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STUDY OF EIGENVALUES AND MATRIX EIGENVECTORS USING MATLAB: VIBRATION SYSTEMS

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Abstract
The vibration system in everyday life can be a useful thing but it can also be something to avoid. One type of vibration that is avoided is the vibration system in vehicles such as cars, as it can affect passenger comfort. This paper discusses the approach to multi-degree of-freedom (MDOF), what is observed in this approach is the pitch, angle, and displacement that occur in several components of the vehicle. The methodology that be used in this paper is to know the properties of the vehicle, then an equation have been searched based on several forces that occur in the vehicle, a matrix would be made, and a study of the eigenvector and eigenvector values in the vibration system that occurs in the vehicle would be studied and interpreted numerically in the MatLab. The study's output includes illustrations of the displacement of the front and rear tires, the displacement of the car body, the pitch angle of the car, and the exact stiffness and damping values of the suspension system of the vehicle using MatLab corrections. It also included research on the damping coefficient to represent the tires in this model.

Keywords: Eigenvalue, eigenvector, vibrating system, MatLab.

1. Introduction

In the automotive field or machining, vibration is commonly associated with engine performance[1], [2]. A suspension system is a complex vibrational system that is easily described with several degrees of freedom. It matters in terms of the car's ability to brake steadily, comfort and enjoyment while driving, isolation from noise, vibration, and bumps on the road, etc[3]. Vibrations in cars can affect the vertical and horizontal movements of the vehicle when it is exposed to external forces[4]. When analyzing vehicle bodywork, vibrations are attributed to each mass-point using a Multi-Degree-of-Freedom (MDOF) technique[5].

Many differential equations can benefit from eigenvalue / eigenvector[6], [7]. Eigenvalues and eigenvectors are common in engineering and research matrix applications. Advanced dynamics, quantum mechanics, control theory, vibration analysis, and electric circuits are applications [8]. Sharma et al, 2017 researched the dynamic stability of a three-wheel vehicle is investigated by determining the ride behavior of a linked vertical-lateral 9 degree of freedom model. This is done through MATLAB simulations, where eigenvalues are used to establish the critical speed and analyze the parameters that influence it [9].

[10] study investigate the natural frequencies and simulate dynamic modes of a four-wheeler SUV suspension spring and modeled in MATLAB using a half-car model and 4 DOF. MATLAB solves motion equations and derives dominant dynamic mode frequencies using a suspension system eigenvector. [11] the study focused on analyzing the connection and oscillation of brakes. The outcome of the study involved calculating the variability and pseudo-variability of the complex eigenvalues. These values were then utilized to determine the statistical properties of the real and imaginary components.

[1] explores a method for analyzing the pitch and bounce of a vehicle body with multiple degrees of freedom (MDOF), taking into account damping and stiffness. The methodology employs manual computations, OCTAVE, and ANSYS. The study has been successfully conducted, including a thorough analysis of each graphical element, and the results have been effectively disseminated.

[12] use MATLAB to analysis the vibration of a specific mechanical system, specifically the dual-mass system consisting of a body and wheel. The objective is to determine the amplitude-frequency characteristics of the system and investigate how the system parameters affect the root mean square value of vibration. From all previous research, the author will conduct a study on eigenvalue and eigenvector

matrix using MATLAB[13] on the vibration system that occurs in Multi Purpose Vehicle (MPV) type cars, the technical data in this study is taken from the technical guide book of type A car.

2. Experimental and Procedures

2.1 Materials

This study uses data from the technical guide book of the type of MPV car that we call car A [14] and the following properties that will be captured for vibration modeling.

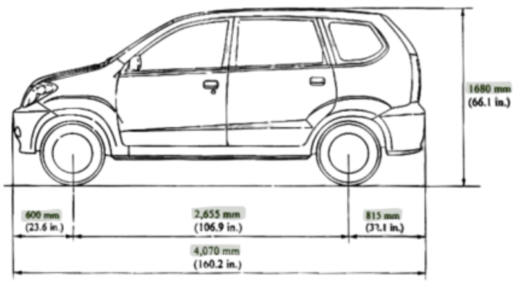


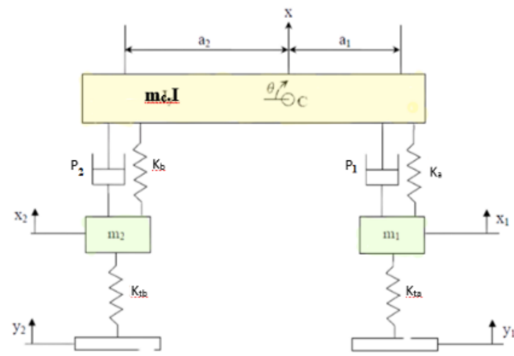
Fig. 1. Dimensions of a type A MPV car

Model Code				F601RM-GMDEJ
Major Dimensions & Vehicle Weights	Overall	Length	mm (in.)	4,070 (160.2)
		Width	mm (in.)	1,630 (64.2)
		Height	mm (in.)	1,685 (66.3)
	Wheel Base		mm (in.)	2,655 (104.5)
	Tread	Front	mm (in.)	1,405 (55.3)
		Rear	mm (in.)	1,415 (55.7)
	Effective Head Room	Front	mm (in.)	1,010 (39.8)
		Rear	mm (in.)	997 (39.3)*1, 876 (34.5)*2
	Effective Leg Room	Front	mm (in.)	
		Rear	mm (in.)	
	Shoulder Room	Front	mm (in.)	1,400 (55.1)
		Rear	mm (in.)	1,400 (55.1)
	Overhang	Front	mm (in.)	600 (23.6)
		Rear	mm (in.)	815 (32.1)
	Min. Running Ground Clearance		mm (in.)	190 (7.5)
	Angle of Approach		degrees	35.4°
	Angle of Departure		degrees	25.1°
	Curb Weight	Front	kg (lb)	535 (1,179)
		Rear	kg (lb)	520 (1,146)
		Total	kg (lb)	1,055 (2,326)
	Gross Vehicle Weight	Front	kg (lb)	625 (1,378)
		Rear	kg (lb)	860 (1,896)
		Total	kg (lb)	1,485 (3,274)
	Fuel Tank Capacity		L (Imp. gal.)	45 (9.9)
	Luggage Capacity		m^3 (cu.ft.)	0.151 (5.3)

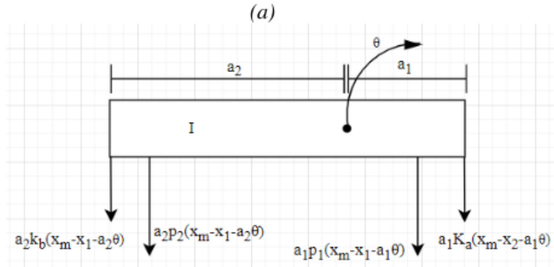
Fig. 2. Major Technical Specification car A

2.2 Experiment

Road excitation for load conditions will use modeling from bicycle shock vibration as shown in Fig. 3[15].



(a)



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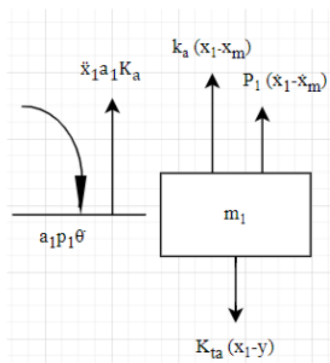

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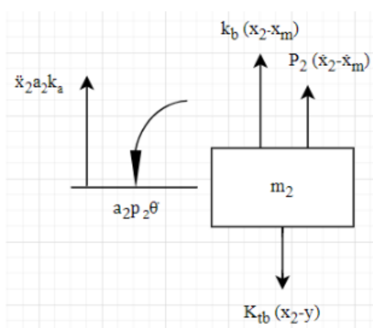

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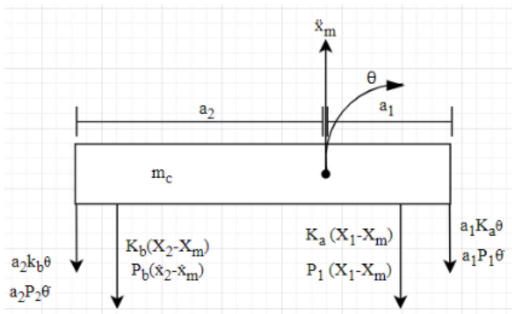

(e)

Fig. 3. Vehicle Bicycle Model with 4 Degrees-of-Freedom (a) Free body diagram of car rational (b) Free body diagram of rear tire (c) Free body diagram of front tire (d) Free body diagram of car translation (e)

The following are the equations of motion for the vibrating bicycle model of a vehicle.

$$I\ddot{\theta} + (a_1^2 p_1 + a_2^2 p_2)\dot{\theta} + (a_1^2 k_a + a_2^2 k_a)\theta + (a_2 p_2 - a_1 p_1)\dot{x}c + (a_2 k_b - a_1 k_a)x_c + a_1 p_1 \dot{x}_1 - a_2 p_2 \dot{x}_2 + a_1 k_a x_1 - a_2 k_b x_2 = 0 \quad (1)$$

$$m_1\ddot{x}_1 + p_1\dot{x}_1 + (k_{ta} + k_a)x_1 + a_1 p_1 \dot{\theta} + a_1 k_a \theta - p_1 x_c - k_a x_c = 0 \quad (2)$$

$$m_2\ddot{x}_2 + p_2\dot{x}_2 + (k_{tb} + k_b)x_2 + a_2 p_2 \dot{\theta} + a_2 k_b \theta - p_2 x_c - k_b x_c = 0 \quad (3)$$

$$m_c\ddot{x}_c + (p_2 + p_1)\dot{x}_c + (k_a + k_b)x_c + (a_2 p_2 - a_1 p_1)\theta + (a_2 k_b - a_1 k_a)\theta - p_1\dot{x}_1 - p_2\dot{x}_2 - k_a x_1 - k_b x_2 = 0 \quad (4)$$

3. Results and Discussion

3.1 Matrix of displacement vector, mass, stiffness, damping

$$M = \begin{bmatrix} I & 0 & 0 & 0 \\ 0 & m_1 & 0 & 0 \\ 0 & 0 & m_2 & 0 \\ 0 & 0 & 0 & m_c \end{bmatrix} \quad (5)$$

$$P = \begin{bmatrix} p_1 + p_2 & a_2p_2 - a_1p_1 & -p_1 & -p_2 \\ a_2p_2 - a_1p_1 & p_1a_1^2 + p_2a_2^2 & a_1p_1 & -a_2p_2 \\ -p_1 & a_1p_1 & p_1 & 0 \\ -p_2 & -a_2p_2 & 0 & p_2 \end{bmatrix} \quad (6)$$

$$K = \begin{bmatrix} k_a + k_b & a_2k_b - a_1k_a & -k_a & -k_b \\ a_2k_b - a_1k_a & k_aa_1^2 + k_ba_2^2 & a_1k_a & -a_2k_b \\ -k_a & a_1k_a & k_a + k_{ta} & 0 \\ -k_b & -a_2k_b & 0 & k_b + k_{tb} \end{bmatrix} \quad (7)$$

These matrices are left symbolic, but they make use of the variable data from Figure 2. where ω is the I natural frequency, $\tilde{K}$ is the mass normalized stiffness matrix, and I is the spectral matrix of $\tilde{K}$.The system's natural frequencies are obtained by taking the square root of the eigenvalue diagonal after determining the eigenvalues.

$$\tilde{K} = \frac{1}{\sqrt{M}}\frac{1}{\sqrt{KM}} \quad (8)$$

$$P^T\tilde{K}P = \Lambda \quad (9)$$

$$\Lambda = diag\ (\lambda) = diag\ (\omega^2) \quad (10)$$

$$S = \frac{P}{\sqrt{M}} \quad (11)$$

3.2 Result of MatLab from Eigenvalue and Eigenvector

For each equation of motion, the vibration responses to different figures are shown. The front tire, rear tire, car pitch, and car bounce all correlate to the numbers. Plotting and recording are done within a 1.0-second analytical time period. The MatLab-generated figure below illustrates the system under initial conditions of a 50 mm displacement on the front tire unsprung mass.

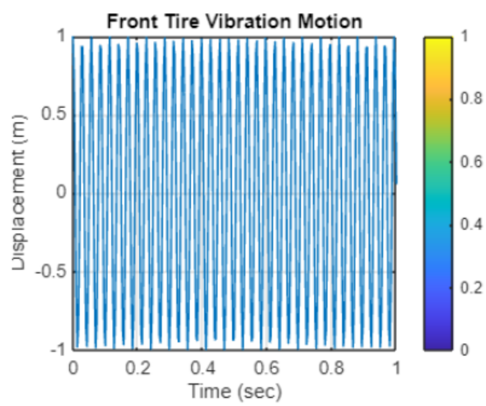

Fig. 4. Front Tire Vibration Motion

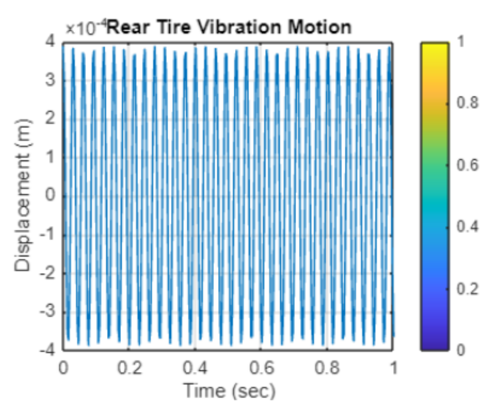

Fig. 5. Rear Tire Vibration Motion

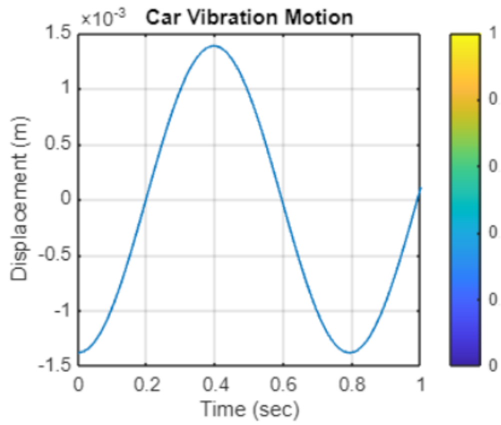

Fig. 6. Car Vibration Motion

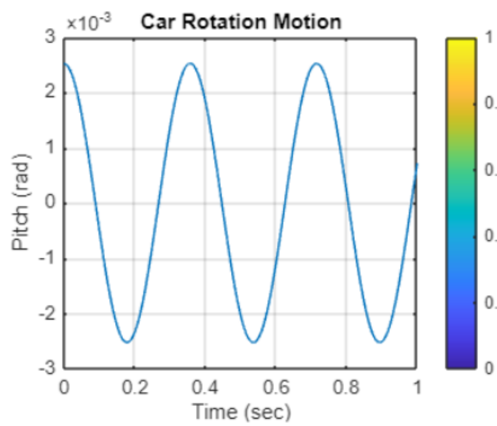

Fig. 7. Car Rotation Motion

Front Tire Movement: The front tire of the car has the largest bounce oscillation, which is +/- 1 mm. This means that the tire moves up and down with a maximum amplitude of 1 mm. Rear Tire Movement: Compared to the front tire, the rear tire movement is much less, i.e. +/- 0.04 mm. Although connected to the front tire, the interference that the rear tire receives from the front tire looks minimal. Overall Car Movement: Meanwhile, the overall movement of the car (estimated from the car body) is less than that of the front tires, which is a maximum of +/- 1.3 mm. This shows that the car's suspension can partially dampen the movement of the front tires.

No Damping: This data shows the absence of attenuation in the car's suspension system. This means that the vibration will continue to occur without decreasing its amplitude over time. Response to Rotation: The car also shows a response to rotation of +/- 0.0025 radians or about +/- 0.02 degrees. This value is relatively small and may be related to the flexibility of the tire or other suspension components.

Based on the discussion above, the current car suspension system is indicated not to have good damping. This can cause the car to feel less comfortable and vibrate more when passing through uneven roads. It is recommended to carry out further checks on the car's suspension components to find out the cause of the absence of damping

4. Conclusions

Eigenvalues and Natural Frequencies: The eigenvalues of a vibrational system can be interpreted as the natural frequency of the system. In this study, eigenvalues are calculated using the mass and stiffness matrices of the vehicle system to obtain natural frequencies that describe the vibration characteristics of the vehicle. Eigenvectors and Vibration Shape Modes: Eigenvectors represent the vibration shape modes of the system. This mode shows how each part of the system (such as the front tires, rear tires, and car body) vibrates at a certain frequency. Eigenvectors provide information about the relative displacement of each part of the system when it vibrates.

Vehicle Vibration Analysis: This study shows that the front tires have the largest vibration amplitude (+/- 1 mm), while the rear tires have a smaller vibration amplitude (+/- 0.04 mm). The overall vibration of the vehicle (car body) has a maximum amplitude of +/- 1.3 mm, indicating that the suspension system is able to dampen some of the front tire vibrations. Damping and Rotational Response: The suspension system analyzed in this study showed no effective damping, which resulted in vibrations not decreasing over time. The car's rotational response is +/- 0.02 degrees, which is relatively small but important in driving comfort analysis.

Effectiveness of MATLAB in Simulation: MATLAB is used effectively to simulate the vibration movement of a car using a symmetrical model. This simulation helps in visualization and recognition of vibration models in the vehicle body as well as the effect of changes in stiffness and damping coefficient on the vehicle structure.

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