Kinematical analysis of macpherson suspension system engineering essay

In this paper, Kinematic Modeling of Macpherson Suspension System has been done and Design or Constraint equations are derived for different kinematic link of Suspension system by using Displacement Matrix method and Instantaneous Screw Axis method. Suspension mechanism is analyzed under the sinusoidal displacement of wheel with relevant data and results. Then Macpherson Suspension system is analyzed by computer software " Suspension Analyzer" by taking example of Ford Mustang 1999.

Introduction

Suspension system have been widely used , right from age of horse drawn carriage having flexible leaf spring, to modern automobiles with complex systems. The many objectives of suspension system in vehicle are to isolate the vehicle from road irregularities and to maintain proper contact of wheel with road during various conditions. This can be done by proper use of spring and damper and by rubber mountings at various suspension component connections.

There are two main categories of disturbances of vehicle. First one is disturbance from the road and second is from load variations in vehicle. Road disturbance have characteristics of large magnitude in low frequency (such as hills) and small magnitude in high frequency (such as road roughness). Load disturbance include load variation by accelerating, braking and cornering. For good suspension

system design it is required to reject these disturbances to the output. So the suspension system is needed to be soft against road disturbances and hard enough for load disturbances. So it is required to make compromise between these two goals.

These are basically two types of suspension system, dependent and independent. Independent front suspension are mostly used nowdays, because it provides better resistance to vibration. One of the commonly used independent front suspensions is MacPherson suspension system.

In the literature, different studies exist which deals with MacPherson suspension system. Conventional studies of suspension system are mainly focused on displacement and velocity. Suh,[1] used displacement matrix for analysis of displacement and velocity of suspension system and also analysis instantaneous screw axis during bump and rebound by using velocity matrix. He also, did force analysis at each joint using displacement matrix. Kang et al.[10] carried out analysis of displacement velocity and acceleration for MacPherson suspension using displacement matrix.

The aim of this study is to analyze the MacPherson suspension system by using displacement matrix method and instantaneous screw axis, and to derive various design and constraint equations. In this study MacPherson suspension system was analyzed and evaluated by computer software " Suspension analyzer". Suspension system of Ford Mustang (1999) [9] had been analyzed as it has Macpherson suspension system as front suspension system.

Kinematic Modeling and Design equations

The first step in designing of suspension system is modeling of system and then deriving design equations. Macpherson suspension system is kinematically modeled so that its kinematic analysis can be done. It is assumed that (i) all components are rigid bodies with no elastic deformation (ii) joints are ideal with no friction or strain. Then design equations are derived for displacement, velocity and acceleration between links of system by using displacement matrix and instantaneous screw axis theorem.

Kinematic modeling of suspension system

Macpherson suspension system is used in this study. The mechanical [11] system consists of the main chassis, standard Macpherson suspension mechanism, a Tie-rod and a wheel. The standard Macpherson suspension consist of a A-arm or lower arm, coil spring and strut and a knuckle on which wheel is mounted. Figure 1 shows knuckle or spindle, lower arm connecting wheel assembly and chassis and tie rod for steering and strut involving spring damper system. The chassis is constrained to move vertically upward or downward. The steering rod or tie rod connects the chassis and knuckle of wheel assembly via two spherical joints. Chassis and lower-arm are connected by revolute joints, lower arm knuckle and chassis and strut both connect by spherical joints, one cylindrical joint connects strut and knuckle, which imposes 5 constraints. So the system has 2 degrees of freedom the mechanism can be specified by defining a set of points on the links and joints by A1, B0, B1, C0 and cylindrical joint at J1

Figure Assembly [2] of Macpherson Suspension System

Figure Kinematic modeling of McPherson strut suspension [2]

Design Equations

After getting kinematic model of Macpherson Suspension system, next step is to write design equations. Design equations can be written as constraint equations of displacement, velocity and acceleration using displacement matrix and instantaneous screw axis. Each link connecting two rigid bodies impose kinematic constraint on each other because of relative motion of rigid bodies

Displacement matrix method

Rigid body motion [12] can be expressed by the displacement matrix [D], which consists of rotation angles and displacements.

So Macpherson Suspension system [4] can be analyzed with Displacement matrix method. In this method the general three-dimensional displacement matrix is given in terms of a translation from a point p(x1y1, z1) to another point p(x2y2, z2), and a rotation about a fixed coordinate frame

[D] = =

where aij are components of the rotation matrix. Rotational matrix can be expressed by the product of rotation about principle axis x0 , y0 , z0. This define the roll, pitch, and yaw angles, which are denoted as É¸, Î¸ and Ïˆ.

Next thing in Displacement Matrix method is writing constraint equations.

Spherical-spherical (SS); link constraint equations

SS link [4] is defined by a spherical joint at a point p0(x0, y0, z0) on a fixed body and another spherical joint at a different point p1(x1, y1, z1) on a moving body. The constraint equation that specifies the constancy of the distance between the two spherical joints is

$(x1 – x0)2 +(y1 – y2)2 + (z1 – z2)2 = constant$

So, Displacement constraint equation

$(xBj – xBo)2 + (yBj – yBo)2 + (zBj – zBo)2 = (xB1 – xBo)2 + (yB1 – yBo)2 + (zB1 – zBo)2$

Where j = 2, 3, 4……

Revolute-spherical (RS) link constraint equations

An RS link connects a revolute joint at a point p0(x0, y0, z0) with rotation axis U0(Ux0, Uy0, Uz0) on

a fixed body and a spherical joint at another point p1(x1, y1, z1) on a moving body. The constraint

equations which specify the constancy of distance between the revolute and spherical joints and the perpendicularity between the revolute axis and the axis defined as the link are

$(x1 – x0)2 +(y1 – y2)2 + (z1 – z2)2 = constant, Ux0 (x1 – x0) + Uy0 (y1 – y0) + Uz0 (z1 – z0) = 0$

Displacement constraint equation

$(xA1 – xAo)2 + (yA1 – yAo)2 + (zA1 – zAo)2 = (xAj – xAo)2 + (yAj – yAo)2 + (zAj – zAo)2$

Uxo (xAj – xAo) + Uyo (yAj – yAo) + Uzo (zAj – zA0) = 0,

Spherical-cylindrical (SC) link constraint equations

The SC link[4] connects a spherical joint at a point p0(x0, y0, z0) on a fixed body and a cylindrical joint at another point p1(x1, y1, z1)on a moving body with an axis of translation/rotation U0(ux0, uy0, uz0)along the link axis. The constraint equations that specify that the straight line defined by the link, or the cylindrical joint axis, remains a straight line during any displacement are

Uz1 (x1 – x0) + Ux1 (z1 – z0) = 0, Uz1 (y 1 – y 0) + Uy1 (z1 – z0) = 0,

Ux12 + Uy12 + Uz12 = 1

Displacement constraint for strut (j is arbitrary point on strut)

Uzj (xcj – xco) – Uxj (zc1 – zco) = 0, Uzj (ycj – yco) – Uyj (zcj – zco) = 0

Uxj2 + Uyj2 + Uzj2 = 1

Formulae to calculate caster angle and king pin angle in vehicles[4]

Caster Angle = tan-1 –(1)

Kingpin Inclination = tan-1 —(2)

Analysis

In Analysis part, various parameters[2] are analyzed under different input condition. Analysis is done in two part, in first part analyses of Displacement, velocity and Acceleration of different components is carried out and in second part , variation of design parameter like caster and kingpin inclination has been analyzed. This is done by considering sinusoidal displacement of wheel center. The initial position and its bounds(lower and upper) of hard point(design variable) are as in Table 1.[2]

Table Initial [2] position and its bounds of hard point

Calculations of Design factors.

By using data from Table 1 few design factors has been analyzed.

From equation (1)

Caster Angle = tan-1

So caster angle at initial condition = tan-1 = 3. 41 degrees

From equation (2)

Kingpin Inclination = tan-1

At initial condition= tan-1 = -12. 53 degrees

Computer software

In this paper, Macpherson Suspension system is analyzed by using " Suspension Analyzer V 2. 0" This software can analyze different kind of suspension system like Double wishbone and Macpherson suspension system. In this case suspension system of " Mustang 1999" had been analyzed as it has MacPherson Suspension as its front suspension.

In this software input data like lower ball joint, lower frame pivot, Macpherson strut height, tie-rod on rack and spindle, track, tire circumference, camber is required. Some of the input data has been circled in figure 3[9].

Figure Layout [9] of Ford Mustang on Suspension Analyzer software

And this process this input to give output like spring length, caster angle, kingpin angle, Instantaneous center height, roll center height etc. Some of these output are shown in figure 4 [9].

Figure Various output in Software

This software has many useful features like it animate the system, can optimize our suspension system. We can see different views of system and one of the feature is that is plot graphs of various parameters like caster, camber, roll center height, etc., as shown in figure

Macpherson system can be analyzed by this software. Let’s take example how camber angle varies by changing any of the input parameter like initially Macpherson strut top is at 19 inches so variation of camber angle vs Dive inches is shown in graph 1[9]

Graph variation of camber vs Dive for initial data

Graph 2 Camber angle Vs Dive inches when strut height changed

But if Macpherson struts top height is changed to 21 inches from 19 inches. Variation of camber can be shown by graph 2.

Now how roll center change when ride of vehicle change by changing wheel radius can be analyzed by table .

Table Roll center variation with Dive (Tire radius 12. 65 in)

Table Roll center variation with (Tire radius 13. 1 in)

“ Suspension Analyzer” software is used to get the variation of various parameter of suspension system like camber, caster, toe-in, roll center etc. All variations are shown in Figure 5

Figure Variation of different parameters with Dive in.

These variations can be plotted on Graphs.

Conclusion

Kinematic Model for Macpherson Suspension has been drawn. Design or Constraint equations are derived for different kinematic link of Suspension system by using Displacement Matrix method and Instantaneous Screw Axis method. Kinematical parameters such as king-pin angle, caster are investigated by using given data. A computer software “ Suspension Analyzer” has been used to analyze Macpherson suspension by taking example of Ford Mustang 1999 various system parameters has been studied and plotted on graph