Overview of Active Suspension System

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Abstract - *The suspension system is one of the important sub-system in vehicles. It is something which connects the vehicle to its wheels. Whether the suspension system is further classified into the three categories. i.e. Active, semi-active and passive suspension systems. These categories differentiate according to the way of its operation and control. In this paper the active suspension system is reviewed on the basis of its control-oriented models and its control approaches. The control-oriented models of the suspension system are further classified into the three categories; (a)Quarter car model, (b)Half car model, (c)Full car model, these models are well described in the paper. And the control objectives of the suspension system along with its control approaches which industry is applying currently has been discussed in this paper. The features of few control approaches are covered in the paper, which are Model Predictive Control, Active Roll Control, Predictive active suspension. Also, the control objectives of the Active suspension system are discussed*

***Key Words*: suspension system, active, semi-active, control oriented model**

1.Introduction

Suspension system is an automotive system which acts as a bridge between the vehicle occupants and the road. The advancement in the suspension system has been seen right from the carriages which were drawn by horses having leaf spring at four corners to the today's automobiles with control system. The main function of the suspension system is to transmit the forces between vehicle body and road and thus maintain ride comfort, road handling and ride safety. In order to increase vehicle performance, the suspension system is the topic which was most adored by the researchers. The vehicle suspension system is further differentiated into 3 categories: passive, semi-active & active suspensions. Passive suspension has springs and dampers in between body of vehicle and wheel-axle assembly. It has the advantage of simple mechanism, easy implementation and high reliability, but they are not adequate when it comes to improving ride comfort or road holding because of their invariant spring and damper characteristics which are unable to cope with different road conditions. Semi-Active suspension has variable dampers or springs, so that the damping coefficient or the spring stiffness can be adjusted in a given range. The energy consumption for this system is low also it is highly reliable and thus available in production vehicle in a wide range. This system shows considerable improvement over passive suspension system. As compared to these two suspension systems the active suspension requires the power to generate independent forces of the relative suspension motion. Due to their energy requirement as well as weight it have not been integrated in production vehicles, but undoubtedly, it'll be the trend of the future vehicle suspension design.

1.1 Active Suspension System

The active suspension system actively controls the vertical movement of the wheel-axle assembly through computer-controlled system. This suspension system offers smooth riding experience whereas in passive suspension system the condition of the road decides the entire movement. The active suspension provides freedom to adjust the entire suspension system and the control force here can be introduced locally as per the system state.

The active suspension came in picture more than two decades ago. The F1's racing car lotus first employed the active suspension. That time it had numerous problems such as excessive noise, vibrations, & harshness. It also had excessive power consumption issue. Its manufacturing cost was very high at initial stages so manufacturers were not sure whether to implement this in a passenger car.

An active suspension has an actuator in addition to the spring and damper. The actuator makes continuous adjustment to the suspension based on the road conditions.

The design of the active suspension system can be determined by two stages. The first stage is to construct control oriented dynamic model of a vehicle active suspension and then by choosing appropriate control strategy, which has substantial impact on the ride comfort and ride safety.

1.2 . Control oriented suspension model

Vehicle dynamic modeling is an important step in the design of suspension systems.According to the requirement of controller design, the three dynamic models: two DOF quarter-car model, four DOF half-car model, and seven DOF full-vehicle model, are often used for the theoretical analysis and design of suspension systems.

1.2.1. Quarter Car Model

The Quarter car model is most preferred when it comes to the analysis, as it deals with the vertical vehicle dynamics. The Degree of Freedom for this model is two. If the motions of the four wheels are assumed to be decoupled and the suspension dynamics are only considered in the frequency range then the quarter car model is used as it captures more important characteristics. It consists of dynamic behaviour of unsprung mass which mainly represents mass of tire, the wheel, the brake, the wheel carrier, and the parts of the suspension system and the sprung mass which represents quarter of the chassis mass, including passenger and vehicle payload connected by suspension system. However, the tire can be represented by a parallel spring and damper configuration.

$m_s z''_s = -k_s(z_s - z_u) - c_s(z'_s - z'_u) + u$

$m_u z''_t = k_s(z_s - z_u) + c_s(z'_s - z'_u) - k_u(z_u - z_r) - c_t(z'_u - z'_r) - u$

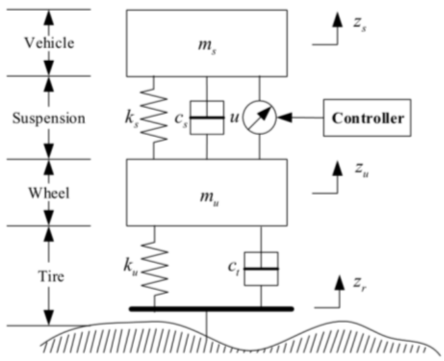

Fig.1.1 Quarter Car Model

where m_s is the quarter-car body mass; m_u is the unsprung mass (tire, wheel, brake calliper, suspension links, etc.), and g is the gravitational constant. z_s is the vertical position of the car body, z_u is the vertical position of the unsprung mass, and z_r is the vertical position of the road profile.

1.2.2. Half Car Model

The half car model can be determined when the left and right side of the car are symmetrical. As compared to the quarter car the half car model has both pitch and vertical motions thus the degree of freedom for this model four. As shown in Fig. 1.2, M and I stand for the mass of the vehicle body and mass moment of inertia for the pitch motions, respectively, and m_f, m_r are the unsprung masses of front, rear, respectively. F_{df}, F_{dr}, F_{sf} and F_{sr} denote the forces produced by the springs and dampers, respectively, and F_{tf} , F_{bf} , F_{tr}, F_{br} are the elasticity force and damping force of the tires. F_l and F_φ are friction forces of suspension components. z_c is the vertical displacement, φ represents the pitch angle, z_1, z_2 are the unsprung mass displacements and z_{o1}, z_{o2} are the road inputs to the related wheel. a, b show the distances of the suspensions to the center of mass of the vehicle body, and u_1, u_2 are the control inputs of the active suspension systems.

The ideal dynamic equations of the sprung and unsprung masses are given by:

$Mz''c = \Psi_1(t) + u_1 + u_2 + F_l,$

$I\varphi'' = \Psi_2(t) + au_1 - bu_2 + F\varphi,$

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$m_f z'1 = F_{sf} + F_{df} - F_{tf} - F_{bf} - u_1,$

$m_r z'_2 = F_{sr} + F_{dr} - F_{tr} - F_{br} - u_2$

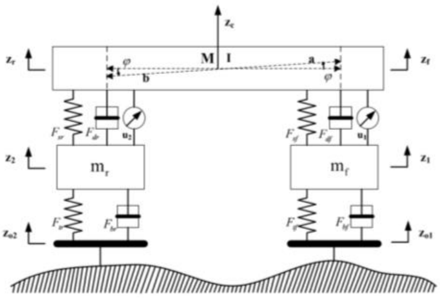

Fig.1.2 Half Car Model

1.2.3. Full Car Model

The full car model consists of a single spring mass i.e. the mass of a vehicle body connected to four sprung masses at each corner. The sprung mass is free to heave, pitch and roll motions, however the unsprung mass is free to bounce vertically w.r.t sprung mass. Due to this, the full car model has 7 degree of freedom.

In Fig. 1.3, M, I_x and I_y stand for the mass of the vehicle body, mass moment of inertia for the roll and pitch motions, respectively, and mi, are the unsprung masses of front left, front right, rear left, and rear right, respectively. F_{si} and F_{di} denote the forces produced by the spring and damper, respectively, and kti is the stiffness of the tire. For the vehicle body, z, θ and φ represent the heave, pitch and roll motions, respectively. y_i is the unsprung mass displacement and y_{oi} is the road input to the related wheel. The actuators are placed parallel to the suspension springs and dampers, and their output forces are denoted by u_i . a, b, c and d show the distances of the suspension to the center of mass of the vehicle body. V is the velocity of the vehicle in x-direction.

$z'' = -1/M \sum(F_{di} + F_{si}) + 1/M\, u_i(t),$

$\theta'' = -1/I_y\, (a(F_{di} + F_{si} - u_i(t)) - b(F_{di} + F_{si} - u_i(t))),$

$\phi'' = -1/I_x(d(F_{di} + F_{si} - u_i(t)) - c\, (F_{di} + F_{si} - u_i(t))),$

$y_i'' = 1/m_i\, \{F_{di} + F_{si} - k_{ti}(y_i - y_{oi}) - u_i(t)$

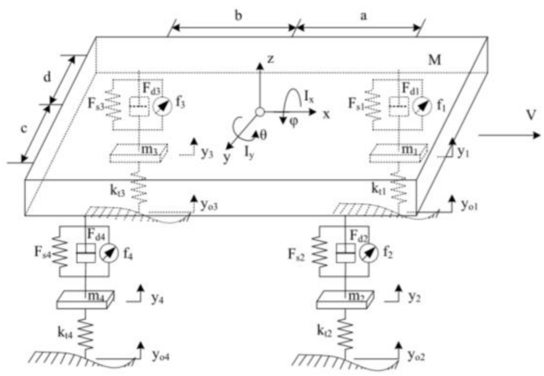

Fig.1.3 Full Car Model

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2. CONTROL OBJECTIVES OF AN ACTIVE SUSPENSION SYSTEM

The main fusnction of the vehicle suspension system is to connect vehicle body with the wheels. Thus, it is possible to carry body along the driveway and transmit forces in the horizontal plane. Moreover, vehicle suspension impacts the position of wheel relative to the road by its geometry and the spring and damping rate. To design control for a suspension system, usually we need to take the following considerations

• Ride comfort: It is well-known that ride comfort is an important performance for vehicle design, which is usually evaluated by the body acceleration in the vertical, longitudinal and lateral directions. This quality is affected by multiple factors including high frequency vibrations, body booming, body roll and pitch. Ride is perceived as most comfortable when the natural frequency is in the range of 60 to 90 cycles per minute. The perception of ride quality is degraded by virtually any disturbance experienced by the occupant. In active suspension system the ride comfort can be easily achieved as compared to the other suspension systems.

• Road holding ability: In order to ensure a firm uninterrupted contact of wheels to road, the dynamic tire load should not exceed the static ones. It can also be said as the suspension's ability to maintain directional stability over variety of road surfaces.

• Maximum suspension deflection: Because of the constraint of mechanical structure, the maximum allowable suspension strokes have to be taken into consideration to prevent excessive suspension bottoming, which can possibly result in deterioration of ride comfort and even structural damage.

3. CONTROLLERS IN ACTIVE SUSPENSION SYSTEM

The essential function of the vehicle suspension is to connect the vehicle body with the wheels. Thereby it is possible to carry the body along the drive way and to transmit forces in the horizontal plane. The suspension gives the wheel a primary vertically aligned movement possibility. As a result, the wheel follows a route with uneven road surfaces to a certain extent. By using spring and damping elements, the resulting body movements are reduced and driving safety and comfort are ensured. Furthermore, the vehicle suspension influences the position of the wheel relative to the road by its geometry and the spring and damping rate. This allows a systematic influence on the dynamic driving characteristics of the vehicle. The adjustment of these characteristics takes up a compromise, because the requirements of a good driving behavior and a high comfort are the most time inconsistent with one another. Therefore, in designing the control law for a suspension system, usually we need to take the following aspects into consideration.

1. Model Predictive Control (MPC): The working of the active suspension and passive suspension is completely different. Active suspension is able to change the dynamic of suspension by transmitting the force to the system. MPC can be said as the advanced optimal control strategy. The optimality criteria can be achieved by optimal control strategy. As we know, the quality of ride depends on the acceleration and frequency of vibration to which the passenger is exposed. With MPC the change of oscillation can be observed as it reduces drastically in a sprung and un sprung mass.

2. *Active roll control (ARC):* The active roll system comes under the electronically controlled active suspension system. Active roll control mainly focuses on vehicle rollover prevention instead of complete body roll elimination. The ARC improves the comfort feeling of the passenger by reducing the roll angles by small values.

3. *Predictive active control* : The predictive active control is also an electromechanical suspension system. Unlike ARC it can actuate each wheel individually. There are compact electric motors located at each of the wheels. This controls system operates highly efficiently. Its average power consumption is low as compared to the hydraulic systems. It also offers a feature called transverse force reduction.
It can reduce the forces acting on the human body.

4. CONCLUSIONS

An active suspension system has the capability to adjust itself continuously to changing road conditions. The suspension system is designed on the base of the model. The major benefit of the model is for the active suspension as it becomes easy to design the controller for it.

The controllers are designed for the active suspension system as well as semi-active suspension systems. The active suspension system works by constantly sensing changes in the road surface and feeding this information via controller to outlying components. These components then act upon the system to modify its character by adjusting shock stiffness, spring rate, etc. to improve ride performance, drive ability, etc.

Many control approaches are there in active suspension system.

The active suspension, thus is beneficial for increasing the vehicle's maximum suspension deflection and performance. Hence, resulting in ride comfort. Thus we can say that as a critical component of transportation vehicles, active suspension systems are instrumental in improvement of ride comfort.

For improvement of ride quality the controllers are used. By comparing these three controllers the Predictive active control is most suitable type of a controller for the better ride quality. It has Immense spectrum i.e maximum comfort.

The progression in this technology field warrants analysis of possibility enforcing the available suspension system with electromagnetic actuators to increase performance without raising cost and energy consumptions.

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