

VIBRATION OF RAIL VEHICLES AND MODELLING OF SYSTEM BY USING MATLAB

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ABSTRACT

Investigation of vibration is an important topic for the purposes of ride comfort in railway engineering. The vibration of rail vehicles becomes very complex because it is affected by the condition of vehicles, including suspensions and wheel profile, condition of track sections, including rail profile, rail irregularities, cant and curvature.

To get the proximate approach for reality is the main object for the designer for the ride quality. So, during the obtaining of mathematical models, it is too important to consider all motion freedoms such as rolling, yawning, pitching, longitudinal, lateral and vertical motion.

In the present paper, the mathematical model of rail vehicle and related motion equations are established for a six degrees of freedom rail vehicle model consisting vertical and pitch movement of the vehicle and then, the steps for transferring the related mathematical model of the system to the MATLAB for the solution are presented.

Keywords: rail vehicle, vibration, vehicle dynamics

1. INTRODUCTION

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2. VEHICLE MODEL AND EQUATION OF MOTIONS

Lagrange method is presented due to energy equations in modeling. In the general form Lagrange Equation is given in equation (1):

$$\frac{d}{dt} \left(\frac{\partial E_k}{\partial \dot{x}_j} \right) - \frac{\partial E_k}{\partial x_j} + \frac{\partial E_p}{\partial x_j} + \frac{\partial E_D}{\partial x_j} = Q_j \quad (1)$$

It is explained below that how the movement equations are obtained for two degrees of freedom model given in figure 1:

Total kinetic energy equation of the system;

$$E_k = \frac{1}{2} [m_1 \dot{x}_1^2 + m_2 \dot{x}_2^2] \quad (2)$$

Total potential energy equation of the system;

$$E_p = \frac{1}{2} k_1 (x_1 - x_2)^2 + \frac{1}{2} k_2 (x_2 - x_y)^2 \quad (3)$$

Total damping energy equation of the system;

$$E_D = \frac{1}{2} c_1 (\dot{x}_1 - \dot{x}_2)^2 + \frac{1}{2} c_2 (\dot{x}_2 - \dot{x}_y)^2 \quad (4)$$

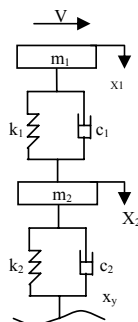


Figure 1. Quarter vehicle model.

$$m_1 \ddot{x}_1 + c_1 (\dot{x}_1 - \dot{x}_2) + k_1 (x_1 - x_2) = 0 \quad (5)$$

$$m_2 \ddot{x}_2 + c_1 (\dot{x}_2 - \dot{x}_1) + k_1 (x_2 - x_1) + k_2 (x_2 - x_y) + c_2 (\dot{x}_2 - \dot{x}_y) = 0 \quad (6)$$

In the matrix form equation (5) and (6);

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix} + \begin{bmatrix} c_1 & -c_1 \\ -c_1 & c_1 + c_2 \end{bmatrix} \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1 + k_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ k_2 \end{bmatrix} (x_y) + \begin{bmatrix} 0 \\ c_2 \end{bmatrix} (\dot{x}_y) \quad (7)$$

For the first integration of equations (5) and (6) it is possible to obtain speed and for the second integration it is possible to obtain displacement.

3. MODELLING OF RAIL VEHICLES

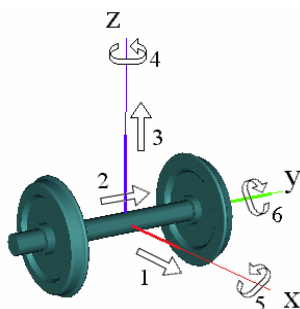


Figure 2. Wheelset degrees of freedom

A full rail vehicle consists of car body, bogie, wheelset, primary and secondary suspension. Due to the number of these components and their moving modes, model degrees of freedom are determined. In figure 2, the rotation around x (θ), y (ϕ), z (φ) axes are called rolling, pitch and yaw respectively. And also vertical (z), longitudinal (x) and lateral (y) motions are shown in the figure 2. Chudzikiewicz presented a wider expression by giving equations for all kinds of motion and also creep in his study[1].

To model rail and wheel relation it is useful to see the papers of. Esveld, Knothe and Jenkins and et all. for Hertzian spring [2,3,4]. Furthermore, for the dynamic response of vehicle-track interaction Yalcin and et all, have analysed rail vehicle vibrations for different types of track and operating speeds [5].

3.1. Six Degrees of Freedom Rail Vehicle Model

Based on the model given in figure 3, m_g is the car body mass, m_b is the bogie mass and m_a is the axle mass, J_g is the car body inertia, J_b is the bogie inertia and J_a is the axle inertia. kes_1 , kes_2 , c_1 and c_2 are the secondary suspension stiffness and damping coefficients and k_1 , k_2 , c_3 and c_4 are the primary suspension stiffness and damping coefficients. kh_1 , kh_2 , are the Hertzian spring stiffness.

The rail vehicle model has six degrees of freedom; Z_g , Z_b , Z_a , θ_g , θ_b , θ_a . Z_g is the vertical movement of car body, Z_b is the vertical movement of bogie and Z_a is the vertical movement of axle. θ_g , θ_b , θ_a are the yaw movement of car body, bogie and axle respectively. Z_{y1} and Z_{y2} are the irregularities on the track and regarded as a sinus function [6].

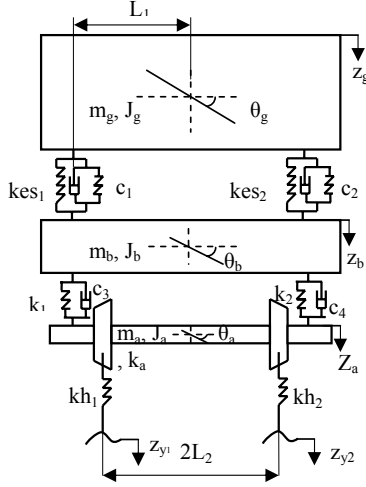


Figure 3. Quarter rail vehicle model[6].

The equations of motion of the rail vehicle are obtained by the use of the Lagrange Equation. The equation of motion of the rail vehicle system is:

$$[M]\ddot{z} + [C]\dot{z} + [K]z = Fz \quad (8)$$

$[M]$, $[C]$ and $[K]$ are mass, damping and stiffness matrices and $[Fz]$ is the force resulting track irregularity motion.

4. MATLAB/SIMULINK

Simulink able setting up dynamic system models by using block diagrams. So it is possible to examine the systems as in a laboratory. The equations of motion obtained from the former part are given in the MATLAB form in equations (9)-(14):

$$(-1/mg)*(kes1*((u[1]-u[3])-L1*u[7])+kes2*((u[1]-u[3])+L1*u[7])+c1*((u[2]-u[4])-L1*u[8])+c2*((u[2]-u[4])+L1*u[8])) \quad (9)$$

$$(-1/m_b)*(-kes1*((u[1]-u[3])-L1*u[7])-kes2*((u[1]-u[3])+L1*u[7])+k1*((u[3]-u[5])-L1*u[9])+k2*((u[3]-u[5])+L1*u[9])-c1*((u[2]-u[4])-L1*u[8])-c2*((u[2]-u[4])+L1*u[8])+c3*((u[4]-u[6])-L1*u[10])+c4*((u[4]-u[6])+L1*u[10])) \quad (10)$$

$$(-1/m_a)*(-k1*((u[3]-u[5])-L1*u[9])-k2*((u[3]-u[5])+L1*u[9])+kh1*((u[5]-u[13])-L2*u[11])+kh2*((u[5]-u[14])+L2*u[11])-c3*((u[4]-u[6])-L1*u[10])-c4*((u[4]-u[6])+L1*u[10])) \quad (11)$$

$$(-1/J_g)*(-kes1*L1*((u[1]-u[3])-L1*u[7])+kes2*L1*((u[1]-u[3])+L1*u[7])-c1*L1*((u[2]-u[4])-L1*u[8])+c2*L1*((u[2]-u[4])+L1*u[8])) \quad (12)$$

$$(-1/J_b)*(-k_1*L_1*((u[3]-u[5])-L_1*u[9])+k_2*L_1*((u[3]-u[5])+L_1*u[9]) -c_3*L_1*((u[4]-u[6])-L_1*u[10])+c_4*L_1*((u[4]-u[6])+L_1*u[10])) \quad (13)$$

$$(-1/J_a)*(-k_h1*L_2*((u[5]-u[13])-L_2*u[11])+k_h2*L_2*((u[5]-u[14])+L_2*u[11])) \quad (14)$$

These equations (9)-(14) are written in the boxes named as vertical motion of car body, bogie and axle(wheelset) and yaw of car body, bogie and axle (wheelset) respectively. And then, with the help of m.file it is possible to realize the simulations for asked parameters.

4.1. Create a Model in Simulink

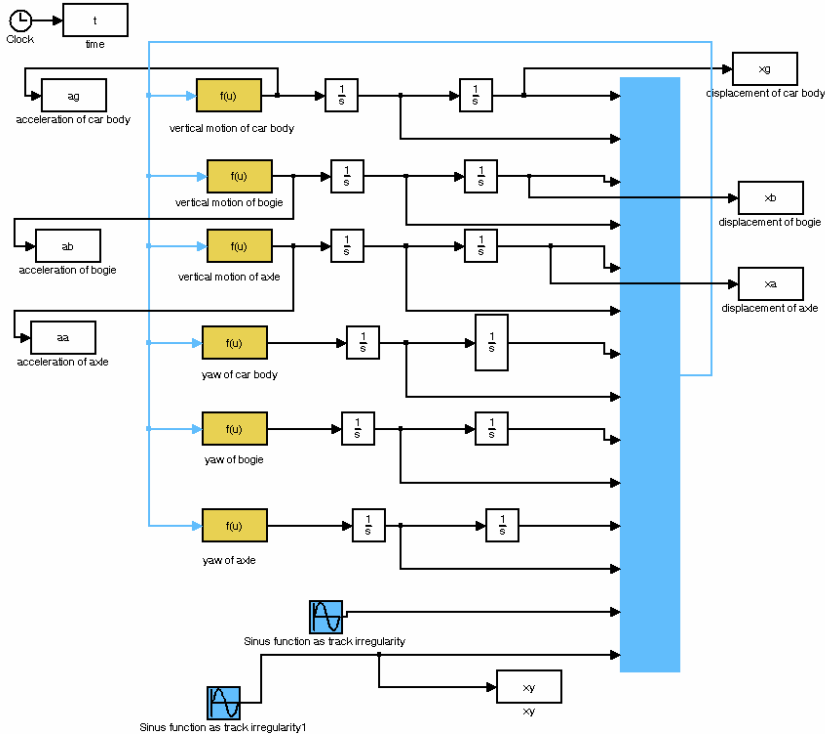


Figure 4. Simulink block diagram of quarter rail vehicle model.

5. RESULTS

The application of the MATLAB as environment gives us a chance to build a user friendly interface and using the possibilities of the MATLAB/Simulink made the package open for inserting new options by the user as well as decreasing the time of preparing and carrying out the simulation process. In the light of this paper it is possible to obtain motion equations for all degrees of freedom systems and to realize the simulation in MATLAB/Simulink.

6. REFERENCES

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