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MODELLING OF AIR SPRINGS IN A RAIL VEHICLE

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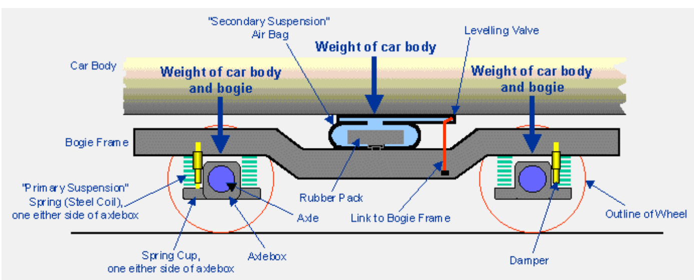
ABSTRACT
The quality of ride is predominantly controlled by the design of the secondary suspension in rail vehicles. That is why air springs are increasingly important suspension component in rail vehicles. This is necessary for higher preload, higher speed as well as improved ride dynamics and noise levels. These necessities have created an interest for modeling the air springs for the simulations of train dynamics.
In this study, some kinds of air spring models such as simple spring-damper model, Nishimura, Vampire, Simpac and Gensys are explained. Then, the secondary suspension in the bogie of the rail vehicles serving in Istanbul Transportation Co. in Istanbul have been modeled as a simple spring-damper model and Nishimura model. Finally, the results of these two models have been presented.
Keywords: railway vehicle, secondary suspension, air springs

1. INTRODUCTION
In railway vehicles, suspension systems are used for isolating vibrations and improving comfort for the passengers. Also, the suspension is necessary for reducing the forces between wheels and rail. A bogie supporting railcar body is mainly composed of four bodies; the bolster, frame and two wheelsets (see figure1).The bolster is rigidly fixed to the carbody. The primary suspension is classically modeled by linear springs and dampers between the bogie frame and the bolster [1,2]. On the other hand, the secondary suspension generally consists of air springs [3]. In figure 2 it is possible to see different models for air spring.



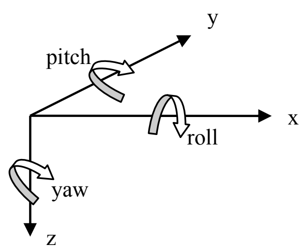


Figure 1. Diagram of bogie with steel primary and air spring secondary suspension [4].

The Vampire model handles vertical and horizontal behavior of the spring. Gensys model is three dimensional and can describe lateral, longitudinal and vertical behavior of the air spring. It is described for elasticity friction and viscosity effects. The vertical model has a non linear damping.

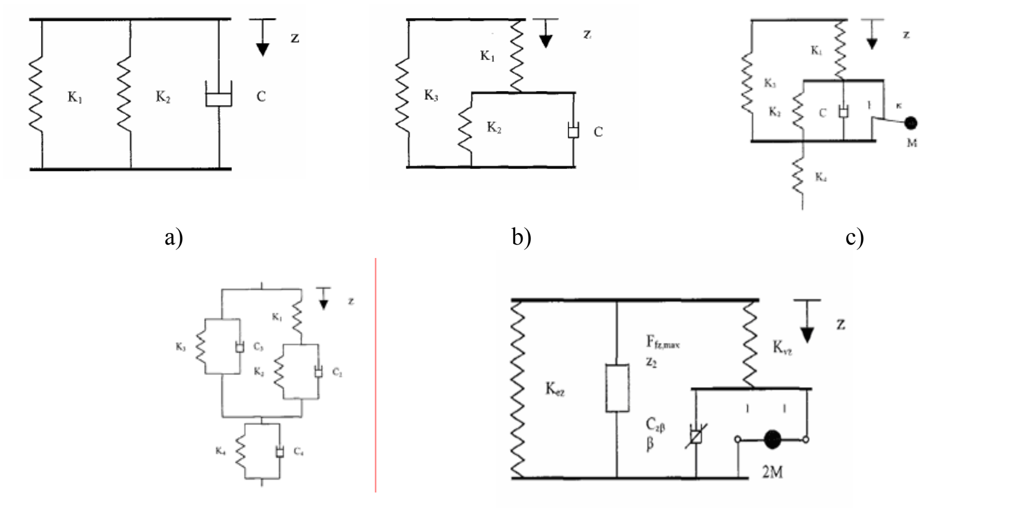


Figure 2. Air spring models a) a simple model for vertical air spring dynamics, b) Nishimura air spring model, c) Vampire air spring model, d) Simpack linear air spring model, e) Gensys model [5].

This work deals with the modeling of secondary suspension in a rail vehicle. Firstly, the secondary suspension of the rail vehicle is modeled as a simple spring-damper model [6] and then a Nishimura spring model. The simulations are resulted by obtaining the displacements and accelerations of car body, bogie and wheelset. Also the frequency responses of these components for a sinus function which is defined as irregularities on the track. This track irregularity has 0.1m amplitude and 20m wavelength.

2. THE RAILWAY VEHICLE MODEL

Based on the rail vehicle model given in figure 3 has 16 degrees of freedom: $Zg_1, Zg_2, Zb_1, Zb_2, Zb_3, Zt_1, Zt_2, Zt_3, Zt_4, Zt_5, Zt_6, \theta g_1, \theta g_2, \theta b_1, \theta b_2, \theta b_3$.

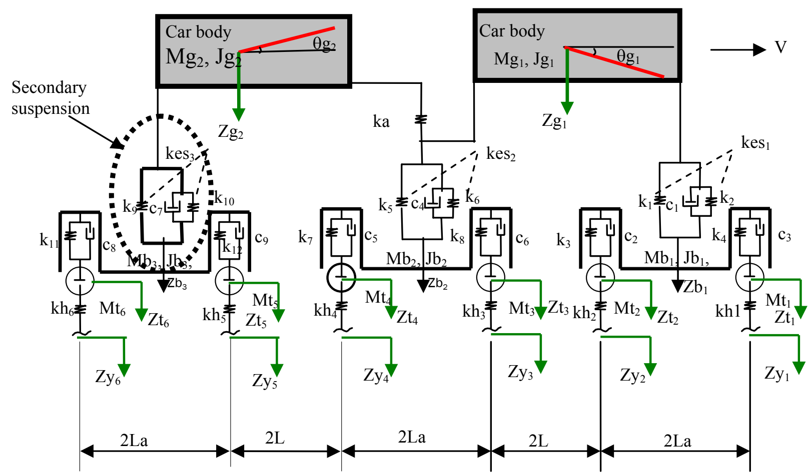


Figure 3.Rail vehicle model (16 degrees of freedom)

Zg is the vertical movement of the car body, Zb is the vertical movement of the bogie and Zt is the vertical movement of wheelset. θg and θb are the pitch of car body and bogie respectively. $Zt_1, \ldots Zt_6$ are the vertical movements of wheelsets.

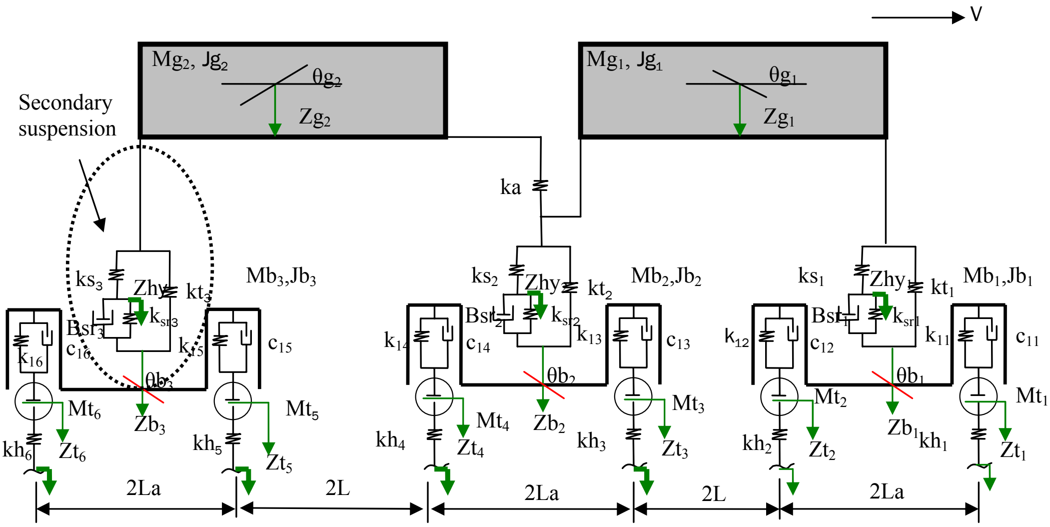


Figure 4.Rail vehicle model (16 full and 3half degrees of freedom)

The second rail vehicle model has 16 full and 3 half degrees of freedom: Zg_1, Zg_2, Zb_1, Zb_2, Zb_3, Zt_1, Zt_2, Zt_3, Zt_4, Zt_5, Zt_6, Zhy_1, Zhy_2, Zhy_3, θg_1, θg_2, θb_1, θb_2, θb_3. As a distinct from the first model, Zhy is the vertical movement of air spring in this model.

For both of two models given in figure 3 and 4, Mg_1 and Mg_2 are the car body masses, Mb_1, Mb_2 and Mb_3 are the bogie masses, Mt_1, Mt_2, Mt_3, Mt_4, Mt_5 and Mt_6 are wheelsets masses.Jg_1 and Jg_2, Jb_1, Jb_2 and Jb_3 are inertia moments of car body and bogie. Also, for the first model, k_3, k_4, k_7, k_8, k_{11}, k_{12} and c_2, c_3, c_5, c_6, c_8, c_9 are the primary suspension stiffness, damping coefficients. kes_1, kes_2, kes_3 and c_1, c_4, c_7 are the second primary suspension stiffness, damping coefficients. For the second model, k_{11}, k_{12}, k_{13}, k_{14}, k_{15}, k_{16} and c_{11}, c_{12}, c_{13}, c_{14}, c_{15}, c_{16} are the primary suspension stiffness, damping coefficients. ks_1, ks_2, ks_3, ksr_1, ksr_2, ksr_3, kt_1, kt_2, kt_3, and Bs_1, Bs_2, Bs_3, are the air spring stiffness, damping coefficients. kh_1,…kh_6 are the Hertzian spring stiffness defining the wheel-rail contact in linear form[7].

2.1. Simulations

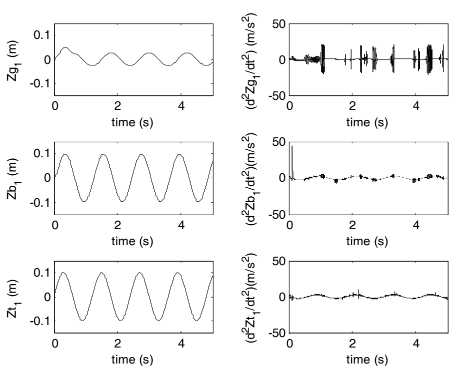


Figure 5. Displacement and acceleration of car body (Zg_1), bogie (Zb_1) and wheelset (Zt_1) for train speed V=60 km/h.

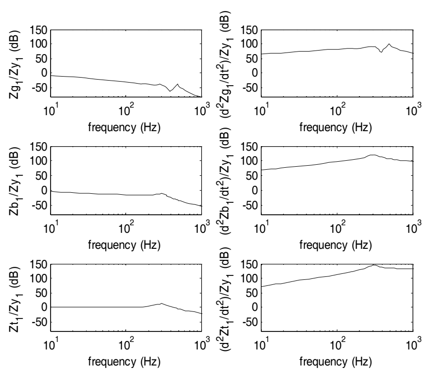


Figure 6. Frequency responses of car body (Zg_1), bogie (Zb_1) and wheelset (Zt_1).

The equations of motion of the railway vehicle are obtained by the use of the Lagrange Equation. And the simulations have been realized in Simulink /MATLAB. The results of simulations are given in figures 5-8.

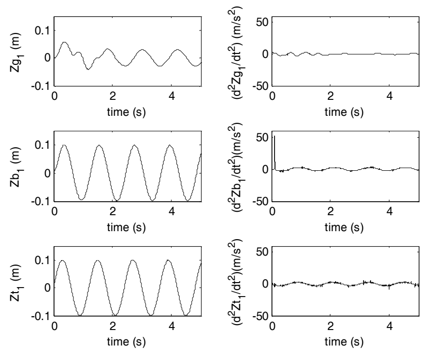


Figure 7. Displacement and acceleration of car body (Zg_1), bogie (Zb_1) and wheelset (Zt_1) for train speed V=60 km/h.

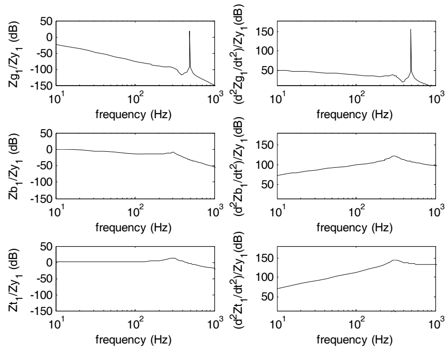


Figure 8. Frequency responses of car body (Zg_1), bogie (Zb_1) and wheelset (Zt_1).

3. RESULTS

In this study, the vertical motions of the rail vehicle car body bogie and wheelset have been investigated and the frequency responses have been obtained. In figures 5 and 7, the displacements of car bodies are about 0.05m for the sinus function input as irregularity on track which has 0.1m amplitude, but the displacements of the bogies and the wheelsets are the same. When figures 6 and 8 have been compared, it is seen that the frequencies have increased.

4. REFERENCES

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Parameters of 16 degrees of freedom and 16 full and 3 half degrees of freedom rail vehicle model.

M_{g1}=6500kg	J_{g1}=37550kg/m^2	k_{11}=1600000N/m	k_{14}=1600000N/m	ksr_3=488000N/m	c_{12}=400000Ns/m
M_{g2}=6500kg	J_{g2}=37550kg/m^2	k_{12}=1600000N/m	k_{15}=1600000N/m	c_1=400000Ns/m	c_{13}=110000Ns/m
M_{b1}=1750kg	J_{b1}=1121kg/m^2	k_3=1600000N/m	k_{16}=1600000N/m	c_2=1100000Ns/m	c_{14}=110000Ns/m
M_{b2}=1000kg	J_{b2}=640kg/m^2	k_4=1600000N/m	ks_1=1160000N/m	c_3=1100000Ns/m	c_{15}=110000Ns/m
M_{b3}=1750kg	J_{b3}=1121kg/m^2	k_7=1600000N/m	ks_2=1160000N/m	c_4=400000Ns/m	c_{16}=110000Ns/m
M_{t1}=275kg	L=3,2m	k_8=1600000N/m	ks_3=1160000N/m	c_5=110000Ns/m	Bsr_1=350000Ns/m
M_{t2}=275kg	L_a=0,9m	ka=8.10^{9}N/m	kt_1=508000N/m	c_6=110000Ns/m	Bsr_2=350000Ns/m
M_{t3}=200kg	V=60km/h	$kh_1…kh_6$= 1015549009N/m	kt_2=508000N/m	c_7=40000Ns/m	Bsr_3=350000Ns/m
M_{t4}=200kg	kes_1=7244N/m	k_{11}=1600000N/m	kt_3=508000N/m	c_8=110000Ns/m	
M_{t5}=275kg	kes_2=7244N/m	k_{12}=1600000N/m	ksr_1=488000N/m	c_9=110000Ns/m	
M_{t6}=275kg	kes_3=7244N/m	k_{13}=1600000N/m	ksr_2=488000N/m	c_{11}=400000Ns/m	