

Modeling, Analysis and Optimization of the Twist Beam Suspension System

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ABSTRACT

A twist beam rear suspension system is modeled, analyzed and optimized in this paper. An ADAMS model is established based on the REC (Rigid-Elastic Coupling) Theory, which is verified by FEM (Finite Element Method) approach, the effects of the geometric parameters on the twist beam suspension performance are investigated. In order to increase the calculation efficiency and improve the simulation accuracy, a neural network model and NSGA II (Non-dominated Sorting Genetic Algorithm II) are adopted to conduct a multi-objective optimization on a twist beam rear suspension system.

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INTRODUCTION

The twist beam suspension is widely adopted on passenger vehicles as the rear suspension system because of its simplicity in construction, comparably reasonable cost, and easy installation. Unfortunately, some drawbacks are also challenging automotive manufacturers at the same time [1]:

- The vehicle tends to over-steer when cornering and therefore sacrifices the stability;
- In order to maintain vehicle's drivability and stability, the twist beam suspension system's parameters need to be carefully designed and optimized.

Several studies have been conducted to investigate the performance and characteristics of the twist beam suspension system. The geometric parameters' effects on the vehicle's performance and drivability have been studied through DOE analyses, the full vehicle model was established and the vehicle dynamics have been verified [2]. The twist beam suspension system performance can also be modified by changing its constructions [3 and 4].

This research investigates the effects of the geometric parameters on twist beam suspension performance, applies Pareto theory and NSGA II genetic algorithm [5 and 6], and conducts multi-objective optimization on bushing stiffness and setting angle. The results show the twist beam suspension performance is well improved.

MODELLING AND VERIFICATION OF THE TWIST BEAM SUSPENSION SYSTEM

The REC Theory is introduced in this section, the ADAMS model is established, and the model is also verified by FEM calculations.

The REC Theory

The REC Theory is a method to introduce FEM model into a multi-body hybrid model which contains both rigid and elastic bodies. In general, a FEM model has huge DOF's (Degrees Of Freedom), and they need to be reasonably reduced in order to maintain its accuracy and calculation efficiency. The CMS (Component Mode Synthesis) reduction method proposed by Craig and Bampton [7] is adopted in this research.

According to CMS method, DOF $\{u\}$, mode shapes $\{\phi\}$, and modal coordinates $\{q\}$ can be stated as:

$$\{u\} = \begin{Bmatrix} u_B \\ u_I \end{Bmatrix} = [\phi] \{q\} = \begin{Bmatrix} I & 0 \\ \phi_{IC} & \phi_{IN} \end{Bmatrix} \begin{Bmatrix} q_C \\ q_N \end{Bmatrix} \quad (1)$$

Where u_B is boundary DOF

u_I is internal DOF

I is identity matrix

0 is null matrix

ϕ_{IC} is constrained mode shape internal displacement

ϕ_{IN} is natural mode shape internal displacement

q_C is constrained modal coordinate

q_N is fixed boundary natural modal coordinate

The generalized stiffness and mass matrices corresponding to the Craig-Bampton modal are obtained via modal transformations. The stiffness transformation is:

$$K = \phi^T \hat{K} \phi = \begin{bmatrix} I & 0 \\ \phi_{IC} & \phi_{IN} \end{bmatrix}^T \hat{K} \begin{bmatrix} I & 0 \\ \phi_{IC} & \phi_{IN} \end{bmatrix} = \begin{bmatrix} K_{CC} & 0 \\ 0 & K_{NN} \end{bmatrix} \quad (2)$$

And the mass transformation is:

$$M = \phi^T \hat{M} \phi = \begin{bmatrix} I & 0 \\ \phi_{IC} & \phi_{IN} \end{bmatrix}^T \hat{M} \begin{bmatrix} I & 0 \\ \phi_{IC} & \phi_{IN} \end{bmatrix} = \begin{bmatrix} M_{CC} & M_{NC} \\ M_{CN} & M_{NN} \end{bmatrix} \quad (3)$$

Where the subscripts I , B , N and C denote internal DOF, boundary DOF, normal mode and constraint mode, respectively. M and K denotes the generalized mass and stiffness.

The governing equations for a flexible body are derived from Lagrange's equations as:

$$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{\xi}} \right) - \frac{\partial L}{\partial \xi} + \frac{\partial F}{\partial \dot{\xi}} + \left[\frac{\partial \psi}{\partial \xi} \right]^T \lambda - Q = 0$$

$$\psi = 0 \quad (4)$$

Where:

L is the Lagrangian

F is an energy dissipation function

ψ are the constraint equations

λ are the Lagrange multipliers for the constraints

ξ are the generalized coordinates

Q are the generalized applied forces (the applied forces projected on ξ)

Plug eq. (1) into Lagrange Equation (4), the elastic multi-body dynamics equation can be derived as:

$$M \ddot{\xi} + \dot{M} \dot{\xi} - \frac{1}{2} \left[\frac{\partial M}{\partial \xi} \dot{\xi} \right]^T \dot{\xi} + K \xi + f_g + D \dot{\xi} + \left[\frac{\partial \Psi}{\partial \xi} \right]^T \lambda = Q \quad (5)$$

Where M is elastic body's modal mass matrix

K is elastic body's modal stiffness matrix

D is elastic body's modal damping matrix

f_g is gravity

λ , Ψ , ξ and Q are the same as shown in Lagrange Equation (4)

The ADAMS Model vs. FEM Model

The ADAMS model is established based on REC Theory, please refer to Figure 1. Based on the same boundary and loading conditions, the ADAMS model is compared and verified by FEM calculations, refer to Figure 2.

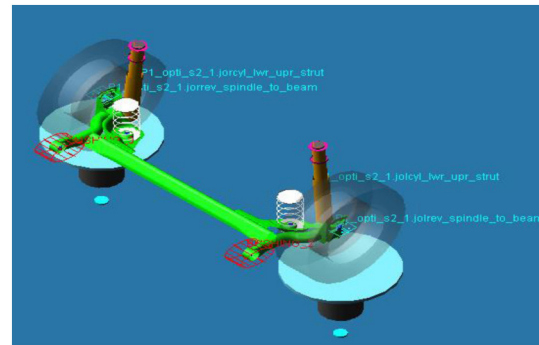


Figure 1. The Twist Beam Suspension System ADAMS Model

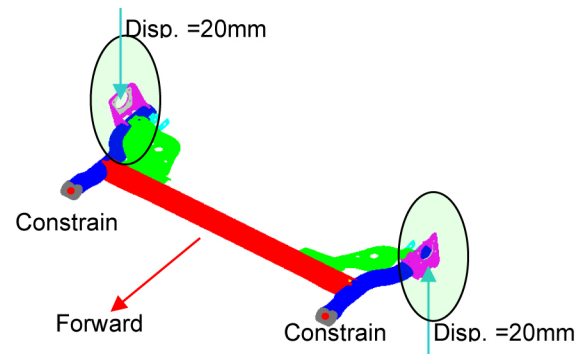


Figure 2. The Twist Beam Suspension System FEM Model - Apply 20mm Vertical Displacement at the Left and Right WC (Wheel Center) in Opposite Directions

Assuming the position of twist beam suspension longitudinal arm connected to the vehicle platform remains the same, the loading conditions are to:

- Apply 20mm vertical displacement at the left and right wheel center in opposite directions, refer to Figure 2. The vertical loads (reaction forces) on the wheel centers are compared in Table 1;
- Apply 2000N force at the left and right wheel center in X, Y and Z positive and X, Y and Z negative directions, refer to Figure 3. The displacements in X, Y and Z directions on the left wheel center are listed in Table 2.

Table 1. Results of Applying 20 mm Vertical Displacement at WC in the Opposite Directions

Models	loads on left WA	Loads on right WA
ADAMS	-27774.65 N	28321.98 N
FEM	-28044.76 N	28044.76 N

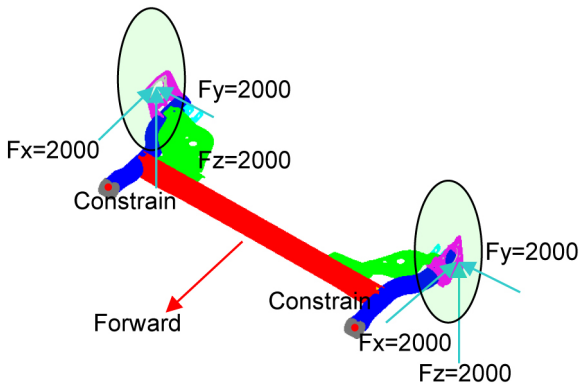


Figure 3. Apply 2000N Force at the Left and Right WC in the Positive and Negative directions

Table 2. Displacements in X, Y and Z Directions of Left WC Of Applying 2000N Force on the Left and Right WA in the Positive and Negative directions

Models		X – Disp.	Y– Disp.	Z – Disp.
Positive Direction	FEM	0.418 mm	0.987 mm	1.257 mm
	ADAMS	0.417 mm	0.987mm	1.254 mm
Negative Direction	FEM	0.352 mm	0.747 mm	1.322 mm
	ADAMS	0.352 mm	0.746 mm	1.317 mm

The results of Tables 1 and 2 show that the ADAMS model is comparable with FEM calculations.

GEOMETRY PARAMETRIC STUDIES OF THE TWIST BEAM SUSPENSION

This section is to investigate the effects of the geometric parameters on twist beam suspension performance. This paper studies two major parameters:

- The lateral beam's orientation; and
- The position of the lateral beam installed on the longitudinal arm.

Focusing on vehicle's drivability and stability, two performance indices are compared:

- The toe angle vs. wheels travelling in opposite directions; and
- The wheel center longitudinal displacement vs. longitudinal force.

The Lateral Beam's Orientation

The lateral beam's orientation 0° is for the beam open side facing down, as shown in Figure 4. Four orientations, i.e. 0° , 90° , 180° , and 270° , are studied.

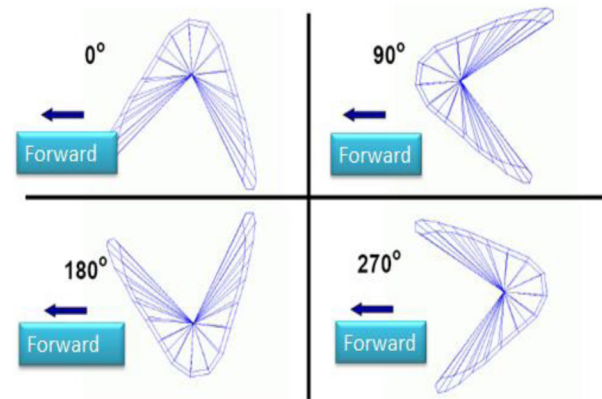


Figure 4. The Lateral Beam's Orientation

As shown in Figure 5, the lateral beam orientation play a very important role on toe angle changes. Only when the lateral beam open side facing down, i.e. at the 0° position, the toe angle responds in the way to be under-steering and therefore increase the vehicle's stability during cornering. All the other 3 orientations tend to be over-steering and vehicle's drivability would be comprised.

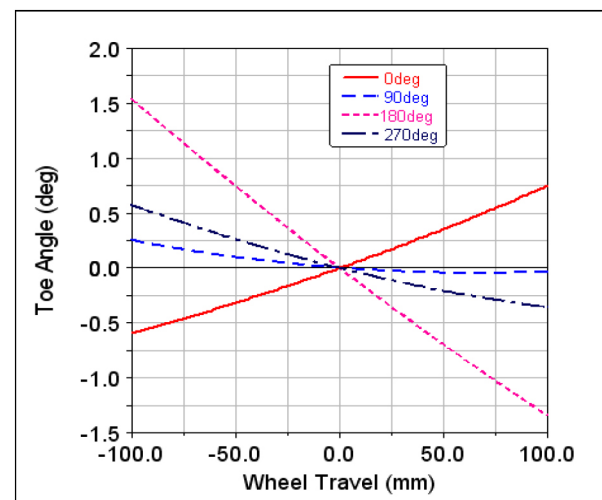


Figure 5. The Toe Angle vs. Wheels Travelling in Opposite Directions with Different Lateral Beam's Orientation

Figure 6 shows the lateral beam's orientations do not affect suspension's longitudinal stiffness significantly, though the lateral beam open side facing down position is still slightly better than the other three orientations.