

Vehicle Parameter Estimation Based on Full-Car Dynamic Testing

Yu Zhang
Hunan University

Lifu Wang
University of Technology

Bangji Zhang and Nong Zhang
Hunan University

ABSTRACT

Effectively obtaining physical parameters for vehicle dynamic model is the key to successfully performing any computer-based dynamic analysis, control strategy development or optimization. For a spring and lump mass vehicle model, which is a type of vehicle model widely used, its physical parameters include sprung mass, unsprung mass, inertial properties of the sprung mass, stiffness and damping coefficient of suspension and tire, etc. To minimize error, the paper proposes a method to estimate these parameters from vehicle modal parameters which are in turn obtained through full-car dynamic testing. To verify its effectiveness, a visual vehicle with a set of given parameters, build in the Adams(Automatic Dynamic Analysis of Mechanical Systems)/Car environment, is used to perform the dynamic testing and provide the testing data for the parameter estimation. Two parameter estimation methods based on half-car and full-car models are illustrated and compared with the parameters given in the Adams. Furthermore, the full-car parameter estimation method is applied on a bus, and the simulation results using the estimated parameters are compared with the data collected from real vehicle tests.

CITATION: Zhang, Y., Wang, L., Zhang, B., and Zhang, N., "Vehicle Parameter Estimation Based on Full-car Dynamic Testing," *SAE Int. J. Passeng. Cars - Mech. Syst.* 8(2):2015, doi:10.4271/2015-01-0636.

INTRODUCTION

Advanced vehicle control programs have been widely applied in automotive industry in the past few centuries, and their performances largely depend on how accuracy is the vehicle model they employed [1]. Thus, an appropriate model and correct parameters of the vehicle are essential for deriving these advanced controllers. The derived model should be sufficiently simple for the controller design and should also capture the system dynamic characteristics.

During the past years, many time-domain identification techniques have been developed to identify the parameters of the on-road vehicles to build more accurate vehicle dynamic model[2]. A large number of studies activities on modal parameter identification and physical parameter identification have been carried out. Here the modal parameters include the natural characteristics of a system[3], such as natural frequencies, damping ratios and modal shapes. And the physical parameters include the mass, stiffness and damping parameters of a system[4,5]. These parameters are essential to accurate vehicle dynamic models that are widely used in research[6,7].

The parameter estimation in practice is always with difficulties. Previous presented methods not only are time consuming but also require expensive sensors, such as Identification Measurement Unit,

ground clearance and wheel force measurements, which are expensive [8,9]. In contrast, parameter estimation methods based on vehicle drop tests are less expensive and also can achieve good accuracy. The proposed estimation approach is simple and cost effective. It has two steps as shown in Figure 1., (1) estimation of the modal parameters of a vehicle from its free decay responses[10,11]; (2) estimation of the physical parameters of the vehicle from its modal parameters by solving the inverse problem.

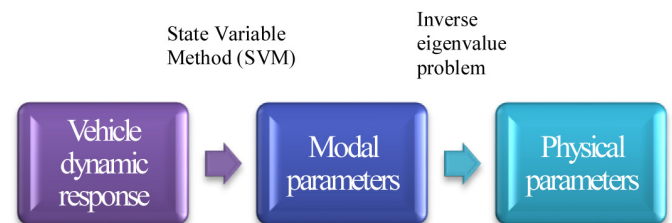


Figure 1. Flow chart of the procedure of vehicle parameter estimation.

The first step of estimation employs the SVM to extract the transition matrix of the vehicle system from its free decay responses. By solving the eigenvalues problem of the derived transition matrix, the modal parameters of the vehicle system can be obtained, such as natural frequencies and damping ratios. The next step is to reconstruct the system characteristic matrix from the obtained

eigenvalues, which is the so-called inverse eigenvalues problem. As the system matrix certainly exists in this case, and its form is known from the modelling, a numerical solution is developed to estimate the mass-spring parameters in the vehicle model.

To verify the proposed method, a visual vehicle with given parameters in the multi-body simulation program Adams (Automatic Dynamic Analysis of Mechanical Systems) is employed. The proposed method is applied to estimate the parameters of this “visual vehicle”, and compare the results with its given values. And the vehicle model information in the Adams/Car is obtained from the software data navigation.

Vehicle Simulation Model

The simulation model, using the “Vehicle_full_4post_PAC2002” model in the database of the Adams/Car which is shown in Figure 2, indicates the model which is to be simulated for the vehicle drop-test, the simulation model using the “Full-Vehicle Analysis/ Four Poster Testing” shown in the Figure 2. Then get the acceleration response for the estimation of vehicle system from the Postprocessor Tool.



Figure 2. The simulation vehicle model

Vehicle Parameter

In the Adams/Car, use the Database Navigator to extract the physical parameters from the simulation vehicle, can get the body inertial properties, unsprung mass, the suspension stiffness and the tire stiffness parameters which can be found and are shown in the Table 1.

Table 1. Reference vehicle properties in the ADAMS/CAR model

variable	value	unit
Vehicle Sprung Mass (m_s)	1312	kg
Front Unsprung Mass (m_{uf})	52.9	kg
Rear Unsprung Mass (m_{ur})	72.4	kg
Roll Inertial (I_{xx})	475	kg.m ²
Pitch Inertial (I_{yy})	5081	kg.m ²
COG location(a)	1.48	m
COG location(b)	1.08	m
The distance between the front left and right spring installation(l_f)	0.5	m
The distance between the rear left and right spring installation(l_r)	0.5	m
Front Spring Stiffness (k_{sf})	125000	N/m
Rear Spring Stiffness (k_{sr})	125000	N/m
Front tire Stiffness (k_{tf})	210000	N/m
Rear tire Stiffness (k_{tr})	210000	N/m

PROPOSED METHODOLOGIES

This section describes the theoretical basis of the proposed methodology for identifying physical parameters for spring-lump-mass type vehicle models. Consider that a vehicle can be modeled as different degree-of-freedom (DOF) vehicle model, the estimation methods are derived based on the four DOF half-car model and seven DOF full-car model.

The vehicle free decay responses are stimulated by simultaneously dropping a particular group of the vehicle tires from blocks to flat ground, according to different motion-modes. Theoretically, we can stimulate the vehicle in such a way that its response contains all of four motion-modes; however, when processing the data, the noise mode may overwhelm the four motion-modes. To enlarge the signal-noise ratio, both bounce and roll tests are performed separately to obtain more accurate results. For instance, the vehicle roll mode can be stimulated by rolling one side of the tires off the blocks together and the bounce mode can be stimulated by rolling four tires off the blocks together.

The vehicle's free decay responses are obtained by accelerometers mounted on the strong point of the vehicle chassis, away from the engine and flexible structures.

Vehicle Half-Car and Full-Car Models

A bilateral symmetry four-DOF half-car model employed in the study is presented in Figure 3.

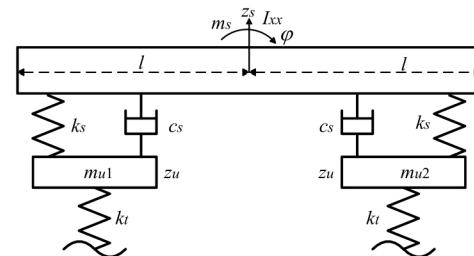


Figure 3. A four-DOF vehicle model

In the half-car model, we can obtain the following equation for the half-car system.

$$q_1 = [z_s \quad \phi \quad z_{u1} \quad z_{u2}]^T \quad (1)$$

$$M_{-1} = \begin{bmatrix} m_s & 0 & 0 & 0 \\ 0 & I_{xx} & 0 & 0 \\ 0 & 0 & m_{u1} & 0 \\ 0 & 0 & 0 & m_{u2} \end{bmatrix} \quad (2)$$

$$K_{-1} = \begin{bmatrix} 2k_s & 0 & -k_s & -k_s \\ 0 & 2l^2 k_s & -lk_s & lk_s \\ -k_s & -lk_s & k_s + k_t & 0 \\ -k_s & lk_s & 0 & k_s + k_t \end{bmatrix} \quad (3)$$

