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DYNAMICAL PARAMETRIC BEHAVIOR BASED ON CREEP COEFFICIENT FOR LINEARIZED RAILWAY VEHICLE WHEELSET MODEL

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Abstract

The essential dynamic parameters for proper running of vehicle through wheelset on rail track are discussed. Alternately state space equation is manipulated for application and observation of simulation results. The kinematic and torsional modes are watched by migration of eigenvalues through concerned stiffness properties. As creep coefficient has great importance with respect of adhesion to avoid slip. Hence two major maximum and minimum coefficients of creep are implemented to watch the attitude of eigenvalues with damping and frequency of railway wheels. The frequency behavior is also observed with vehicle velocity through wavelength. This research paper amends some principle ideas for stability of railway vehicle wheels over track.

Keywords: Creep coefficient, damping, eigenvalue, frequency kinematics, torsional mode, wavelength.

INTRODUCTION

When the value of yaw stiffness is comparatively low damping of torsional and kinematic mode is decreased as creep coefficients are increased. It is also important to note that the frequency of torsional mode decreases as creep coefficients are increased where as frequency of torsional mode remains almost constant [Charles *et al.* 2008]. A slightly higher value of yaw stiffness is used which makes kinematic mode more stable as compare to the previous case. Yaw stiffness does not affect the damping of torsional mode too much [Stefano Bruni *et al.* 2007].

Eigen values represent the signaling behavior of any model to review into system by expertizing characteristics such as the frequency of oscillation and damping of different modes. The dynamical attitude of the rail-wheel varies when velocity of vehicle, contact conditions are varying [Baeza *et al.* 2008]. An appropriate knowledge of the dynamical attitude of a rail-wheel needs enough scrutiny of wheelset dynamics in various speeds and contact conditions. An analysis of the railway wheels dynamics based on the small signal model is provided. Variations in natural frequency, damping and the root locus plots with respect to variation in contact conditions and at different values of speed and yaw stiffness are provided [Knothe *et al*. 2008].

The minimum and maximum values for the creep coefficients used are *g11=g22*=1×107 and *g11=g22*=1×105 respectively shows the frequency and damping variations of the kinematic mode when the vehicle is moving at a speed of 20 m s^{-1}. The stiffness of the yaw spring used in calculations is 1.5×106 N rad^{-1}. The natural frequency of the kinematic mode changes slightly as the contact condition is varied, whereas the damping ratio is decreased significantly with an increase in creep coefficient values [True *et al.* 2002 and Andersson *et al*. 2002].

The eigenvalue migration of the kinematic and high frequency modes for the same speed and yaw stiffness used shows the locus of the eigenvalues as the creep coefficient is increased. The values on the right-hand side of the zero on the horizontal axis represent the stable part of the plane, and the right-hand side of the plane is an unstable portion. As the creep coefficient is increased, the kinematic mode eigenvalues move towards instability, whereas in the high frequency mode the eigenvalues are moving further away from the unstable region of the plane, and the right-hand side of the plane is an unstable portion [Pombo *et al*. 2007]. As the creep coefficient is increased, the kinematic mode eigenvalues move towards instability, whereas in the high frequency mode the eigenvalues are moving further away from the unstable region. When the longitudinal velocity of the vehicle is enhanced up to 80m/s the frequency of the kinematic mode is also raised [Lata and Michael 2008].

In this paper, the applicable dynamic factors in shape of mathematical formulations are modeled. These parameters are used for acquiring the simulation results pertaining upon higher and lower creep coefficients segments. This relationship of frequency of wheelset is assimilated with eigenvalues and damping in first portion. In second part it is compared with velocity of vehicle and concerned wavelength.

RAILWAY WHEEL DYNAMIC PARAMETERS

For proper stability of railway vehicle running over track, it is very essential to learn the fundamental dynamic parameters. This perception can help the railway wheelset to slip away from rail road. The rail track for running of left and right wheels axle within center line is sketched usually for concept.

The railway vehicle has three speeds in basically three directions as forward, lateral and yaw velocities [Popp *et al*. 2003] along with creepages are explained in following mathematical relations.

$$\dot{y} = V \sin\psi \cong v.\psi$$

Where $\dot{y}$ is lateral velocity and ψ is yaw motion.

$$\dot{\psi} = \frac{V_L - V_R}{2l_o} = -\frac{\omega.\Delta r}{2l_o} = -\frac{V}{l_o r_o}\lambda.y$$

This is yaw velocity with λ=creep, ω= angular velocity, l_o= Outer length of the axle, and r_o= outer radius of the wheel.

$$\lambda_x = \frac{v_w - v}{v}$$

$$\lambda_y = \frac{\dot{y}}{v} - \psi$$

These are longitudinal and lateral Creepages.

$$\lambda = \sqrt{\lambda_x^2 + \lambda_y^2}$$

This is total creepage [Soomro *et al.* 2014].

$$\varphi = \frac{V}{2\pi}\sqrt{\frac{\lambda}{l_o r_o}}$$

$$\zeta = \frac{\varphi}{V} = 2\pi\sqrt{\frac{l_o r_o}{\lambda}}$$

Above Eqs. for φ and ζ represent frequency and wavelength of vehicle respectively.

$$\mathrm{E} = [\omega_R \;\; \omega_L \;\; \theta_s \;\; \dot{x} \;\; y \;\; \psi \;\; \dot{y} \;\; \dot{\psi}]$$

Where

$$\theta s = \int (\omega_R - \omega_L)dt$$

This is state space equation consisting crucial railway dynamic parameters used for determining eigenvalues in subsequent section of simulation.

RESULTS AND DISCUSSION

Above mathematical equations are used for observing the behavior of dynamic parameters by simulating graphical results. Above equation (9) is used for generating the required below tables eigenvalues, damping and frequency based upon higher and lower co-efficient of creep [Soomro 2014]. It should be noted that the imaginary parts of the eigenvalues are ignored for the simulation to gain the results.

BEHAVIOR OF EIGENVALUES AT HIGHER CREEP COEFFICIENT

Table 1 represents the eigenvalues, damping and frequency of the railway vehicle wheelset based upon higher creep coefficient. In this Table, it can be observed that both damping and frequency parameters are increased upon decline of eigenvalues. It is also observed that on increase of damping, frequency of wheelset decreases.

Table 1: Dynamical parameters with higher creep coefficients.

Eigenvalue	Damping	Freq. (rad/s)
0.00e+000	-1.00e+000	0.00e+000
-2.49e+003	1.00e+000	2.49e+003
-1.20e+003	1.00e+000	1.20e+003
-8.00e+002	1.00e+000	8.00e+002
-1.74e+001 + 2.25e+002i	7.73e-002	2.26e+002
-1.74e+001 - 2.25e+002i	7.73e-002	2.26e+002
-2.28e+000 + 1.22e+001i	1.85e-001	1.24e+001
-2.28e+000 - 1.22e+001i	1.85e-001	1.24e+001

In Fig. 1, the migration of eigenvalues at higher creep coefficient is displayed. Here kinematic mode is compared with torsional mode in the form of eigenvalues in either plane. The nominal yaw and kinematic stiffness values are implemented as 10e5 and 6063260 respectively for overall simulated results usage in higher and lower creep coefficient analysis.

Fig. 1 indicates that eigenvalues travel on vertical scale from zero horizontally on -2500, -1200, -800 and 0 in straight path. On point -800 it is also branched inclined at 225 on vertical scale, then it turns downwardly at points 10 and -10 concurrently to 0. Finally it ends at - 225 down vertical. This shows same attitude of positive eigenvalues parallel to negative values in only vertical plane, while horizontal eigenvalues remain zero. The direction of eigenvalues transfer is denoted by arrow.

Fig. 2 demonstrates the comparison of damping and frequency of railway wheelset with respect to eigenvalues within scaled time range. The black curve representing eigenvalues resembles the red curve for frequency in same manner at opposite directions. This conceives that frequency is inversely proportional to eigenvalues. While damping shows its neutral role for travelling with zero in horizontal direction.

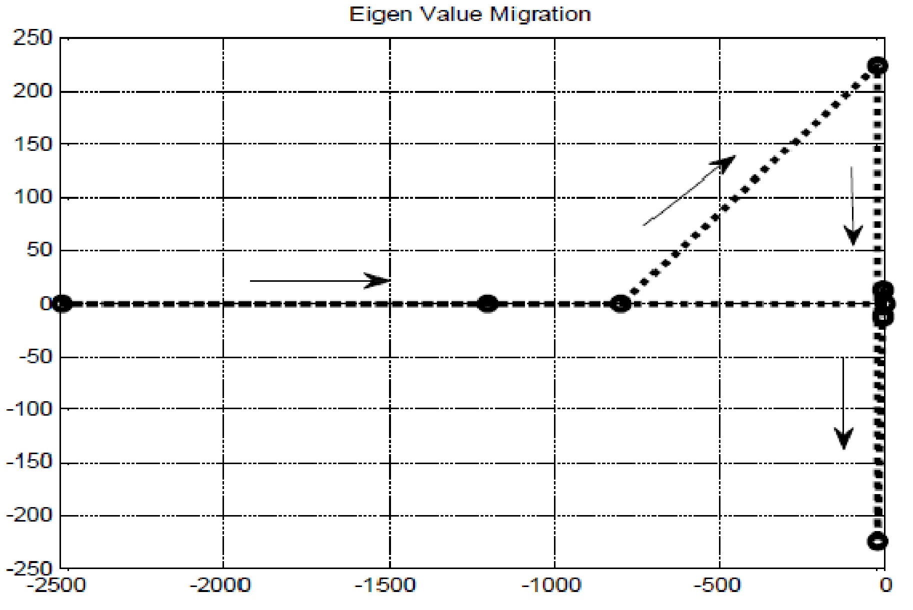

Fig. 1: Migration of eigenvalues travelling on higher creep coefficient.

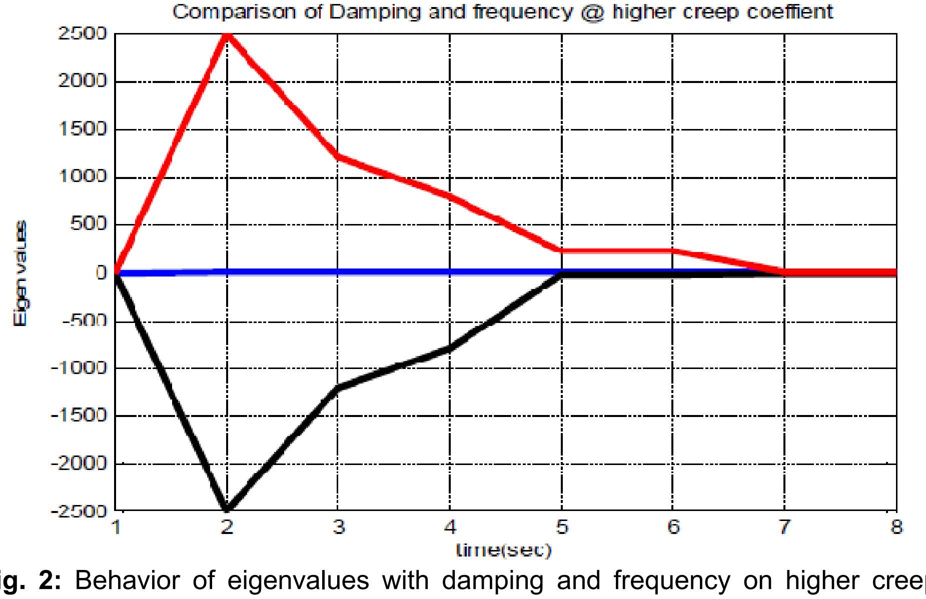

Fig. 2: Behavior of eigenvalues with damping and frequency on higher creep coefficient.

Fig. 3 represents the comparison of wavelength to vehicle velocity and frequency of wheels. Here wavelength denoted by black color remains nearly 30 constantly at overall time. While velocity denoted by red color increases from 10 to 80 m s^{-1} as speed provided to vehicle within range of time. The blue color displays frequency raise from zero to 2500 of wavelength on vertical scale in 2 seconds, then it goes down gradually in minor zigzag to end within 7 second. This reflects the idea that at inception of wavelength, frequency rises rapidly then it goes down with span of time.

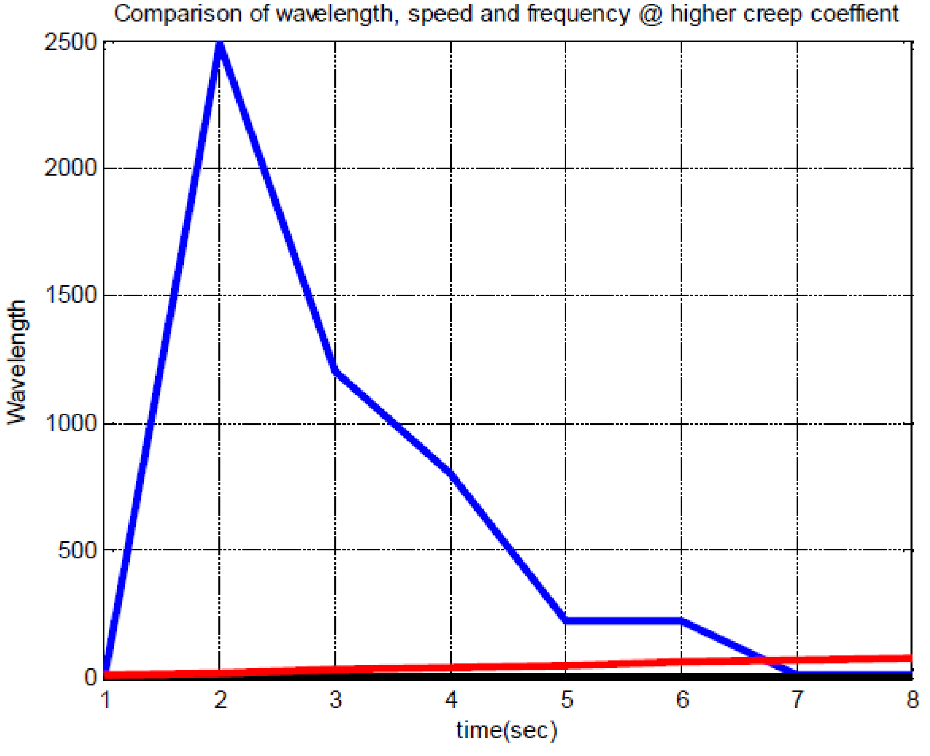

Fig. 3: Behavior of eigenvalues with speed and frequency at higher creep coefficient.

BEHAVIOR OF EIGENVALUES AT LOWER CREEP COEFFICIENT

Table 2 represents same dynamic parameters as discussed in Table 1 with only apparent difference in values. Here also both damping and frequency parameters increase on decrease of eigenvalues. The difference e between these two tables is that frequency increases on decrease of damping parameter.

Initially when eigenvalues are zero at first iteration, frequency also shows same result of zero rad s^{-1} in its first step except the damping in -1.0000 %. While at final stage both eigenvalue and frequency with same opposite sized values.

This Table 2 like Table 1 represents the eight cardinal dynamic railway vehicle wheelset parameters as used in state space equations as denoted in Eq. for E (see section Railway wheel dynamic parameters).

Here four dynamic parameters have imaginary values too, which are ignored for the simulating results and concerned graphs.

Table 2: Dynamic parameters with lower creep coefficient

Eigen value	Damping	Freq. (rad/s)
0.00e+000	-1.00e+000	0.00e+000
-8.26e+000 + 3.77e+002i	2.19e-002	3.77e+002
8.26c+000 3.77c+002i	2.19c 002	3.77c+002
-4.02e+000 + 6.42e+001i	6.25e-002	6.44e+001
-4.02e+000 - 6.42e+001i	6.25e-002	6.44e+001
1.28c+001	1.00c+000	1.28c+001
-7.68e+000	1.00e+000	7.68e+000
-3.24e-001	1.00e+000	3.24e-001

Fig. 4 represents the eigenvalues to show the comparison of kinematic and torsional stiffness modes based upon lower creep coefficient. The directions of the eigenvalues are displayed arrows.

In Fig. 4, it can be observed a different attitude of the eigenvalues in comparison to that of Fig. 2 for higher creep coefficient. Here it is perceived that four points of eigenvalues migrate in horizontal way at -13, -7.8, and –0.8, 0 to end zero with 0 of vertical direction. Similarly two maxima and minima values are denoted by ±380 and ±80 with vertical directions.

In Fig. 5, eigenvalues are compared with that of damper and frequency at lower creep coefficient. Here eigenvalues are denoted by black color migrates initially from zero with deviated sizes of 12, 8 and 14 with minor zigzag manner within specified time. While damping assigned by blue color with zero with horizontal in straight line as entire constant value. The red color represents the frequency rising to 380 in 2 seconds straightly up to 3 seconds to make trapezoidal till 40 with vertical then it ends with little fluctuation in prescribed time.

In Fig. 6, attitude of the wavelength with frequency and vehicle velocity is checked at lower creep coefficient. Here wavelength denoted by black color travels with limited value 8 along zero in straight path within stated time. The velocity of the vehicle starts at 10 to rise inclined at 80 of wavelength with vertical. While the main frequency of wheels denoted by red color makes same trapezoidal to that of Fig. 6 with ranges of both 380 upper within 2 to 3 seconds middle medians and outer time steps of 0 and 4 seconds. Then it ends in z shape within limited of 8 seconds.

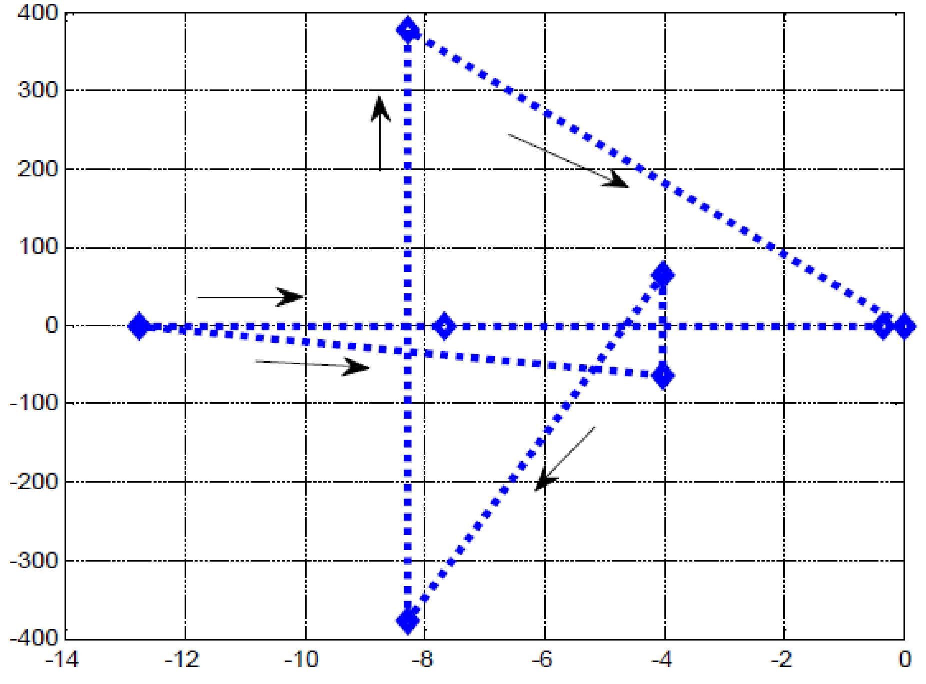

Fig. 4: Migration of eigenvalues travelling on lower creep co-efficient.

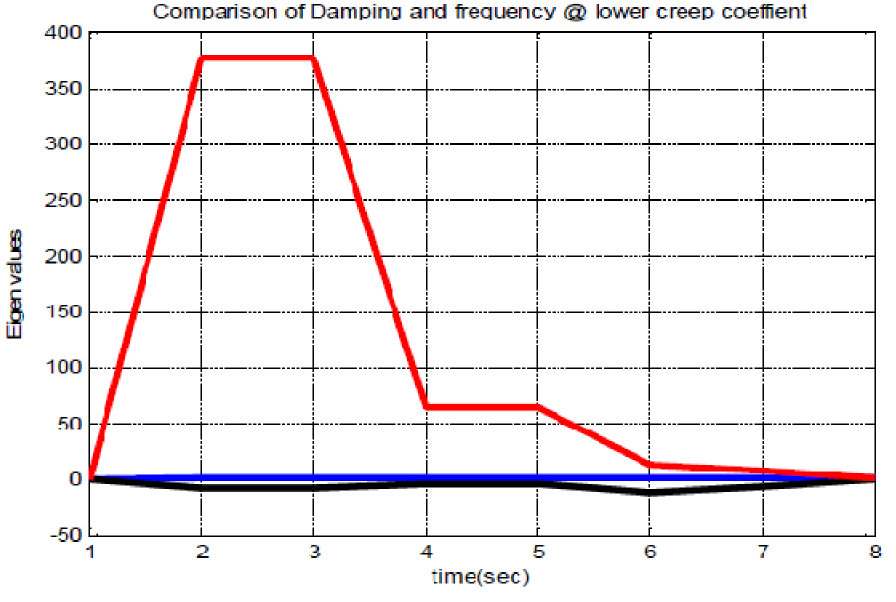

Fig. 5: Behavior of eigenvalues with damping and frequency at lower creep coefficient.

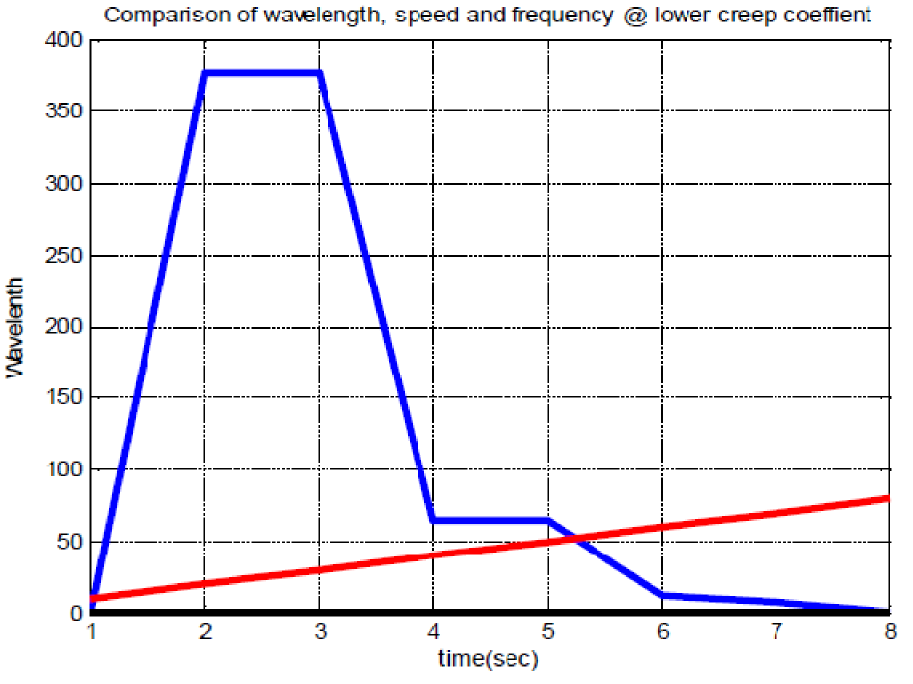

Fig. 6: Behavior of eigenvalues with speed and frequency at lower creep coefficient.

CONCLUSIONS

In simulation, kinematic mode is piloted with torsional mode in the shape of eigenvalues and nominal yaw and kinematic stiffness values are implemented. The simulation results are classified into two major categories of higher and lower creep coefficients for valid dynamic parameters like frequency, damping and velocity. The eigenvalues make one horizontal plane consisting four eigenvalues like that used for higher creep coefficient. While lower creep coefficient eigenvalues make two maxima and minima vertical planes having each of two eigenvalues different to that used for higher creep efficient.

For higher creep coefficient, the frequency of railway wheelset behaves opposite to eigenvalues used in different direction in same manner overlapping zero centerline of damping. While for lower creep coefficient, frequency makes shape of trapezoidal to smaller zigzag path of eigenvalues along with straight zero line at bottom.

The wavelength of both higher and lower creep coefficient to concerned frequency along with velocity is checked. The frequency of wheelset used for higher creep coefficient upwards by making peak different to that of used for lower creep coefficient making shape of trapezoidal with minor z shape at bottom. The velocity upwards inclined little more than that used for lower creep coefficient. The attitude of wavelength remains same in both cases of creep coefficients

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