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Full Length Article

Adaptive suspension strategy for a double wishbone suspension through camber and toe optimization

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ABSTRACT

A suspension system is responsible for the safety of vehicle during its manoeuvre. It serves the dual purpose of providing stability to the vehicle while providing a comfortable ride quality to the occupants. Recent trends in suspension system have focused on improving comfort and handling of vehicles while keeping the cost, space and feasibility of manufacturing in the constraint. This paper proposes a method for improving handling characteristics of a vehicle by controlling camber and toe angle using variable length arms in an adaptive manner. In order to study the effect of dynamic characteristics of the suspension system, a simulation study has been done in this work. A quarter car physical model with double wishbone suspension geometry is modelled in SolidWorks. It is then imported and simulated using SimMechanics platform in MATLAB. The output characteristics of the passive system (without variable length arms) were validated on MSC ADAMS software. The adaptive system intends to improve vehicle handling characteristics by controlling the camber and toe angles. This is accomplished by two telescopic arms with an actuator which changes the camber and toe angle of the wheel dynamically to deliver best possible traction and manoeuvrability. Two PID controllers are employed to trigger the actuators based on the camber and toe angle from the sensors for reducing the error existing between the actual and desired value. The arms are driven by actuators in a closed loop feedback manner with help of a separate control system. Comparison between active and passive systems is carried out by analysing graphs of various parameters obtained from MATLAB simulation. From the results, it is observed that there is a reduction of 58% in the camber and 96% in toe gain. Hence, the system provides the scope of considerable adaptive strategy in controlling dynamic characteristics of the suspension system.

1. Introduction

Over the years, automobiles have been evolving continuously and went through a lot of developments. These developments are a result of advancements in technology, advanced manufacturing methods and the need to satisfy customer expectations. Technological advancements in various automobile systems has been made possible by the incorporation of numerous mechatronic systems which resulted in better performance output [1]. These include a myriad of changes from the incorporation of a basic windshield wiper to an exquisite interior with an air-conditioning and infotainment system. Apart from the physical appearance of the vehicle, an important feature people delve for is enhanced comfort and safety in vehicles. The system that is majorly responsible for a vehicles' comfort level is the suspension system. The suspension system is an integral unit responsible for maintaining the stability of a vehicle under static and dynamic conditions [2]. The suspension system plays a vital role in keeping the occupants comfortable by absorbing road shocks and vibrations and keeping the passenger cabin secluded. Without the suspension system, the vibrations and shocks would also be directly transferred to the steering, thereby making it extremely hard to control the vehicle [3]. From its introduction in horse carts in the form of iron chains and leather belts to the present form, it has

Abbreviations: KPI, King Pin Inclination; PID, Proportional Integral Derivative; FVSA, Front View Swing Arm; SLA, Short Long Arm; IC, Instantaneous Center; RC, Roll Center; RCH, Roll Center Height.

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been one of the most important systems which influenced the level of satisfaction of a consumer when he is inside the vehicle. Hence, the automotive industry strives to make efforts in improving it in every possible way. But any suspension system would face various challenges due to dynamic terrain conditions like uneven road surface, rolling, pitching, yawing, vehicle speed, load shifts and effect due to external forces like wind gusts that have always required the system to find the right balance between itself [4]. To meet these performance requirements in the conventional system there is always a compromise between ride quality and dynamic properties. If a suspension system the operating parameters are tuned for optimum dynamic conditions might be too soft and the ride quality would decrease while improving the ride quality to satisfy passengers would reduce the vehicle manoeuvrability characteristics [5]. Hence, the packaging parameters of the suspension systems such as camber, caster, toe etc. must be set-up accordingly as they are responsible for the response of the system. By varying these parameters in an adaptive manner, the dynamic characteristics of the vehicle can be varied on a real-time basis.

This lead to the development of advanced suspension systems that contain active components ranging from simple self-levelling suspensions to fully active systems. Active suspension is a type of automotive suspension that controls the vertical movement of the wheels relative to the chassis or vehicle body with an onboard data acquisition system and independent actuators. These active systems use the disturbances from the road condition/terrain as input to the electronic control unit (ECU) and the suspension system is tuned accordingly to achieve optimal performance in real time condition [6]. The advantage of active suspension system is that its performance is optimized according to the dynamic road conditions thereby enhancing manoeuvrability and comfort on a real time basis, while in passive suspension systems the behaviour of suspension system is determined entirely by the system parameters and road surface [7]. Implementation of electromagnetic controls to the suspension system gave engineers enhanced control over the vehicle dynamic characteristics [8]. Various types of active suspension systems have been employed in higher end vehicles like Delphi's active suspension or Mercedes's Magneto-Rheological fluid (MRF) technology [9]. However, these systems have high cost and are extremely complex because of the intricate technologies besides requiring very frequent maintenance. Hence, extensive research has been focused on developing active suspension systems that are economical but can adapt to dynamic road conditions. Adaptability to road conditions is achieved by varying the wheel parameters to suit the terrain and by varying them in real time, a dynamic control is achieved [10]. Among the several parameters, camber and toe angle are two important attributes that maximize lateral grip and stability to a great extent. By varying these parameters the reaction of the vehicle can be optimized to the dynamically changing terrain which has been analysed and researched by various people in the past years.

2. Literature review

Thacker et al. [11] have focused their research on suspension arm designs and proposed a design based on topology with material optimization for controlling the arms in finite element analysis to improve the performance of the system. The review work postulates camber and toe as the two important performance parameters affecting vehicle handling characteristics and also determines the camber extremities as 5.5 degrees to 5.5 degrees. Arana et al. [12] proposed a variable geometry suspension with an electro-mechanic actuator which controls the pitching of the chassis and the position of the upper-end eye of the strut system to improve suspension behaviour. The work successfully manages to reduce maximum squatting and diving angles during transients by at least 30%. Groenendijk [13] proposed an idea of active toe control based on signals from longitudinal and lateral acceleration, steering angle and yaw rate sensors in a 4-wheel individual steering control system. From the experiment, it has been concluded that toe-control improves vehicle handling behaviour and also decreases the vehicle side slip angle to achieve better dynamic behaviour of the vehicle. Shad, [14] came up with the idea of mechatronic suspension system with multiple active degrees of freedom to actively change the camber, along with active steer and suspension system to increase the vehicle's lateral forces. The work successfully improved vehicle's lateral tire force by 28% enhancing the vehicle's traction, leading to increased turning capabilities. Choudhery [15] proposed the idea of variable camber suspension system using electro-mechanical devices to sense the lateral forces acting on the vehicle, and employs the camber adjusters to provide necessary response to improve vehicle stability during turns and cornering. Pourshams et al. [16] came up with the idea of using a pneumatic system for providing the variations in camber angle of a double wishbone suspension system to improve traction and vehicle safety. The modelled system was able to adjust the camber angle from −5 to 5 degrees but their performance in dynamic conditions has not been evaluated. Esfahani et al. [17] proposed the idea of varying the camber angle using hydraulic actuators to vary the geometry of suspension system components for better traction and stability. The system was able to provide the camber adjustment of −5 to 5 degrees with a short response time for improved adaptability.

Nemeth and Gaspar [18] presented the advantages of variable geometry suspension system, analysed the relation between steering and suspension and developed a control system to modify camber angle of front wheels during manuever. A change in camber angle is achieved through LPV methods and a change in yaw rate is also induced thereby improving vehicle stability. Nguyen et al. [19] presented the application of linear parameter varying (LPV) based control system to differential brake moment and the auxiliary front wheel steering angle to change the camber angles of the wheels with 4 semi-active dampers in order to improve the tracking of the road trajectory. Nemeth et al. [20] have proposed an LPV based control design for a variable geometry suspension system to reduce the lateral force during wheel tilting and the strategy incorporates the nonlinear tire characteristics. The tilting actuation of the wheel during cornering provides the additional lateral grip required to achieve better performance during manoeuvre. Tandel et al. [21] have studied the implementation of a Proportional Integral Derivative (PID) controller on a suspension system with various combinations of spring parameters and damping constants to reduce the vertical body acceleration. It has been found that after PID implementation to control suspension parameters, the vertical body acceleration reduced by almost 50%.

From various researches, it can be inferred that the active suspension control is accomplished by varying the camber, toe and damping coefficient of suspension system on a real time basis. By means of employing an electromechanical system, it is possible to achieve active camber control which results in improved vehicle stability and traction [22]. Also, it can be concluded from various researches that active toe control helps in decreasing wheel slip rate thereby improving a vehicle's dynamic behaviour.

3. Objective of the present work

Although there are several works in the field of active suspension system, very few work has been attempted to control the suspension system through a mechatronic system involving a PID controller and linear mechanical actuators. There have been