Original Research Article

Kinematics and Dynamics Analysis of McPherson Suspension Based on Planar 1/4 Vehicle Model

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ABSTRACT

The nonlinear asymmetric problem of McPherson suspension has become a challenging problem in the process of establishing the system model. This paper presents a planar 1/4-vehicle model that not only takes into account the vertical vibration of the sprung mass (chassis), but also includes: ix spring mass (wheel assembly) sliding and rotation; ii longitudinal wheel mass And its moment of inertia; iii tire damping and lateral deflection. This dynamic kinematic model provides a solution to two important shortcomings of the traditional 1/4 vehicle model: it explains geometric modeling and tire modeling. This paper provides a systematic development of the planar model and a complete mathematical equation. This analysis model can be applied to hardware in the rapid calculation of ring applications. In addition, the model also gives a repeatable Simulink simulation implementation. The model has been compared with the actual Adams / View simulation to analyze the vibration and rebound motion of the wheel, as well as two related motion parameters: the dynamic characteristics of the camber and the pitch change.

KEYWORDS: suspension, modeling, McPherson suspension, multi-rigid body system, nonlinear model, simulation

1. Introduction

Because McPherson suspended with light weight, small size, low cost characteristics, it is widely used in smalland medium-sized vehicles. [1] This suspension system (Figure 1) includes a suspension arm or control arm,and a pillar that is securely attached to the wheel assembly. According to such a geometrical structure, the road pavement disturbance causes a large and asymmetric change in the camber angle and the wheelbase to cause the wheel to vibrate vertically, which is also closely related to the occurrence of tire wear and direction instability. [2,3]

The current extensive research on active or semi-active suspension systems is mainly focused on the analysis of control strategies to improve ride comfort, handling stability and running quality. [4] Despite this, the development of high-performance suspension control systems still requires a reliable suspension model. Even with such importance, few products are focused on the study of dynamic kinematic suspension modeling. [10,11]

The variable geometry of the McPherson suspension leads to its kinematic and kinetic nonlinear properties, which cannot be analyzed using the traditional 1/4 vehicle linear model [12-14] It ignores the effect of the actual structure of the suspension. [15] Some improvements to the linear model can be achieved by taking the stiffness equivalent parameter and the attenuation coefficient containing the geometrical features as a function of the wheel position. [16,17] In addition, in most products with linear models, tire dynamics are considered as a single-axis spring during modeling while ignoring longitudinal damping and lateral deflection. [4,18]

The two-dimensional model can capture the nonlinear geometric effect of the McPherson suspension. [19-22] In addition, the tire vertical damping and lateral deflection have been included in a planar response model of a double wishbone suspension. [11] In the McPherson suspension, this has a more special connection. The small changes in the geometric parameters of the suspension will greatly affect kinematics and dynamic response. [23,24] However, in the two-dimensional dynamic model of the McPherson suspension, tire damping and lateral deflection caused by the suspension mechanism have not been considered. [20-22]

The mathematical model of mathematics has been proposed and used to study the kinematics of the McPherson suspension. [1, 10, 24-26] However, the three-dimensional dynamics model is a complex problem, and according to estimates, modeling will become very expensive. [27] In this sense, the analytical plane model can provide a simpler and faster implementation for hardware-in-the-loop applications.

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In the previous work, the authors presented a preliminary analytical development for the two-dimensional McPherson suspension model to calculate the geometrical structure as well as the tire lateral stiffness. [28] The model takes into account the two-dimensional rotation and sliding of the unsprung mass (wheel assembly) in the experiment. In addition, the model uses the moment of inertia of the longitudinal wheel.

This paper extends the following results [28]:

• Provides a planar model of system development as well as a complete mathematical equation.

A repeatable Simulink implementation of simulation.

• New experimental results for different key points and parameters of the suspension and comparison with the actual Adams / View simulation to analyze the vibration and rebound motion of the wheel, as well as two related motion parameters: the camber and the pitch change Dynamic characteristics.

The rest of this paper is organized as follows: Chapter 2 is the establishment of a planar model based on the kinematics-kinetic equations; Chapter 3 compares Simulink simulations for this model and the validation models developed with Adams / View as a case To study; Chapter 4 for the conclusion.

2. Plane model of McPherson suspension

Figure 2 (a) is a schematic diagram of the model. The main components of the McPherson suspension system are: (1) chassis (spring quality), (2) control arm, (3) support, (4) wheel assembly (unsprung mass). The displacement of the sprung mass is the displacement of the unsprung mass, the pavement disturbance is, and the meaning of the other symbols is shown in Table 1.

The corresponding mechanism is shown in Figure 2 (b), which is a four-bar mechanism, where the suspension keys are M, Q, P, C, T, and N. The origin of the reference coordinate system is Q, and its Y and Z axes are aligned with the horizontal and vertical directions, respectively. Corresponding to the degree of freedom of the system, this state of the mechanism can be defined as two generalized coordinates (and).

If the following considerations, the model can be considered reasonable:

The chassis is supported by vertical movement.

In addition to the wheels, all other components of the suspension system are rigid.

The quality of the control arm and the support is negligible.

· The wheel assembly movement is in the form of rotation and sliding.

All joints are ideal.

• The spring and damping have a linear characteristic.

The following part is the kinematics and dynamics analysis of the model.

2.1. Kinematics analysis

The kinematics analysis of the model is based on the displacement matrix method. [29] Through the following matrix, the finite displacement of the wheel assembly in the plane can be seen as consisting of rotation and sliding:

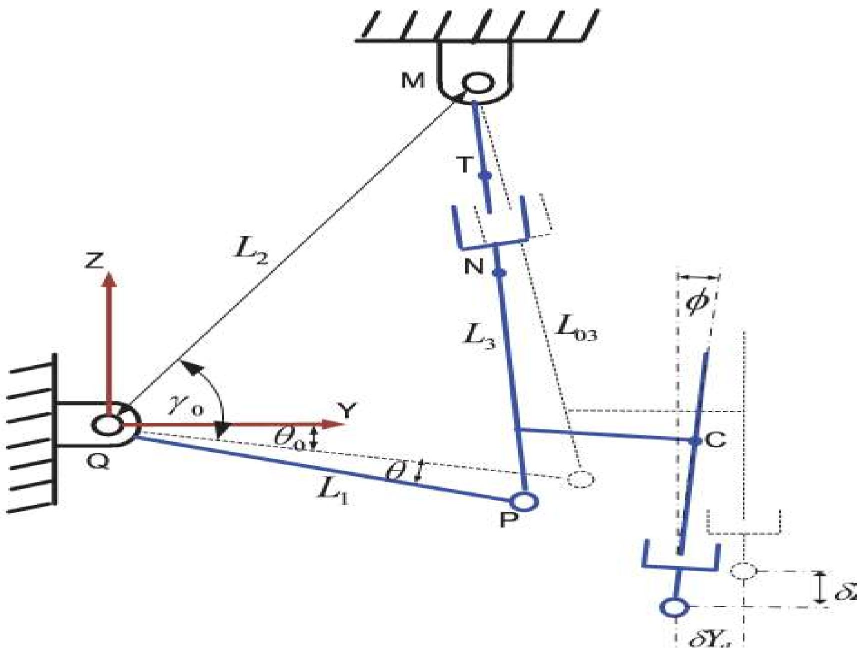
Which is the and instantaneous coordinates of the center of the wheel C, and are the value of their initial equilibrium position. Coefficient, which is the wheel assembly around the X axis of the corner, that is, camber angle. The initial equilibrium state is determined by the coordinates of M, Q, P, C, T and N, and the camber angle is zero. The instantaneous coordinates of the point N, T, and P of the suspension pointin Figure 2b, and the initial equilibrium coordinates can be combined by equation (1)

Where a,b,c,d, e and f are the constant obtained from the initial equilibrium coordinate system:

Equations (3) - (8) describe the kinematic properties of the wheel assembly (ie, points C, P, N, and T) and establish a relationship with the building. But they do not take into account points Q and M.

Considering and taking into account the negative, the system movement shown in Figure 3. The sum in the figure is the length of the control arm and the distance of points Q, M. Is the effective length of the support. The initial values of the angles of the control arms are determined by the respective and relative to the Y-axis and direction. The angle of the control arm changes to. Note that this movement will cause the wheel to be laterally deflected (ie, the track change) and the vertical direction of the branch.

The following three equations can be obtained from the geometries shown in this figure:



2.2. McPherson suspension in Adams software to establish and analyze

Adams / View software can be used as a model validation tool because it provides a real simulation of multi-body dynamics. [11,22,23,30]

In this work, the McPherson suspension system of the 1/4 plane model shown in Figure 5 (a) has been established. The following motion constraints have been determined: the chassis movement is guided by the moving pair; the control arm is connected to the chassis by the rotary pair and connected to the wheel assembly by the ball; the support is modeled as a moving pair, at its upper end by a rotating pair Connected to the chassis, the bottom of which is fixed to the wheel assembly; the wheel is modeled as a vertical deflection of the moving pair and horizontal deflection of the lateral spring. The model for kinematic analysis is shown in Fig. 5 (b), where it is assumed that the chassis is fixed (ie) and the center of the wheel is in the vertical direction. [11]

In addition, Table 3 summarizes the characteristic response values of the displacement and acceleration of the sprung mass. Where 'peak' is the maximum value of the response curve, and the 'setup time' is the time at which the value curve reaches the final value of 2%. The acceleration of the two models is very close to the establishment time, while the displacement is slightly shorter than the plane model. In spite of this, the establishment time of the planar model maintains a difference from the dynamic response under the perturbation of the flange and potholes.

In the case of kinematics, this model analyzes the changes in the camber and the wheelbase that the linear simplification model does not consider. Figures 9 and 10 show the experimental results for a vertical motion of ± 0.1 m wheels. The experimental results show that there is a very good consistency in the vicinity of the linearization point, and the camber and the track are very good. When the wheel displacement is large, the model will produce a certain deviation, which is a normal phenomenon in the approximate model. [11,18,22]. Nevertheless, the model is very accurate for bumps (such as wheel vertical motion), and successfully reproduces the asymmetry of the McPherson suspension.

In addition, the experimental results obtained by the planar model in the above experiments were described as a case study of a McPherson suspension with different geometric and kinetic parameters, as described in [28].

3. Conclusions

Even if the commercial multi-body dynamics simulation software can analyze the vehicle suspension based on the physical model, the rapid calculation of the hardware-in-the-loop application still requires an accurate analysis of the model. The widely used McPherson suspension has made it a difficult problem because of its nonlinear asymmetry. The plane 1/4 vehicle model proposed in this paper not only takes into account the vertical vibration of the sprung mass (chassis), but also includes: ix spring mass (wheel assembly) sliding and rotation; ii longitudinal wheel quality and its Moment of inertia; iii Tire damping and lateral deflection. These improvements make it possible to analyze changes in kinematic parameters such as camber and track; these cannot be solved with conventional 1/4 vehicle models. [31]

This paper extends the following results [28]:

• Provides a planar model of system development as well as a complete mathematical equation.

A repeatable Simulink simulation implementation.

• New experimental results for different key points and parameters of the suspension and comparison with the actual Adams / View simulation to analyze the vibration and rebound motion of the wheel, as well as two related motion parameters: the camber and the pitch change Dynamic characteristics.

The model has been compared with the actual Adams / View simulation to analyze the vibration and rebound motion of the wheel, as well as two related motion parameters: the dynamic characteristics of the camber and the pitch change. The experimental results have shown that the plane model is in good agreement with the Adams model, and that the plane model successfully reproduces the asymmetric properties of the McPherson suspension.

In the future work, the model will be applied to the real-time suspension control system. In addition, it will also be interesting to associate changes in camber and track with vertical control logic.

References

1. Mantaras D, Luque P, Vera C. Development and validation of a three-dimensional kinematic model for the McPherson steering and suspension mechanisms. Mech Mach Theory. 2004; 39: 603-619.
2. Deo H, Suh N. Axiomatic design of automobile suspension and steering systems: proposal for a novel six-bar suspension. Detroit, MI: SAE World Congress;

3. Mántaras DA, Luque P. Virtual test rig to improve the design and optimization process of the vehicle steering and suspension systems. Veh Syst Dyn. 2012; 50: 1563-1584.
4. Choi SB, Lee HS, Park YP. H-infinity control performance of a full-vehicle suspension featuring magnetorheological dampers. Veh Syst Dyn. 2002; 38: 341-360.
5. Biglarbegian M, Melek W, Golnaraghi F.A novel neuro-fuzzy controller to enhance the performance of vehicle semi-active suspension systems. Veh Syst Dyn. 2008; 46: 691-711.
6. Abu-Khudhair A, Muresan R, Yang S. Fuzzy control of semi-active automotive suspensions. International Conference on Mechatronics and Automation; 2009 Aug 9-12; Changchun, China. P. 2118-2122.
7. Kashani R, Strelow JE. Fuzzy logic active and semi-active control of off-road vehicle suspensions. Veh Syst Dyn. 2010; 32: 409-420.
8. Dong XM, Yu M, Liao CR, Chen WM. Comparative research on semi-active control strategies for magnetorheological suspension. Nonlinear Dynam. 2010; 59: 433-453.
9. Sun J, Sun Y. Comparative study on control strategy of active suspension system. Proceedings of the International Conference on Measuring Technology and Mechatronics Automation. Vol. 1; 2011 Jan 6-7; Shanghai, China. P. 729-732.
10. Sancibrian R, Garcia P, Viadero F, Fernandez A, De-Juan A. Kinematic design of double-wishbone suspension systems using a multiobjective optimisation approach. Veh Syst Dyn. 2010; 48: 793-813.
11. Balike K, Rakheja S, Stiharu I. Development of kineto-dynamic quarter-car model for synthesis of a double wishbone suspension. Veh Syst Dyn. 2011; 49: 107-128.
12. Hrovat D. Survey of advanced suspension developments and related optimal applications applications. Automatica. 1997; 33: 1781-1817.
13. Akcay H, Türkay S. RMS performance limitations and constraints for quarter-car active suspensions. 16th Mediterranean Conference on Control and Automation; 2008 June 25-27; Ajaccio, France. P. 425-430.
14. Dean K. How significant are transfer function relations and invariant points for a quarter car suspension model? Veh Syst Dyn. 2009; 47: 457-464.
15. Kim C, Ro P, Kim H. Effect of the suspension structure on equivalent suspension parameters. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering Vol. 213; 1999 May 1; London: Sage Publications P. 457-470.
16. Siau G. Equivalent spring and damper for conceptual suspension modeling [Master's thesis]. Eindhoven: University of Technology;
17. Dixon JC. Suspension geometry and computation. Chippenham, UK: First Antony Rowe Ltd .; 2009.
18. Fallah M, Bhat R, Xie WF. H∞ robust control of semi-active MacPherson suspension system: new applied design. Veh Syst Dyn. 2010; 48: 339-360.
19. Stensson A, Asplund C, Karlsson L. The nonlinear behavior of a MacPherson strut wheel suspension. Veh Syst Dyn. 1994; 23: 85-106.
20. Andersen ER. Multibody dynamics modeling and system identification for a quarter-car test rig with McPherson strut suspension [Master's thesis]. Faculty of the Virginia Polytechnic Institute;
21. BasariA, Samy, Hamzah N. Nonlinear active suspension system with backstepping control strategy. 2nd IEEE Conference on Industrial Electronics and Applications; 2007 May 23-25; Harbin, China. P. 554-558.
22. Fallah M, Bhat R, Xie W. New model and simulation of MacPherson suspension system for ride control applications. Veh Syst Dyn. 2009; 47: 195-220.
23. Kim C, Ro P. Reduced-order modeling and parameter estimation for a quarter-car suspension system. Proceedings of the Institution of Mechanical Engineers, Part D: Journal ofAutomobile Engineering.Vol. 214; 2000Aug 1; London: Sage Publications P. 851-864.
24. Yang J, Abdel-Malek K. Design propagation in kinematics of mechanical systems. Mech Mach Theory. 2007; 42: 807-824.
25. Papegay YA, Merlet JP, Daney D. Exact kinematics analysis of car's suspension mechanisms using symbolic computation and interval analysis. Mech Mach Theory. 2005; 40: 395-413.
26. Sandu C, Andersen ER, Southward S. Multibody dynamics modation and system identification of a quarter-car test rig with McPherson strut suspension. Veh Syst Dyn. 2011; 49: 153-179.
27. Zhao JS, Liu X, Feng ZJ, Dai JS. Stiffness of a rectilinear suspension with automatic length compensation branches. Mech Mach Theory. 2012; 56: 99-122.
28. Hurel J, Mandow A, García-Cerezo A. Nonlinear two-dimensional modeling of a McPherson suspension for kinematics and dynamics simulation. The 12th International Workshop onAdvanced Motion Control; 2012 Mar 25-27; Sarajevo, Bosnia and Herzegovina: IEEE. P. 1-6.
29. Suh C. Synthesis and analysis of suspension mechanisms with use of displacement matrices. SAE Trans. 1989; 98: 171-182.
30. Dressler K, Speckert M, Bitsch G. Virtual durability test rigs for automotive engineering. Veh Syst Dyn. 2009; 47: 387-401.
31. Reimpell J, Stoll H, Betzler JW. The Automotive Chassis: engineering principles, 2nd ed. Oxford, UK: Butterworth-Heinemann; 2001.