

## Investigation of Forced Frequency in a Commercial Vehicle Suspension System

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Received (1 April 2018)

Revised (10 September 2018)

Accepted (20 November 2018)

Vehicle suspension plays a vital role in maintaining the center of gravity to achieve perfect balancing of the vehicle to provide the comfortable ride. While designing the suspension system of automobile, vibration is the main aspect to be considered. This paper aims to analyze the automobile front and rear suspension for a four wheeler using analytical and numerical approach. Existing details of the suspension is collected using the concept of reverse engineering. Natural and forced frequency of the front and rear suspension system is calculated theoretically based on the collected data's. The natural frequency and forced frequency is numerically computed for front and rear suspension. The amplitude of vibration is reduced by replacing the spring material and its forced frequency is reduced by 1.18 % and 1.56 % for front and rear suspension system respectively. This result reveals that low carbon steel has ability to reduce the forcing frequency and can produce comfort ride.

*Keywords:* Suspension, vibration, ANSYS APDL, natural frequency, forced frequency.

### 1. Introduction

To achieve a comfort ride, the suspension system plays a vital role in a vehicle. It takes up the entire weight of the automobile including the weight of the passenger. Desirable vibration is needed to maintain the wheel in the appropriate position to achieve better ride and to maintain the wheel in contact with the ground. Vibration resonant frequencies affect the physical structure and organs of the human being;

hence safety has to be considered. Vibration also decreases the safety and reduces the efficiency of automobile. An undesirable effect is felt by human being when the vehicle passes the irregular road surface or over the speed breaker due to the presence of vibration in a suspension system. Hence it is necessary to construct a suspension system with negligible vibration effect. In this paper suspension vehicle model and its subsystem are parameterized by numerically and investigated the effect of vibration in connection to the human comfort.

Parametric modeling and analysis of the front and rear suspension is carried out numerically and optimized the various factor which have impact on ride comfort [1]. Improper suspension design creates the high magnitude shock and vibration due to impact which occurs frequently in the road vehicle. When the natural frequency of suspension is close to the bounce mode of forced frequency of the vehicle resonance will happen [2]. Using the magneto-rheological technique in the damping an intelligent damper can be provided as automobile suspension for absorbing the vibration. Magnetic circuit was analyzed numerically, the properties of designed damper were investigated by experimental and the relationship between damping force and speed was determined through the results [16]. Result provides the damping properties of the shock absorber on the vibration being generated. Experiment was conducted on the car, which was excited by the machine with changeable frequency [9]. Nonlinear quarter car model comprising quadratic type stiffness and cubic stiffness in suspension spring, frame, and seat cushion with four degree of freedom is modeled and analyzed. Optimization of the car suspension seat driver system is successfully implemented using NGSAAI and MDPSO-CD with prenatal function algorithm. MDPSO-CD algorithm has consumed less time compared to NGSAAI [10].

Design of passive suspension system by an optimization technique is used to minimize the vibration by choosing the optimize value of spring stiffness, damping co-efficient, spring mass, unsprung mass, type stiffness to have a comfort ride. Modeling is done as four degree of freedom using SIMULINK software [11]. Least square method is used to determine the relationship between clamping force and current. Using the parameter speed the damper performance and with lesser number of experiments is described [12]. Determined the safe load for the light vehicle suspension spring with different materials [13]. Considering the realistic values for suspension, natural frequencies are evaluated using matrix iteration technique [14]. The vibrational analysis for active and passive suspension for linear and nonlinear system using the various controllers. Equations of motion with respect to the different disturbing conditions for the suspension system are derived [15]. The stress, deformation of the suspension spring with three different materials for constant load of 850 N is determined. Stability of the suspension was determined till the load varying till the yield strength of the material [16].

## **2. Modeling of Suspension System**

The key areas to be considered and its relation with one another in order to determine the frequency of suspension are discussed. The steps involved in the methodology are shown in Fig. 1. To perform the model and harmonic analysis of suspension system, the needed data of the suspension system is collected from the specifica-

tion manual. Measurements are captured using the concept of reverse engineering. The parameters used for analysis are tabulated in the Tab. 1. The modeling and analysis of suspension system of vehicle is performed in the ANSYS APDL 12.0 comprising of five nodes is shown in Fig. 2. Nodes 1, 2, 5, 4 are the spring mass system and nodes 2, 4 are connected to chassis of automobile, node 3 denotes the lumped masses of the automobile.

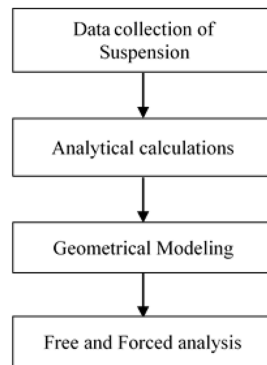


Figure 1 Methodology

### 3. Model analysis and harmonic analysis

Elements with BEAM 3 (2D Elastic3), COMBIN14 (Combination of spring damper), MASS21 (structural mass) are selected for the numerical analysis with 2D degree of freedom. BEAM 3 element geometry is defined by two nodes. The cross sectional area of chassis, area moment of inertia, height and considered material properties are tabulated in Tabs. 1 and 2. The node number 2, 4 is of beam element. COMBIN14 element is defined for the geometry of two spring suspension system the number 1 and 2 on front suspension and 4 and 5 on rear suspension. It has 2D degree of freedom at each node that is translation in the X and Y direction. Spring stiffness value is substituted as input parameter of this element which is taken from Table 1 and 2. MASS21 is a part element which deforms the lumped weight of the automobile. Lumped weight is added to the node 3.



Figure 2 Model of suspension

**Table 1** Technical specification of suspension system

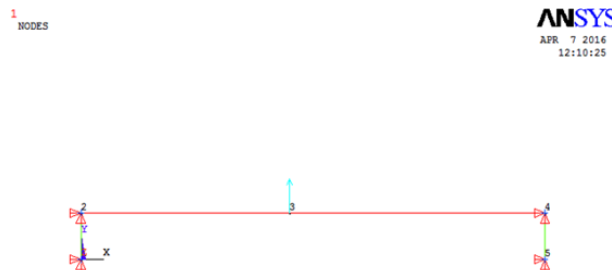
Sl No	Details		Values	
1	Mass of automobile, $M$ [kg]		100	
2	Centroidal moment of inertia, $I$ [Nm <sup>2</sup> ]		1600	
3	Spring stiffness [Nm]	Front suspension	Chrome vanadium steel $K_{1C}$	2400
4			Low carbon steel, $K_{1L}$	2800
5		Rear suspension	Chrome vanadium steel $K_{2C}$	2600
6			Low carbon steel, $K_{2L}$	3200
7	Distance b.w front springs and lumped mass $L_1$ , [m]		2.5	
8	Distance b.w lumped mass and rear springs $L_2$ , [m]		4.5	
9	Force acting on suspension, $F$ [N]		$168 \cdot 10^3$	

**Table 2** Material properties

Sl. No	Properties	Chrome vanadium steel	Low carbon steel
1	Density, [kg/m <sup>3</sup> ]	7860	7700
2	Young's modulus, [N/m <sup>2</sup> ]	$2.07 \cdot 10^{11}$	$1.98 \cdot 10^{11}$

### 3.1. Boundary condition

Figure 3 shows the boundary condition of front and rear suspension system.  $X$  and  $Y$  displacements of the node 1, 2, 4, 5 are fixed. For harmonic analysis the force is applied at the node 3 with the frequency range between 0–4000 Hz. Material chrome vanadium steel with isotropic and elastic properties is selected as the material.

**Figure 3** Boundary condition for harmonic analysis

#### 4. Finite element solution

##### 4.1. Natural frequency

After applying the material properties and boundary condition in the ANSYS APDL 12.0 the model is processed in the solution module with the default parameters. Modal analysis is performed to determine the fundamental frequencies and mode shape of the chassis. The natural frequency and obtained mode shape is shown in Fig. 4. In the same fashion harmonic analysis is performed with forced frequency range with mode of superposition as solver. Obtained solution is obtained from the time history generator and is shown in Figs. 5 and 6. The forced frequency is obtained from the largest amplitude from the largest amplitude of the suspension for both chrome vanadium steel and low carbon steel.

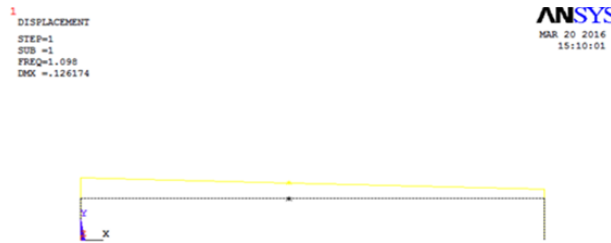


Figure 4 Boundary condition for harmonic analysis

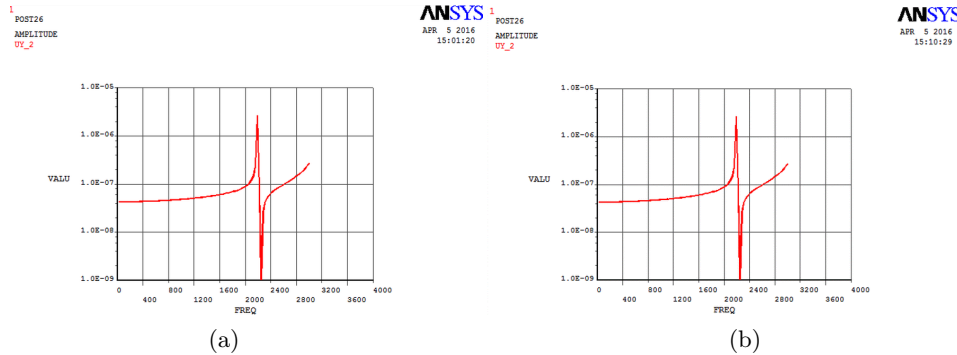


Figure 5 Natural frequency of suspension: (a) chrome vanadium steel, and (b) low carbon steel

##### 4.2. Analytical method

It is first attempted to determine the natural frequency and forced frequency of the front, front and rear suspension system of two material by using mathematical equations 1,2,3 & 4. Analytical results are tabulated in the Tab. 3 for comparison with the numerical results.

$$(K_{1C} + K_{2C} - m\omega^2)(K_{1C}L_1^2 + K_{2C}L_2^2 - I\omega^2) - (K_{1C}L_1 - K_{2C}L_2)^2 = 0 \quad (1)$$

$$(K_{1L} + K_{2L} - m\omega^2)(K_{1L}L_1^2 + K_{2L}L_2^2 - I\omega^2) - (K_{1L}L_1 - K_{2L}L_2)^2 = 0 \quad (2)$$

$$(K_{1C} + K_{2C} - m\omega^2)(K_{1C}L_1^2 + K_{2C}L_2^2 - I\omega^2) - (K_{1C}L_1 - K_{2C}L_2)^2 = F \times m \quad (3)$$

$$(K_{1C} + K_{2C} - m\omega^2)(K_{1C}L_1^2 + K_{2C}L_2^2 - I\omega^2) - (K_{1C}L_1 - K_{2C}L_2)^2 = F \times m \quad (4)$$

**Table 3** Results

Condition	Analytical results [Hz]		Numerical results [Hz]	
	Chrome vanadium steel	Low carbon steel	Chrome vanadium steel	Low carbon steel
Natural freq. $\omega_N$	1.52	1.28	1.74	1.40
Forced freq. $\omega_F$	2228	2193	2230	2195

## 5. Result and discussion

Table 3 illustrates the vibration result of the chrome vanadium and low carbon steel. Used for the front and rear suspension. Natural frequency and forced frequency are obtained by FEM method and analytical method. From the result it was observed that there is only 2% of error between the FEM method and analytical method. Analytical and FEM method shows the good agreement result of natural and forced frequency.

The natural frequency, forced frequency amplitude is reduced by changing the spring material from chrome vanadium steel to low carbon steel. Especially forced frequency is reduced by 1.87% and 1.56% for front and rear suspension system. This changes of spring material helps to reduce the frequency which can give the comfort ride to driver and passengers.

## 6. Conclusion

This paper presents the analytical and numerical investigation of the suspension system with two different materials. The modal and harmonic analysis of the automobile suspension adopting finite element analysis and analytical method provides good reliable results for design of suspension system to achieve a comfort ride. In general, close correlation is achieved between finite element analysis and analytical results. Important parameters for comfort ride are natural frequency and forced frequencies are well predicted. Vibration frequency of low carbon steel is smaller than the vibration frequency of chrome vanadium. Analysis is performed for the front and rear suspension by Numerical and analytical investigation and its results gives the comfort ride to customer by replacing the material of the spring.

## Nomenclature

$m$  = mass of automobile

$I$  = centroidal moment of inertia

$K_{1C}$  = spring stiffness front suspension chrome vanadium steel

$K_{2C}$  = spring stiffness rear suspension chrome vanadium steel

$K_{1L}$  = spring stiffness front suspension low carbon steel

$K_{2L}$  = spring stiffness rear suspension low carbon steel

$L_1$  = distance from front springs

$L_2$  = distance from rear springs

$F$  = force acting on suspension

$\omega_{NC}$  = natural frequency of chrome vanadium steel

$\omega_{FC}$  = forced frequency of chrome vanadium steel

$\omega_{LC}$  = natural frequency of low carbon steel

$\omega_{FC}$  = forced frequency of low carbon steel

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