Design of Variable Adaptive Suspension – A Review

Anbu.G, Ajith H, Ezhilan V, Magesh Gowtham T, Pradeep L, Sathish Bharathi M

Abstract: The design of adaptive suspension system for ride comfort and performance is discussed .The drawbacks of various suspension system and methods to overcome them are listed along with various material which have desirable characteristics are describe in brief .Section are devoted for describing road surfaces, modeling vehicle and setting of performance criteria .The active, passive and slow adaption of variable stiffness suspension are compared for optimal performance and comfort.

Keywords: modeling vehicle.

I. INTRODUCTION

Suspension system in automobile plays a major role in vehicle design. It improves the stability of the vehicle, ride comfort, reduce vibrations and shocks due to various road conditions, and avoid rolling of chassis in cornering due to speeding and also mainly to withstand the forces caused by braking and acceleration of the vehicle. Normally, based on the comfort needs suspensions are designed and classified. Namely active, semi-active, adaptive and passive suspensions. These suspension systems use different methods like varying damping coefficient, stiffness, suspension travel to design. In active suspension, vertical movement of chassis to wheel is controlled and varied. Damping coefficient values determines the materials ability to return back the applied energy and its oscillatory motion to reduce the applied energy. By implementing this concept in designing suspension system, a new type of suspension is developed namely semi-active and adaptive.

Stiffness and damping coefficient of the suspension determines whether it is soft, hard or variable tuning. Time response for the force applied also determines the suspension usage. Semi-active suspension have very low timing response compared to adaptive suspension as they have various damping coefficient values ,while adaptive have only few damping coefficient values which reduces its usage only to comfort, normal, sports, heavy loads.

Revised Manuscript Received on March 08, 2019.

Anbu.G, Department of Automobile engineering, Karpagam college of Engineering, Coimbatore, Tamilnadu

Ajith H, Department of Automobile engineering, Karpagam college of Engineering, Coimbatore, Tamilnadu

Ezhilan V, Department of Automobile engineering, Karpagam college of Engineering, Coimbatore, Tamilnadu

Magesh Gowtham T, Department of Automobile engineering, Karpagam college of Engineering, Coimbatore, Tamilnadu

Pradeep L, Department of Automobile engineering, Karpagam college of Engineering, Coimbatore, Tamilnadu

Sathish Bharathi M, Department of Automobile engineering, Karpagam college of Engineering, Coimbatore, Tamilnadu

II. ACTIVE SUSPENSION

A. HAĆ have proposed that the active suspension system optimization problems is solved using linear quadratic optimal control theory in which white noise disturbance assumptions are made, where structure, parameters and others required things are fixed. But during driving all the variables will vary according to the road conditions and load applied. Therefore, this method can't be used for optimization purpose. The important parameters like road condition and vehicle velocity should be taken in account [13]. An iterative method is used due to the variance in the parameters of suspension system and tyre deflection, to calculate control gain matrix. The purpose of the paper is to show the potential of adaptive suspensions in comparison to other proposed systems [13]

R. S. Sharp & S. A. Hassan have studied the varying velocity of the vehicle, the passengers dis-comfort, suspension travel length and tyre dynamics are calculated for different suspension stiffness and damping coefficient values [14]. Designing of passive suspension system is easily done as the parameters were made constant and didn't taken account for various velocity and load conditions. To overcome those problems pneumatic or hydraulic damping coefficient controller was introduced. But it doesn't provide the required comfort and load withstanding. Therefore to overcome those troubles a variable stiffness suspension with varying damping parameters in three different vehicle velocity is considered along with different road conditions. Thus increasing the ride comfort to maximum of 30% under rough road conditions [14].

W. Sun et al The performance characteristics of active suspensions has been improved time to time using various methods mainly focused on its normal parameters like its deflection, ride comfort, actuator saturation, road holding ability. In this, varying a single parameter affects others in greater way. Therefore to over-come this, finite frequency control method was discussed in this paper with time domain constraints also guaranteed in the framework of linear matrix inequality optimization [3]. By using "Kalman-Yakubovich-Popov (KPY)" varying the finite frequency, the other parameters were improved compared to other methods [3].

G.Priyandoko et al have used Skyhook and adaptive neuro active force control system was implemented in a semi active suspension system to separate the unwanted vibrations and forces in both the suspension spring and damper system [6].

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

A Levenberg-Marquardt learning algorithm was used in looping system to estimate mass and inverse dynamics of the pneumatic actuator in the AFC loop [6]. This improves the tyre and wheel deformation by increasing the stability of vehicle body over bumps. In active suspension actuators were used to change mode during the driving, where as in passive a fixed suspension system is used where only one set of actuations is obtained. In both cases, unwanted or over vibrations travelling affects the stability of the vehicle body or actuation time of the coils [6]

M. Sunwoo et al conducted preliminary feasibility Model reference adaptive Control is a computer algorithm developed to independently tune the active suspension to reduce the varying load conditions and vibration of the vehicle to ideal condition, thus improving the characteristics of active suspension. The implementation have not yet done. Real time simulation and animation software was used to visualize and to understand its working [11]. This type of system can be adjusted based on the sprung load and road conditions by making changes in the computer code (algorithm). The performance characteristics was improved by 50 %. To run it in real world, further studies and experiments has to be done to examine its limitations, tyre dynamics on quarter, half and full car models. [11]

III. ADAPTIVE SUSPENSION

D. Karnopp and D. Margolis studied and given different methods by which adaptive suspension can be achieved **.**The adaptive suspension system can be achieved in many way but fully optimized system is very hard to achieve as the vehicles don't operate in a single well defined roadway input. The suspension system is rarely optimized for real world inputs. The usage of adjustable dampers is easy but not optimized .The usage of variable stiffness suspension can be optimized better but the spring stiffness and dampers cant it adjusted simultaneously and rapidly it will require high power since it is impractical to recover stored energy from the spring but slow adaptation and switching of variable stiffness suspensions requires less power and signals like braking angular velocity of steering wheel to maneuver can be detected and stiffen the suspension immediately. [8]

Ian Fialho et al presents a novel approach to the design of road adaptive active suspensions via a combination of nonlinear back stepping techniques and linear parameter-varying control to achieve the desired nonlinear response of the vehicle suspension. For designing, two levels of adaptation are considered: The higher level design involves adaptive switching between these different nonlinear characteristics based on the road condition, while the lower level control design shapes the nonlinear characteristics of the vehicle suspension as a function road conditions,. They have provided the framework for road adaptive suspension controllers[25]

L. M. Jugulkar et al, designed a suspension system with variable stiffness and damping properties they have arrived at the design consideration with help of the quarter car model .The numerical model was created with MATLAB Simscape. They also fabricated a working prototype and various testing's have been done .The prototype has two helical springs with a variable fluid damper. Intensity of fluid damper is changed in four different diameters to gain variable stiffness for the prototype. Quarter car model was used for simulation to quantify the passenger comfort and vehicle handling evaluation for varying load conditions. Simulation results shows that the proposed model shows 15% improvement in acceleration transmissibility and tyre discomfort, in comparison to conventional fluid passive shock absorber. [12]

C Kim and P I Ro discussed the linear suspension system only has a defined set of parameters only for certain conditions. Therefore to develop or to apply the developed system, a nonlinear suspension systems is take in to account. Here robustness of the system is increased by implementing a sliding mode controller in active suspension system. For the controller a modified skyhook damper system is used for reference, which makes the whole process simple and outputs in improved ride quality and vehicle handling performance [7]. The non-linear suspension system with sliding mode controller shows a quick recovering actions compared with linear suspension system with normal controllers. [7]

P. L. Walsh et al has designed and investigated an adaptable vibration absorber. The objectives of the absorber are to minimize transient vibrations of rotating machines during startup and shut-down conditions, and to adapt to changes in steady state operating speeds such as might occur in engines and pumps during varying load conditions. The model on which the design was based is a single-degree-of-freedom main system consisting of variable stiffness but with constant mass, stiffness and damping ratio, and an absorber consisting of constant mass and damping ratio. Numerical integration was used to find system responses. A variable stiffness spring design is investigated, and is shown to provide a sufficient range of stiffness variation to yield the previously mentioned improvements. [22]

IV. VARIABLE PARAMETERS

G.Z. YAO et al have studied the characteristics of MR dampers. Both the advantages of active and passive suspension can be achieved with the help of semi active suspension since its economical and does not needs high power to operate it overcomes the disadvantages of both active and passive suspension system. The damping factor of MR damper is increased by the application of external magnetic field which is produced by a electromagnet which can be varied continuously by changing the current and thereby enabling continuously varying damping of the MR damper .Testing have been done with the help of "INSTRON TEST machine" which uses a load cell and displacement sensors to monitor the forces and displacement of suspension system . After certain limit the increase in current does not increases the damping factor of suspension this helps the suspension to function under that rated current thereby reducing power requirement. The test results have illustrated the benifitis of a semi active suspension system [5].

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

YANQING LIU et al proposed a new configuration of using two controlled dampers and two constant springs. This paper presents theoretical and experimental analysis of the proposed system.

To control the system stiffness, a voigt element and a spring in series are used. It is experimentally implemented using two magnetorheological fluid dampers for the controllable dampers. Eight different control schemes involving soft suspension, stiff suspensions with low and high damping, damping on-off(soft and stiff),stiffness on-off, and damping and stiffness on-off control are explored. The time and frequency responses of the system to sinusoidal, impulse and random excitations show that variable stiffness and damping control can be realized by the proposed system. [19]

Junjiro Onoda investigated the concept of active vibration suppression, by varying the stiffness of a new type of variable –stiffness structural member. The characteristics of this type of variable-stiffness system is shown to be different from previously studied types. The active vibration suppression with this type of variable-stiffness member is shown to be always stable. A theoretical investigation on a single-degree-of-freedom system shows potential high efficiency for this type of variable-stiffness system due to its unique hysteretic characteristics. Two different types of control logic are proposed for realistic multi-degree-of-freedom structures with multiple variable stiffness members. [20]

J. A.Tamboli et al has done the response analysis for Mean Square Acceleration Response (MSAR) has been carried out by considering the power spectral density (PSD) of the actual road excitation has been found to follow an approximately exponentially decreasing curve.Also the change in vehicle velocity has a significant effect on thevalues of Root Mean Square Acceleration Response (RMSAR). Therefore, in this Work, to account for the effect of the actual PSD of road excitation and the frequent changes in vehicle velocity, the RMSAR of a vehicle dynamic system subjected to actual random road excitations. [21]

Miao Yua et al, presents vibration control responses of a controllable Magnetorheological (MR) suspension system of a passenger car. The MR damper is designed and manufactured based on the mixed-mode operation, and its time response is experimentally evaluated to integrate with the suspension model.,A human simulated intelligent control (HSIC) scheme is developed to attenuate unwanted vibrations such as pitch angle acceleration after formulating the dynamic model of a half-car MR suspension system. The road test of the passenger car installed with four MR dampers is undertaken after verifying the effectiveness of the HSIC via computer simulation. The power spectrum densities of dynamic motions such as body acceleration and pitch angle acceleration are measured and analysed. [23]

V. CONTROLLERS

D. Fischer et al have proposed algorithm to control the fault diagnosis of active suspension systems. Body accelerometers and various sensors are used in parameter estimation to obtain the various unknown parameters required for fault diagnosis. The information processing from the data obtained from the sensors integrated into the system is used to estimate the various parameter which cannot be predetermined .Testing have been done in real time driving and test rigs and estimated the model based fault detection system. From the results it is determined that both driving comfort and vibration isolation of the vehicle is considerably improved by the usage of variable damper or springs. [24]

Xubin song et al, Semi active damper with skyhook controls have been studied and used in vehicle suspension system for a long time they have developed an algorithm using various analytical and experimental methods to improve the vibration isolation performance of semi active suspension to match that of the active suspension. This algorithm is based on MR damper but they can also be used for other damper tuning systems.[9]

Weichao sun et al proposed the used of “adaptive backstepping control strategy” in a half car model to stabilize the vertical and pitching motion of the vehicle and improve ride comfort .The lateral movements of the system in neglected so only the pitching motion of the vehicle is considered. Using a design example the effectiveness of the proposed model is tested and the results shows considerable improvements in ride comfort and stabilization.[10]

H. Gao et al have proposed a “Load-dependent controller design” which is to be used in active suspension system to meet high performance requirements this have shown to improve various aspects like ride comfort, road holding ability etc. The multiple objective controls requied for the active suspension is achieved with the help of load dependent controller. The real time information form body mass and its distribution is used to determine the gain matrix. The different advantages of the proposed system are demonstrated with the helps of various simulations[4]

VI. MATERIALS

B.S. Chang et al The authors have developed a new “mechanically triggered stiffness tuning composite material“ which can used to change its stiffness without any external stimuli i.e. the composite is mechanically triggered and needs no extra energy to induce a state change by the use of irreversible phase change and thermodynamic relaxation. They have used a meta stable liquid metal core shells to induce self-healing and self-strengthening behaviour the stiffness change can be targeted selectively and 50 times the materials weight can be supported with the material and the young’s modulus have shown to increase by a very large degree. Its can be used in avariety of application like sensors and robotics etc.[17]

H.P. Monner have studied various commercially available smart materials and newly emerging smart materials mainly required in the field of active noise cancelation and vibration isolation for both sensor and actuator purposes. The fundamental characteristics various smart materials like piezo-electric crystals piezo-electric polymers, shape memory alloys etc. he have also discussed the emerging

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

smarts material which can be used to bring big changes in materials like different electro active polymers and their advantages and limitations.[15]

A.M. Albaneseet al developer a “Unconstrained Magneto Rheological Elastomers” (MRE) which can be used to change its own stiffness by elastomeric deformation upon action of a external magnetic field. They are created by low carbon steel threads (Ferro magnetic) along with nonmagnetic thread to form a smart fabric .The change in stiffness observed in the fabric is due to both the geometric effects and magnetic effect of the MRE. The change in stiffness and natural frequency can be done either instantaneously or continuously varied. The magnetic component of the stiffening behaviour is studied. [16]

B.E. Schubert have created a new material which is a combination of “Low melting point alloy(LMPA) under soft stretchable encapsulated layer polydimethyl siloxane (PDMS)”.which can be used to transition between rigid and soft states by controlling the phase changing behaviour of the LMPA with joules heating effect and changing the LMPA micro structure. This change in microstructure brings a change in the net effective stiffness of the material .The base stiffness is majorly defined by the properties of the PDMS enclosure and increase in stiffness is due to the phase change i.e. solidification of the LMPA in the tracks inside PDMS enclosure. Thestiffness increase can be in range of 25 times to a 1000 times this is achieved by changing the percentage of LMPA in the material. Different failure modes of the material have been studied both in solid and liquid phase of LMPA. [18]

VII. CONCLUSION

The various methods of achieving active suspension system controls and adaptive systems are listed along with the various strategies followed to achieve vibration isolation and methods followed to design the different types of controllers like skyhook and other controllers and their advantages, disadvantages and methods used to overcome disadvantages and alternate approach to the same problem producing the same desirable output without the said disadvantages. Various methods to achieve adaptive ,active suspension system with optimal performance compared with passive suspension is mentioned. The different smart materials that can be used to achieve variable stiffness are also discussed and their main advantage being highly tunable stiffness at really short response time. They can be used in addition to conventional materials to support them to achieve variable stiffness.

REFERENCE

1. N Lavanya, P Sampath Rao, M Pramod Reddy, Design and Analysis of A Suspension Coil Spring For Automotive Vehicle ISSN : 2248-9622, Vol. 4, Issue 9(Version 5), September 2014, pp.151-157
2. R. S. SHARP a & D. A. CROLLA ,Road Vehicle Suspension System Design - a review Department of Mechanical Engineering, University of Leeds, Leeds, LS2 9JT, U.K Published online: 27 Jul 2007
3. Weichao Sun, Huijun Gao, Okyay Kaynak, Finite Frequency Control for Vehicle Active Suspension Systems, IEEE Transactions on control systems technology, Vol. 19, no. 2, march 2011
4. Huijun Gao, James Lam, Changhong wang, Multi-Objective Control of Vehicle active suspension systems via Load dependent controllers, Journals of Sound and Vibration 290(2006) 654-675
5. G Z Yao , F F Yap, G Chen, W H Li, S H Yeo, MR damper and its application for semi-active control of vehicle suspension system, Mechatronics 12 (2002) 963–973
6. G Priyandoko, M Mailah, H Jamaluddin ,Vehicle active suspension system using skyhook adaptive neuro active force control, Mechanical Systems and Signal Processing 23 (2009) 855–868
7. C Kim, P I Ro, A sliding mode controller for vehicle active suspension systems with non-linearities, Proc Instn Mech engrs Vol 212 part D, Jan 24, 2015
8. Dean Karnopp, Donald Margolis, Adaptive Suspension Concepts for Road Vehicles, Vehicle System Dynamics, 13 (1984). pp. 145-1150
9. Xubin Song, Mehdi Ahmadian, Steve Southward, Lane R. Miller, An Adaptive Semiactive Control, Algorithm for Magneto rheological Suspension Systems, Journal of Vibration and Acoustics**,** OCTOBER 2005, Vol. 127 / 493-502
10. Weichao Sun, Huijun Gao, Okyay Kaynak, Adaptive Backstepping Control for Active Suspension Systems With Hard Constraint IEEE/ASME Transactions on Mechatronics, Vol 18, No. 3, June 2013
11. Myoungho Sunwoo, Ka C Cheok, N. J. Huang , Model Reference Adaptive Control for Vehicle Active Suspension Systems ,IEEE Transactions on Industrial Electronics, Vol. 38, No. 3, June 1991 ,217
12. Lalitkumar Maikulal Jugulkar, Shankar Singh, Suresh Maruti Sawant, Analysis of suspension with variable stiffness and variable damping force for automotive aplicationsAdvances in Mechanical Engineering 2016, Vol. 8(5) 1–1
13. A Hac, Adaptive Control of Vehicle Suspension, Vehicle System Dynamics, 16(1987), pp.57-74
14. R S Sharp ,A Hassan , An Evaluation of passive Automotive Suspension Systems with Variable Stiffness and Damping Parameters, Vehicle System Dynamics, 15 (1986). pp. 335-350
15. H P Monner, Smart materials for active noise and vibration reduction,Keynote Paper Novem – Noise and Vibration: Emerging Methods, Saint-Raphaël, France, 18-21 April 2005
16. Anne-Marie Albanese, Kenneth A Cunefare, Smart fabric adaptive stiffness for active vibration absorbers Vol-5383, 490-497, Jan 2015
17. Boyce S. Chang, Ravi Tutika, Joel Cutinho, Stephanie Oyola-Reynoso, Jiahao Chen, Michael D. Bartlett, Martin M. Thuo, Mechanically triggered composite stiffness tuning through thermodynamic relaxation (ST3R),The Royal Society of Chemistry, Volume 5,Number 3,May 2018,Pages 416-422
18. Bryan E Schubert, Dario Floreano, Variable stiffness material based on rigid low-melting-point-alloy micro structures embedded in soft poly (dimethylsiloxane) (PDMS)
19. Yanqing Liu, Hiroshi Matsuhisa, Hideo Utsuno, Semi-active Vibration isolation system with variable stiffness and damping control, Journal of sound and Vibration,313,(2008) ,16-28
20. Junjiro Onoda,Takao Endo, Hidehiko Tamaoki, Naoyuki Watanabe, Vibration Suppression by Variable-Stiffness Members, AIAA Journal, Vol.29, No 6, June 1991
21. J A Tamboli, S G Joshi, Optimum Design of a Passive Suspension system of a vehicle subjected to Actual random Road Excitations, Journal of Sound and Vibration, (1999), 219(2) 193-205
22. P L Walsh , J S Lamancusa, A Variable Stiffness Vibration Absorber for Minimization of Transient Vibrations, Journal of Sound and Vibration, (1992), 158(2), 195-211
23. Mia Yu, X M Dong, S B Choi, C R Liao, Human simulated intelligent control of Vehicle suspension system with MR dampers, Journal of Sound and Vibration, 319, (2009), 753-767
24. D. Fischer, R. Isermann Mechatronic semi active and active vehicle suspensions, Control Engineering Practice 12 (2004) 1353–136
25. Ian Fialho and Gary J. Road Adaptive Active Suspension Design Using Linear Parameter-Varying Gain-SchedulingIEEE Transactions On Control Systems Technology, Vol. 10, No. 1, January 2002.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication