in providing the riding comfort to the passengers by isolating the cabin from various road disturbances. The suspension system is mainly categorized into three type's viz. passive suspension, semi-active suspension and active suspension. The passive suspension uses the conventional springs and dampers to absorb the road disturbances. It also provides trade-off between the ride comfort and road handling. The Semi-active suspension uses the conventional spring and externally controlled damper. In this type, the damping coefficient can be controlled based on the inputs from chassis acceleration sensor that measures the vertical acceleration at body of the vehicle. The suspension system is one of the essential part of the vehicles and it main objectives are to ensure a high quality ride comfort by isolating the vehicle body by road disturbances. To maintain good road holding ability to provide finest vehicle handling capability and to support the mass of the vehicle. An active suspension is investigated which is capable of levelling the car during cornering without consuming energy. Simulations using a full-car model show that this maximizes the car's cornering velocity. As extreme cornering may be required to remain on the road or to avoid an obstacle, implementing the active suspension system improves safety. As the active part of the suspension takes care of realizing good cornering behaviour and of static load variations, the primary suspension springs can be tuned purely for optimizing comfort and road holding. Simulations show that the required energy for levelling the car during cornering is negligible, so it can be concluded that the active suspension system is able to economically level the car.**

***Index Terms*—Automotive, Suspension System, Technology**

## I. Introduction

Vibration control can be classified in three major categories, passive, active and semi-active. Passive control is practical and cost effective; however, the performance is fixed and tuned for a particular frequency range. Passive systems have inherent Limitations in achieving broad performance objectives. On the other hand, active systems can be programmed to perform well under a variety of scenarios, but they are more expensive, require a constant power source, and can potentially destabilize a system. To achieve semi-active suspension, various types of controllable dampers can be used. Among those, magneto rheological dampers (MR) are popular devices since the damping force generated by these dampers can be quickly changed with a change in magnetic field. Other examples include electro-rheological dampers (ER), variable orifice dampers, and controllable fluid Dampers [1]. The active and semi-active suspensions have been investigated extensively in the past 40 years showing improved vehicle dynamic performances at the cost of complexity and additional energy consumption. Passive suspension system is still dominating in the automotive industry because of its simple structure, high reliability, and low cost [2]. The vehicle is equipped with independent MacPherson front suspensions and independent multi-link rear suspensions. The car floor is covered with viscoelastic material to damp floor vibrations, therefore local modes of the floor are not expected. The frame presents a glass sunroof composed of two panels. To understand how the shock absorbers affect the dynamic behavior of the first global flexible modes, the analysis is performed different configurations, so that the modal differences due to the suspension system may be highlighted [3]. To improve the vehicle performance, the controllable suspension systems (i.e. the active suspension) have been widely used due to their flexibility in improving the vehicle performance. Compared with the active type, the System becomes a favorable choice with less power consumption [4].

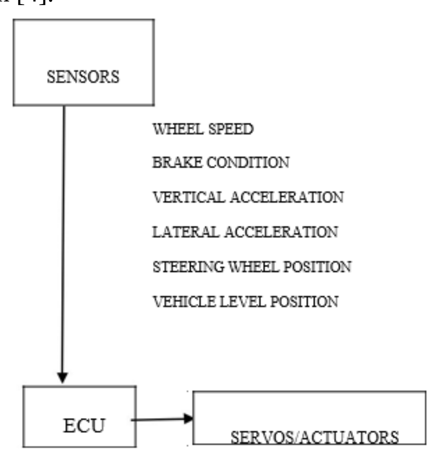

Fig. 1. Basic representation of active suspension system

In the field of structural engineering, mathematical models are utilized to predict the dynamic response of systems such as a suspension strut under different boundary and loading conditions. However, different mathematical models exist based on their governing functional relations between the model input and state output parameters. For example, the spring-damper component of a suspension strut is considered.

Its mathematical model can be represented as linear, nonlinear, axiomatic resulting in different vibrational behavior [5]. Fatigue analysis of automotive coil springs is crucial because these components are constantly exposed to dynamic loads as the vehicle travels across different terrains. Coil springs are also among the critical components in an automotive chassis because they affect passenger comfort and vehicle aerodynamics. The spring durability and vehicle ride quality Dependent on the design of the coil spring-damper pairs in order to handle different road profiles [6].

## II. Magneto-Rheological Fluid

The use of magneto-rheological (MR) fluids is widely spreading in industrial applications: car suspension, seat suspension, bridge vibration control, washing machine vibration control, and gun vibration control. MR damper has a very broad changeable damping force range under magnetic field and the damping coefficient increases with the electric current, but decreases with excitation amplitude. The MR damper will become saturated as the applied electric current reaches a certain value. Under electric current, the MR damper cannot be treated as a viscous damper, but the property of the MR damper can be described with the Bouc–Wen model [7]. A seeder main frame carrying a seed dose mechanism and two no-till seeding assemblies was developed and designed with multiple sensors to capture the dynamics of the assemblies together with the corresponding surface profile. A magneto rheological (MR) damper was implemented into one of the seeding assemblies to optimize its dynamics for better seed placement. A number of strain gauges were used to measure the dynamics of the seeding assemblies, like vertical and impact forces during seeding operation at a travelling speed of 10kmh−1[8]. According to the analysis results of kinetics, parameters of a certain automobile front suspension MR damper were got as follows: the maximum damping force is 1500N, straight distance is 150mm, adjustable ratio of damping force (the ratio of adjustable damping force and un-adjustable damping force which is adjusted by magnetic field intensity) is above 4.5, and then MR damper designed by these parameters [9]. The common approach for the controller output is the MR damper force adding the necessity of two local controllers: a controller for the force, and a controller for the current. These approaches increase the feasibility of a practical implementation given that its output is the current to apply to the MR damper coil and they leave the saturation problem out.

When compared in the frequency domain with a passive suspension, the proposed controllers improved the comfort performance without affecting the suspension deflection and road holding [10]. For a fixed suspension spring constant, the better isolation of the car body from the road disturbances can be achieved with a soft damping by allowing a larger suspension deflection. However, the better road contact can be achieved with a hard damping by not allowing unnecessary suspension deflections. Therefore, the ride quality and the handling performance of vehicle are two conflicting criteria in the control system design of suspension systems. The cost and the weight of a fully active suspension system become obstacles in medium size cars. Comparing the three, a semi-active system is simpler and uses less energy than an active system, but provides better vibration isolation capability than a passive system at the sprung mass resonance frequency. The inferior performance of a semi-active suspension than an active one comes from the fact that the control force can be generated only when the desired control force and the damping have the same direction [11]. The controllers were tested with simulations by implementing them with a nonlinear model of the suspension system. The first test consisted of a long test track input and the second test had a simpler road bump input for clearer visualization purposes. The study shows the superiority of the new controllers over the existing one. The suspension performance is improved especially at low frequencies with no increase in power consumption. Additionally, the new control structures enable an increase in suspension bandwidth if road-level measurements are utilized. Future work will include conducting performance tests in a real test bed, using parameter variation methods during design phase to improve robustness of the controllers, and utilizing gain scheduling methods to improve the performance of the suspension system in different conditions and different suspension modes [12]. To implement semi active suspension system MR (Magneto Rheological) Damper is used .The current controller is developed to vary current from 0.1A to 1A. Design of Experiment (DOE) is a systematic method to determine the relationship between factors affecting a process and output of that process [13].

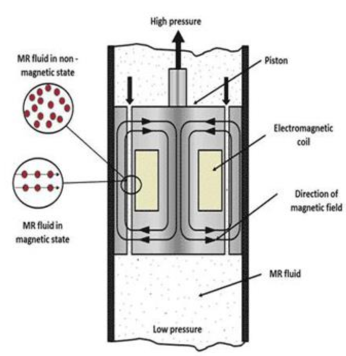


Fig. 2. Cross section of MR Damper

## III. Electromagnetic Suspension System

A levitating suspension system using only an electromagnetic actuator between the sprung and the unsprung masses may be considered. However, in this situation the actuator must provide the entire force needed to support the sprung mass weight. This problem can be solved by a spring supporting the body weight, which allows for a significant reduction in terms of the actuator dimensions. Then, the actuator is controlled in order to compensate the spring deformation force, which results in a like-levitating behaviour [14]. The system proposed uses electromagnets for regional control and help with suspension of the limb. The system consists of pressure sensors, microcontroller, and additional circuits to amplify the sensor outputs and control the amount of power to the magnets. Experimental results showed that the control system works properly and that the magnets are adequate for suspension system of the prosthetic limb. The stabilization of residual limb volume is important for comfort, reduce tissue breakdown, and improve daily function [15]. In modern engineering are increasingly put the task of designing electromechanical systems with ultra-high speed of the rotor to create a high-tech installations (compressors, air-purge, turbo generators, refrigeration units, etc.). To solve the problem of achieving ultra-high speeds (150 000 - 200 000 rpm) it is necessary to use a special bearing supports capable of operating in a given speed range. Hydrodynamic, gas-dynamic or hydrostatic bearings are most commonly used at the present time. These bearings have very low friction coefficients - is much lower than the mechanical bearings. The main source of friction is the viscosity of the liquid or gas. However, the main disadvantage of the use of such supports is complex power system and limit rapidity due to friction.

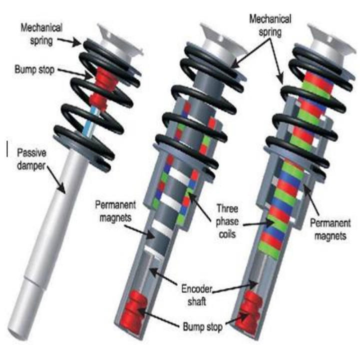


Fig. 3. Electromagnetic suspension system

As an alternative approach of systems construction of high-speed electrical machine bearing supports, completely eliminates friction and is the application of active magnetic bearings (AMB). The use of these bearings allows not only to achieve the rotor speed, but also to implement a system that does not require lubrication [16]. A novel active vehicle suspension rocker-pushrod electromagnetic actuator (EMA) that has the features of easy manufacturing and modular design. Considering the nonlinear influence of the reducer on unsprung mass and the no vertical arrangement of the spring, parameter perturbation bounds are determined through analysis. To provide drivers with more choices and driving pleasure, performance-oriented controllers are designed by frequency shaping in the sense of H1 norm, generating comfort mode, sport mode and hybrid mode respectively. Vehicle suspension performances under different modes are compared in both frequency and time domains, while the system robustness against parametric variations is verified by 81 perturbed systems. To verify the improvement of ride comfort and handling stability, a quarter-vehicle prototype is constructed. Test results show that when driving over certain bumps at speed of 1.4 m/s [17].

## IV. Active Damping System

Vibration control can be classified in three major categories, passive, active and semi-active. Passive control is practical and cost effective; however, the performance is fixed and tuned for a particular frequency range. Passive systems have inherent limitations in achieving broad performance objectives. On the other hand, active systems can be programmed to perform well under a variety of scenarios, but they are more expensive, require a constant power source, and can potentially destabilize a system [18]. To achieve semi-active suspension, various types of controllable dampers can be use, magneto rheological dampers (MR) are popular devices since the damping force generated by these dampers can be quickly changed with a change in magnetic field. Other examples include electro-rheological dampers (ER), variable orifice dampers, and controllable fluid dampers [19]. To investigate the performance of the air spring suspension over the passive suspension in terms of ride performance and road holding performance. Moreover, an extensive parametric analysis was conducted to illustrate the air spring dynamic behavior for different parameters. Based on that, a 2-DOF quarter model was developed in the MATLAB/Simulink platform for the simulation process. The parametric analysis included the air spring dimensions, air pressure, reservoir volume, and hoses dimensions. The dynamic responses including acceleration, suspension travel and dynamic tire force were then compared in the form of time and frequency domain analysis comparing with the passive suspension. The results were obtained for uneven road of Class C and driving speed of 72 km/hr. The obtained results indicated that, for the dynamic air spring model, the body acceleration, suspension travel and dynamic tire load improved by 27%, 10%, and 20%, respectively, which provides more comfort and easy handling performances than the passive suspension. The results are of interest for the researchers and vehicle manufacturers for further considerations during design and test preparation in the design of vehicle suspensions [20].

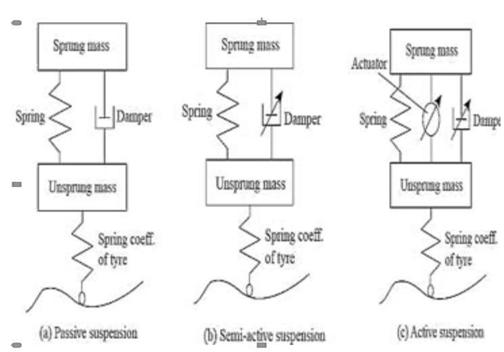


Fig. 4. Active damping system

## V. HYDRO PNEUMATIC SUSPENSION SYSTEM

Large dump trucks are being matched with large shovels to achieve bulk economic production in surface mining operations. This process results in high impact shovel loading operations (HISLO) and exposes operators to severe levels of whole-body vibrations (WBV). The performance of the hydro-pneumatic suspension struts, responsible for vibration attenuation in large dump trucks, decreases as a truck age. There is a need for a system for monitoring and predicting the performance of the suspension struts in real time. Artificial intelligence (AI) has been applied for modelling and predicting the suspension system performance for light/smaller vehicles. However, no work has been done to implement AI for modelling and predicting the performance of hydro pneumatic struts in large dump trucks [21]. Advances have been made to agricultural tractors to improve their ride comfort. However, the ride comfort of tractors is relatively low compared to that of passenger vehicles. Many researchers have developed various types of suspension for tractors. While most studies have focused on the geometry of the suspension, few studies have been carried out on the development of a control algorithm for tractor suspension. To improve the ride comfort of an agricultural tractor, hydro-pneumatic suspension model with a semi-active suspension control is developed with computer simulation, and the effectiveness of the suspension is evaluated before the vehicle is equipped with the suspension and placed into production. An optimal control algorithm for the semi-active suspension of the tractor is developed using a linear quadratic Gaussian. In the simulation, a hydro-pneumatic suspension system model is developed using Simulation X and is applied to a full vehicle model using MATLAB/Simulink. The suspension is assessed by experiments and simulations. The ride comfort using the ride comfort index according to ISO 2631 is evaluated by comparing a vehicle with a passive cab suspension to that with a hydro-pneumatic suspension applied with the semi-active control [22]. The vibration transmitted from the irregular road, powertrain and driveline strongly affects the driver's normal health during long-time travel activities In pitch plane the vertical vibration on the driver seat is affected by both the vehicle bounce and pitch motions, while the longitude vibration is predominately determined by the pitch motion. Besides, the pitch motion induces unwanted head nod which may lead to driver fatigue. Therefore, the vehicle pitch vibration control is quite significant to enhance the ride performance to the automotive industry [23]. There are some limitations on conventional suspension system, hence there is a need for a suspension system that could significantly counter the varying load problem. The system should be capable of providing the stiffness and damping which is required for a particular load or a road profile at that particular time. The un-avoidable limitations of conventional suspension system have led to the modelling and study of the hydraulic suspension system. When comparing the dynamic performances between the model with conventional springs and the model with hydro pneumatic springs under the same working conditions, the results shows the superiority of the hydro pneumatic spring over conventional [24].suspension height cannot be stable at desired height when the active suspension system follows a step input. By contraries with VSC+PID control suspension height reaches target height rapidly. The oscillation caused by friction force has been eliminated. When body reached target height the flow of orifice [25].

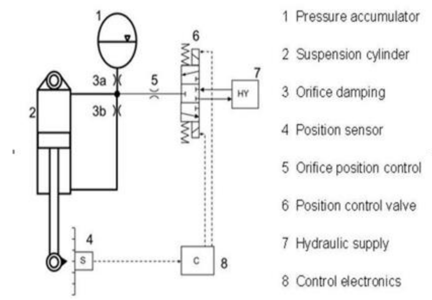


Fig. 5. Hydro pneumatic suspension power

## VI. SUSPENSION DESIGN

The comfort-oriented vehicle suspension design problem by using a skyhook inerter configuration. The skyhook inerter to virtually increase the sprung mass of a vehicle. Demonstrated that increasing the sprung mass can always improve the ride comfort performance. Semi-active skyhook inerter configuration are investigated by using semi active inverters. Three control laws, that is the on-off control, the anti-chatter on-off control, and the continuous control, are proposed for the semi-active Inerter to approximate the skyhook inerter. Numerical simulations are performed to demonstrate the effectiveness and performances of these control laws. It is shown that the semi-active realizations of the skyhook inerter by using the proposed control laws can achieve over 10% improvement compared with the traditional strut, and similar performances are obtained for these control laws, with slight differences with respect to different static stiffness of the suspension system [26]. The design of an integrated suspension tilting mechanism for narrow tilting vehicles. The challenge in the design of such suspension tilting mechanisms is to allow large suspension travels to generate sufficient tilting angles to balance the vehicle in cornering, while at the same time remain as compact as possible to save the space for passengers and cargos. Existing solutions, which are mostly based on parallel mechanisms, are not space-friendly and add extra weight to the expected compact and light-weighted urban vehicles [27]. The design of both autonomously and remotely controlled unmanned agricultural vehicles it is important to use an efficient suspension system that enables free transit over uneven terrain. Most mobile robotic systems use either a direct or inverse kinematic structural model in order to accurately determine the position of the end effectors or joints. However, this increases the complexity of the system and requires greater computational effort. In this context, the objective of this work was to investigate a new strategy that integrates the concepts of zero moment point and fuzzy logic into the control system of a wheel-legged vehicle used in agricultural field operations. The control system was able to maintain the stability and working height of the vehicle within the established standards without the need for a kinematic model, thus offering a simpler solution to the problem [28]. The kinematic parameters such as caster, camber, toe angles etc.

Dynamic analysis of the kinematic linkages gave us stiffness of the spring for a particular ground clearance (static condition). Robustness, sustainability of the components were insured from their corresponding FE analysis. Vibration or ride analysis of the design showed us the effect of damping ratio on comfort and wheel deflection and in turn gave us the optimum value of coefficient of damping. After knowing the spring damper parameters we tested our design to check body roll for a particular speed and radius of curvature. Finally using design of spring data we found the required parameters for spring design [29].The potential of the Series Active Variable Geometry Suspension (SAVGS) for comfort and road holding enhancement. The SAVGS concept introduces significant nonlinearities associated with the rotation of the mechanical link that connects chassis to spring- damper unit. Although conventional linearization implemented multi- body software packages can deal with this configuration, they produce linear models of reduced applicability. To overcome this limitation, alternative linearization approach based on energy conservation principles is proposed and successfully applied to one corner of the car, thus enabling the use of linear robust control techniques [30].

## VII. Conclusion

As tires become ever lower in profile and roads get ever worse, ride comfort is knife with two blades if a car is to have the sharp responses we like. Various active damping systems have promised an answer here, and none has been more impressive than Delphi’s Magnetised, the magneto rheological damper system used by Audi, Ferrari and few other mayor manufacturers. Current car suspension systems show the result of a very long development. Suspension systems remain very crude. Steel springs support the body, with a variety of linkages used to maintain the wheels in a helpful geometry during their movement. To prevent the springs simply oscillating once they have been deflected, dampers ("shock absorbers") are used to stop the spring continuing to bounce. As a result, there are frequent trade-offs required in the design of the suspension. For example, soft springing and little damping can gain excellent vibration isolation. However,such a system will bottom-out frequently on real world bumps. On the other hand, good shockreduction is achieved by a system with a relatively stiff, highly-damped system. And on smooth roads, the stiffer the suspension is, often the better the resulting handling but such an approach is unacceptable on cars that must negotiate bumpy roads. While active suspensions where the entire car's mass is supported by hydraulic or pneumatic rams - were once seen as the answer, the complexity, fail-safe requirements, power consumption and weight of such systems has seen their development slowed to a crawl. Magneto-rheological dampers are answer to compromise between drivability and comfort.

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