Estimating coach suspension parameters through stop braking: Analytical modeling and validation

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Abstract

Air springs, used in secondary suspensions, are complex. Their behaviour depends on amplitude and frequency of dynamic displacement, air pressure (absolute), reservoir volume, surge pipe length, orifice diameter, etc. [2]. Current methods for estimation of secondary suspension parameters include lab based tests [1], roll rigs [3,4] and wedge test [5]. Objectives of these tests are to evaluate the suspension parameters for newly design secondary suspension and while conducting acceptance test of a new vehicle. However, these tests cannot be used to check the performance parameters of secondary suspension during regular running. Hence, in this work we purpose a simple method to estimate secondary suspension parameters during regular running. For this purpose, coach pitching free vibrations during stop braking, are monitored to determine vertical secondary suspension parameters. Spring compressions of a driver motor car, in a six car train, were monitored in oscillation trials on a newly built track in Kolkata, India. Figure 1 shows a photographs of the LVDTs used in the field trials. Four LVDTs were used to record secondary spring compressions and eight LVDTs were used to record primary spring compressions (four on each bogie).

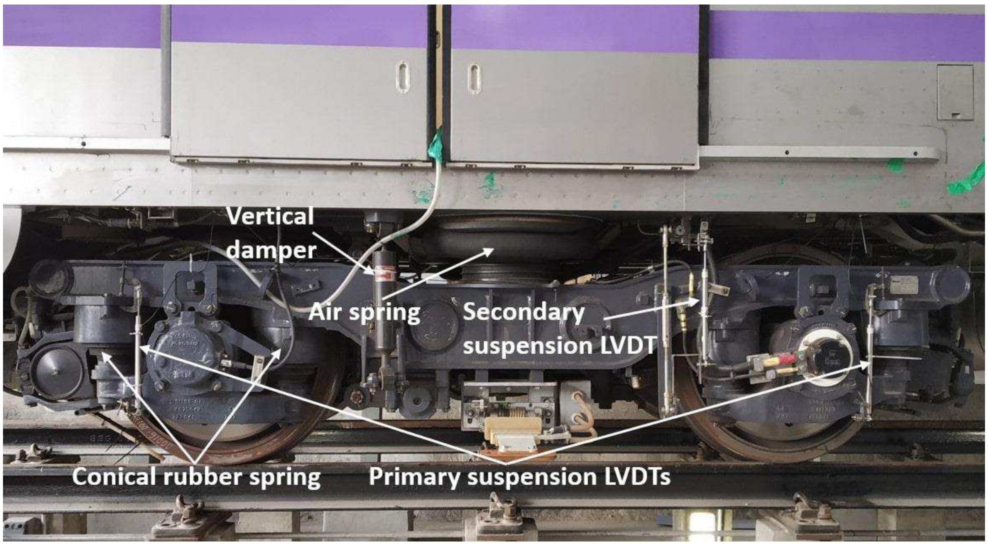

Figure 1: LVDTs used for measuring primary and secondary spring compressions.

Well defined coach free vibrations were observed for around 2 seconds, at stop braking. Figure 2 shows the pitching displacement at secondary spring location and the corresponding filtered signal. Natural frequency and damping ratio associated with these vibrations are determined using the logarithmic decrement method. A simplified six degrees of freedom (DOF) coach model is developed that characterizes these free vibrations. Expression for coach pitching frequency is shown by Equation (1). Vertical secondary suspension parameters in the model are obtained by matching model predictions for coach pitching natural frequency and damping ratio with that observed from trials. The analytical model is validated by comparing natural frequencies predicted from the model, through closed form expressions, with that from the coach model built in commercial multibody dynamics software Simpack. Table 1 shows the comparison between natural frequencies obtained from Simpack and analytical models for coach pitching and bouncing modes. The method adopted here for estimating secondary suspension parameters, is simple and robust, and can be used for online monitoring of these parameters.

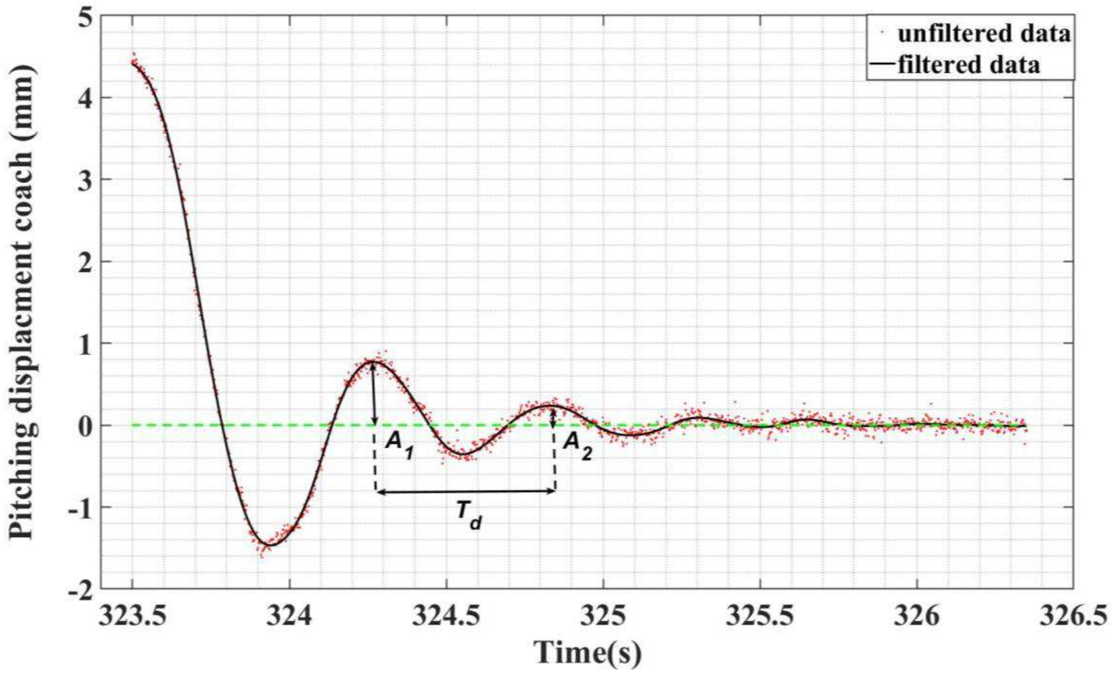

Figure 2: Pitching displacement of coach at secondary spring location during stop braking. Dots represents the unfiltered LVDT signal. Solid line represents the signal after passing through Butterworth filter of fourth order with cutoff frequency of 3 Hz.

$$\text{Coach pitching, } f_p^c = \frac{1}{\pi}\left[\frac{k_z^s\left(L^{sck}\right)^2}{2I^*} + \frac{k^*}{2m^*} - \frac{\sqrt{-16A^* k_z^p k_z^s\left(L^{sck}\right)^2 + \left[k^* I^* + k_z^s\left(L^{sck}\right)^2 m^*\right]^2}}{2A^*}\right]^{0.5} \quad (1)$$

where k_z^s is secondary spring stiffness, L^{sck} is the distance from center of the coach to the LVDTs position measuring secondary spring compression along the length of the coach, $I^* = I_{yy}^c + m^c h_c^2$, $k^* = 4k_z^p + k_z^s$, $m^* = m^{b1} + m^{b2}$, $A^* = (I_{yy}^c + m^c h_c^2)(m^{b1} + m^{b2})$, I_{yy}^c is the mass moment of inertia about lateral axis, m^c is the mass of the coach, k_z^p is primary spring stiffness, m^{b1} and m^{b1} are the mass of the bogies and h_c is the vertical distance between coach floor and its center of gravity.

Table 1: Natural frequencies (Hz) obtained from analytical and Simpack models.

	Analytical		Simpack	
	Pitching	Bouncing	Pitching	Bouncing
Tare (empty)	2.65	2.40	2.57	2.42
Crush (laden)	1.88	1.75	1.89	1.78

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