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An Overview of Disarray in Nonlinear Active Suspension System under Random Road Excitation with Time Delay

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ABSTRACT:

Since the vehicle dynamics is concerned with controllability and stability of vehicle, it is important in design of a ground vehicle. The modeling of the vehicle with the analysis of the dynamic response of the mathematical model have been examined in a large number of investigations. In this paper overview of various works are done. This paper tries to give an idea about the previous researches & their finding about study of nonlinearity of active suspension system parameters by considering half car model. Some times help of quarter car model is taken for more detail understanding of system behavior.

Keywords – **Active suspension, Chaos and Bifurcation, Random road excitation, Time delay.**

I. INTRODUCTION

A passive suspension system (PSS) is designed to preserve two desired aims which are vehicle handling and passenger comfort. A design problem is to provide a trade off between the both aims which are opposite to one another. The PSS cannot adapt itself in the face of wide changes in road conditions. However, this can be accomplished by controlling vertical acceleration of a vehicle using an active suspension system (ASS). It comprises a force generating actuator placed between sprung and unsprung mass.

During the design of a suspension system, a number of conflicting requirements has to be met. The suspension setup has to ensure a comfortable ride and good cornering characteristics at the same time. Also, optimal contact between wheels and road surface is needed in various driving conditions in order to maximize safety. Instead of a passive suspension, in most of today's cars, an active suspension can be used in order to better resolve the trade-off between these conflicts. However, this is generally accompanied by considerable energy consumption. In this paper literature on an active suspension is discussed. Since the disturbance from the road may induce uncomfortable shake and noise in the vehicle body, it is important to study the vibrations of the vehicle. Many studies have been carried out on the dynamic response and the vibration control with linear mechanical model. However, an automobile is a nonlinear system in practice because it consists of suspensions, tires and other components that have nonlinear properties. Therefore, the chaotic response may appear as the vehicle moves over a bumpy road.

By considering all above facts, this paper tries to cover literature which deals with an active suspension system with half car model by considering suspension nonlinearities and time delay parameter. Some times in this paper reference of quarter car model for above situation is considered to elaborate the concept in simple manner.

II. SLIDING MODE CONTROLLER FOR VEHICLE ACTIVE SUSPENSION SYSTEM

C Kim & P I Ro in year 1998 studied the *Sliding mode controller for vehicle active suspension system with nonlinearities* in this paper he investigated the control of an active suspension system using quarter car model. Due to nonlinearities in the real suspension system it is very difficult to achieve desired performance of suspension system. To ensure the robustness for wide rane of operating conditions a sliding mode controller was designed based on Sliding Mode theory and compared with existing nonlinear adaptive control scheme. With simulation results it was shown that both ride quality & handling performance are improved using SM active suspension system in the preference of nonlinearities of suspension system and uncertainties of suspension parameters. The simulation results of SM controller scheme then compared with Self Turning Control (STC) scheme which was developed to deal with nonlinearities of suspension system. Simulation results shows that the both controller can improve the ride quality where as only SM active suspension system shows robust tracking performance even when suspension parameters changed suddenly.[1]

III. STOCHASTIC OPTIMAL PREVIEW CONTROL

In the year 2003 Javad Marzbarad, Goodarz Ahmadi, Hassan Zohoor, Yousef Hojjat made study on *Stochastic optimal preview control of vehicle suspension on random road*. The road roughness height is modeled as a filtered white noise stochastic process and a four-degree-of-freedom half-car model is used in the analysis. The suspension system is optimized by minimizing the performance index containing the mean-square values of body accelerations (including effects of heave and pitch), tire deflections and front and rear suspension rattle spaces. The effect of delay between front and rear wheels is included in the analysis. Responses of a vehicle suspension with active, active and time delay, and active and preview control systems to random road input are evaluated and the results are compared with those for the passive system. Road surface elevation information at distance ahead of the bumper is used as preview and the suspension space velocities are measured by sensors in a noisy environment. Stochastic optimal control theory is used and the states are estimated by an observer, similar to a Kalman filter. It is recognized that the actuator dynamics affects the active control system performance with or without the preview. In manuscript they have shown that the preview information improves the control system performance. One advantage of the preview control approach is that it can compensate for the time delays in the reactions of the system and the actuators; however, interactions of the actuation system with the suspension are not considered. For optimal priview control formulation they considered theorem that is given a system with state equation and preview time *tp*, that is with $w(\sigma)$, $\sigma\varepsilon[t+tp]$ known, the problem is to find a control law $u(t)=f(x(t), w(\sigma), \sigma\varepsilon[t+tp]\ )$ that minimizes the quadratic performance of index. [2]

IV. CHAOS AND BIFURCATIONS IN A NONLINEAR VEHICLE MODEL

Also Q. Zhu and M Ishitobi in 2003 had studied the *Chaos and bifurcations in a nonlinear vehicle model* for their study of chaotic responses and bifurcations of a four-degree-of-freedom vehicle model that is subjected to two sinusoidas disturbances with time delay are studied through numerical simulation. They found that the chaotic response may appear in the instable region of frequency-response diagram. The bifurcation diagram shows that the chaotic response could be sensitive to variation of damping of the suspension. To identify the chaotic motion of the system, dominant laypunov exponent is used. Although the mechanical model of the vehicle is only a simplified one and the parameters used do not agree closely with the practical data for an automobile, the results may still be useful in dynamic design of the ground vehicle.[3]

V. CONTROL OF RANDOM RESPONSE OF A HALF-CAR VEHICLE MODEL

In 2007 L.V.V. Gopala Rao, S. Narayanan *Preview control of random response of a half-car vehicle model traversing rough road* an active control of response of a four degree-of-freedom (dof) half-car model traversing at constant velocity a random road with look ahead preview is considered. The suspension spring is assumed to be hysteretic nonlinear and modeled by the Bouc–Wen model. The statistical linearization technique is used to derive an equivalent linear model. The response of the vehicle is optimized with respect to suspension stroke, road holding and control force. The RMS values of the suspension stroke, road holding and control forces are computed using the spectral decomposition method. The results for the equivalent linear model obtained by the spectral decomposition method are verified using Monte Carlo Simulation (MCS). And come to the result that the overall performance of the vehicle improves with preview control as compared to the performance without preview control. But the improvement with performance saturates beyond a preview distance. The equivalent linearization model and the equivalent step road input assumption are validated by MCS by generating the road input compatible with the power spectral density function and numerically integrating the equations of motion with the nonlinear Bouc–Wen model. [4]

VI. H∞ CONTROL OF ACTIVE SUSPENSION FOR A HALF CAR MODEL

In 2008 H Du and N Zahang presented work on *Constrained H∞ control of active suspension for a half-car model with a time delay in control.* The time delay for the control input is assumed to be

uncertain time invariant within a known constant bound.
Active half car model which is considered for study is shown in Fig1.

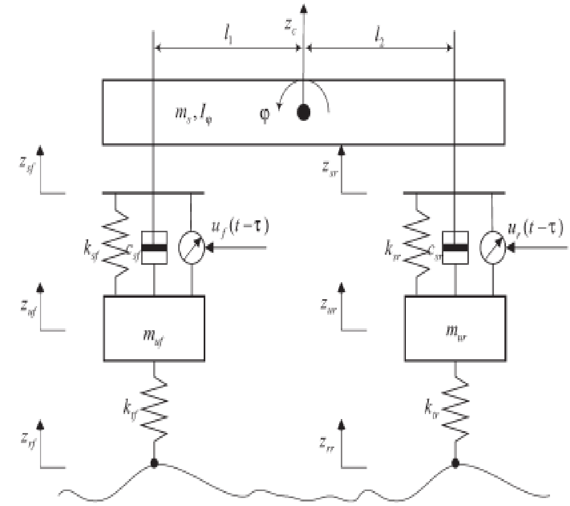

Fig 1: Active half car model

The ride comfort performance of the suspension system is optimized by using the H∞ norm to measure the body accelerations (including both the heaving and the pitching motions) , while the tire deflections and the suspension rattle spaces are constrained by their peak response values in time domain using the generalized H2 (GH_2) norm (energy-to-peak) performance.
Then, a constrained delay-dependent H∞ state feedback controller is designed to realize the ride comfort, road holding and stroke limitation performance to prescribed level in spite of the existence of a time delay in control input. And finds that the designed controller can keep the stability of the closed-loop system while improving the performance on ride comfort, keeping suspension strokes within given bounds, and ensuring firm contact of wheels to road even with the existence of a time delay in the control input to some extent.[5]

VII. Impedance Control of an Active Suspension System

In the same year 2008 Mohammad Mehdi Fateh and Seyed Sina Alavi worked on the *Impedance control of an active suspension system.* They developed novel control system to control dynamic behavior of a vehicle subject to road disturbances. The novelty of their work was to apply the impedance control on an active vehicle suspension system operated by a hydraulic actuator. A relation between the passenger comfort and vehicle handling is derived using the impedance parameters. The impedance control law is simple, free of model and can be applied for a broad range of road conditions including a flat road. Impedance control is achieved through two interior loops which are force control of the actuator by feedback linearization and fuzzy control loop to track a desired body displacement provided by the impedance rule. The system stability is analyzed. A quarter-car model of suspension system and a nonlinear model of hydraulic actuator are used to simulate the control system.The simulation results were presented to show the performance of control system by comparing the ASS and the PSS. Based on the simulation, they concluded that the impedance control of ASS was performed well preferred to PSS. In comparison with model based control laws such as optimal control law, the Ipedance Rule (IR) shows important advantages [6].

VIII. Bifurcation, Chaos and Chaotic Control of Vehicle Suspension

Again in 2008 Yung sheng, Guang-qiang, Xian-jie Meng made study on *bifurcation, chaos and chaotic control of vehicle suspension with nonlinearities under road excitation* they obtained mathematical model for nonlinear suspension model from actual measured data of car by applying it to simulate the nonlinear spring force and damping force of vehicle suspension system. Model used for analysis is shown in Fig. 2

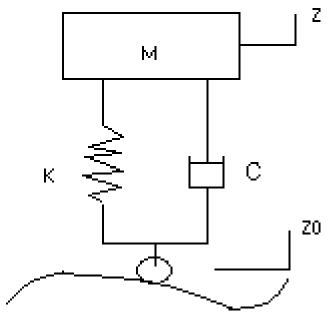

Fig2: Quarter Car Single DOF Model

A dynamic equation of quarter suspension system with s.d.f. is derived. The theory of nonlinear vibration is applied to study the nonlinear model and to reveal its nonlinear vibration characteristics. The bifurcation behavior is analyzed by using central manifold theorem through the way of phase trace, Poincare map, time history, power spectrum diagram and laypunov exponent & response under road stochastic excitation is obtained by computer simulation. After simulation it is revealed that the chaos is occurred in nonlinear suspension system.[7]

IX. CONCLUSION

By the literature review it is seen that compare with passive suspension system active suspension system can give the better handling & road holding characteristics. In earlier recherchés linear parameters of suspensions were considered but in practice the suspension parameters behaves nonlinear characteristic. So it is important to consider the nonlinearities of suspension system while designing the suspension system. This behavior of suspensions system is studied with half car model for better understanding of nonlinearities of suspension parameter because it can elaborate more detail than that of the study quarter car model.

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