Dynamical attitude of non-linearly parameters of rail wheel contact on application of creep coefficient

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Received: 18 October 2015 Accepted: 05 August 2016

Abstract

Non linearity is the complicated problem for the dynamic modeling parameters solutions. The frequency and damping along with wavelength and particularly bogie wavelength are the fundamental terms to analyze the proper running of the railway vehicle wheelset on track. In this paper the brief dynamics of railway wheel contact is discussed and eigen values are generated and simulated to analyze difference depending upon both for higher and lower creep coefficient. Thus damping and frequency of wheelset is also simulated with relation to eigen values to observe their attitude. The wavelength is also compared with frequency and velocity of vehicle based upon both higher and lower creep coefficients along with eigen values. With the help of these wavelengths, a bogie wavelength relationship is developed and observed to detect the performance of railway vehicle wheelset.

Keywords: Wavelength, lateral creepage, longitudinal creepage, damping, frequency, eigen values, adhesion

Introduction

Adhesion is an important factor in operating the railway vehicles properly. Certain level of adhesion is required to transmit the traction and braking forces properly [1]. If the adhesion falls below that level then wheels slip and slide during traction braking respectively. Wheel slip/slide is an undesirable phenomenon and results in excessive wear rails and wheels [2]. The level of adhesion depends upon weather conditions. The adhesion coefficient is a dimensionless quantity while the creep is ratio of difference of the longitudinal and rotational speed of wheel to longitudinal speed [3]. The wheelset dynamics analysis is applied to observe the behavior of concerned various parameters like speed and creep co-efficient on performance of railway wheelset on track. Since damping property and frequency should be deterministic to pass through these parameters for suitable running of wheelst on rail track [4,5].
Entire damping part is lower at higher speeds due to damping terms and thus creepage equations are .reduced [6] and at some resulting speed the wheelset that becomes unstable is known as the critical speed, which can be attuned by raising yaw stiffness. The eigen values of the kinematic mode migrate from the left half plane to the right half plane as the creep coefficient is increased [7]. A stiffer yaw spring stabilizes the kinematic mode at higher speeds. However, the high stiffness values of the yaw spring over-damp the kinematic mode at lower speeds. The damping of the kinematic mode is 100% at lower creep coefficient values when the vehicle is running at lower speeds [8]. Therefore, a suitable value for yaw stiffness should be chosen, keeping in mind the maximum speed of the vehicle, curve radius and various wheel-rail contact conditions [9].
The migration of eigen values for the kinematic and high frequency modes are at higher values of yaw stiffness. Both wheelset modes are over-damped at low creep coefficient values, while the eigen values of the kinematic mode move towards the unstable region as creep coefficients are increased, whereas high frequency eigen values move away [10]. However, the higher yaw stiffness values ensure the dynamic stability of the wheelset dynamics at higher vehicle speed values. The overall damping of the kinematic mode is higher at a vehicle speed of 80 m/sec when the yaw stiffness is 5×10^6 N/rad [11, 12].
In this paper, the fundamental dynamic non linear parameters are discussed along with their mathematical relationships. The primary Skelton railway dynamic parameters associated with state space equation matrix are used for simulation of procured eigen values for damping and frequency based upon higher and lower creep coefficient. Further creep coefficients are used to observe the attitude of wavelengths for bogie wavelength.

Non Linear Dynamic Parameters System

The non-linearity is the complicated problem for railway wheelset dynamics. Below is the simple sample of non linearity of dynamics analysis to detect the behavior of affecting parameters under concerned creepages [13,14].

$$\lambda_x = \frac{v_w - v}{v} \quad (1) \qquad \lambda_y = \frac{\dot{y}}{v} - \psi \quad (2)$$

These are the longitudinal and lateral creepages

$$\dot{y} = v.\psi \quad (3) \qquad \dot{\psi} = -\frac{V}{l_o r_o}\lambda.y \quad (4)$$

Where ẏ is lateral velocity and Ψ is yaw motion, λ=creepage, ω= angular velocity, l_o= Outer length of the axle, and r_o= outer radius of the wheel

$$\lambda = \sqrt{\lambda_x^2 + \lambda_y^2} \quad (5)$$

This is total creaapage [15,16].

$$\varphi = \frac{V}{2\pi}\sqrt{\frac{\lambda}{l_o r_o}} \quad (6)$$

$$\zeta = \frac{\varphi}{V} = 2\pi\sqrt{\frac{l_o r_o}{\lambda}} \quad (7)$$

Above equations (6) and (7) represent the frequency and wavelength of vehicle respectively.

$$\xi_b = \zeta\sqrt{1+\left(\frac{l}{l_o}\right)^2} \quad (8)$$

This is the relation of bogie wavelength

$$\varepsilon_{NL} = [\omega_R \ \omega_L \ \theta_s \ \dot{x} \ y \ \psi \ \dot{y} \ \dot{\psi}]_{nl} \quad (9)$$

Where $\theta s = \int(\omega_R - \omega_L)dt$ (10)

This is state space equation consisting essential railway non linear dynamic parameters used for determining eigen values in subsequent section of simulation to observe their attitude.

Methodology and Results

Above mentioned mathematical formulae are used for observing the non linear behavior of dynamic parameters by simulating graphical results by Matlab. Above equation (9) is used for creating the required below tables of eigen values, damping and frequency based upon higher and lower co-efficient of creep [17] where imaginary parts of the eigen values are ignored for the simulation to get results.

Behavior of eigen values at higher creep coefficient

The Table 1 represents the eigen values for damping and frequency of the railway vehicle wheelset based upon higher creep coefficient. In this table-1, when eigen values decrease then frequency of wheelset increases or almost remains similar to it. This frequency also rises on decline of damping or remains similar to it. Here imaginary values of X and Y for eigen values are ignored for simulation purposes.

Table 1: Nonlinear parameters with higher creep coefficient

Eigenvalue	Damping	Freq (rad/s)
-1.28×10^{-018}	$1.00\times10^{+000}$	1.28×10^{-018}
$-2.84\times10^{-014} + 1.26\times10^{003i}$	2.26×10^{-017}	$1.26\times10^{+003}$
$-2.84\times10^{-014} - 1.26\times10^{+003i}$	2.26×10^{-017}	$1.26\times10^{+003}$
$0.00\times10^{+000} + 6.44\times10^{+001i}$	$0.00\times10^{+000}$	$6.44\times10^{+001}$
$0.00\times^{+000} - 6.44\times10^{+001i}$	$0.00\times10^{+000}$	$6.44\times10^{+001}$
$0.00\times10^{+000}$	$-1.00\times10^{+000}$	$0.00\times10^{+000}$
$0.00\times10^{+000}$	$-1.00\times10^{+000}$	$0.00\times10^{+000}$
$0.00\times10^{+000}$	$-1.00\times10^{+000}$	$0.00\times10^{+000}$

In Fig 1, the migration of non linear eigen values for higher creep coefficient based upon kinematic and yaw stiffness has been displayed. This shapes like isosceles triangle whose one side starts from -1200 to 1200 on vertical side.

This curve then downwards nearly zero horizontally to meet at same starting point of -1200 on -3.8e-14 on horizontal plane. This shows the cycle of eigen migration from inception to end on it in triangular shape. In Fig 2, the relationship of eigen values with respect of damping and frequency is simulated within span of time. Here damping denoted by red color and eigen values shown by black color travel overlapping each other on straight line of zero. While frequency denoted by dotted red line makes trapezoidal shape on 0 to 1250 of eigen value vertically and 1-4 major points and minor 2-3 sec of time on horizontal to end by making small deflection before reaching zero. This line then travels in straight path on zero with damping and eigen values.

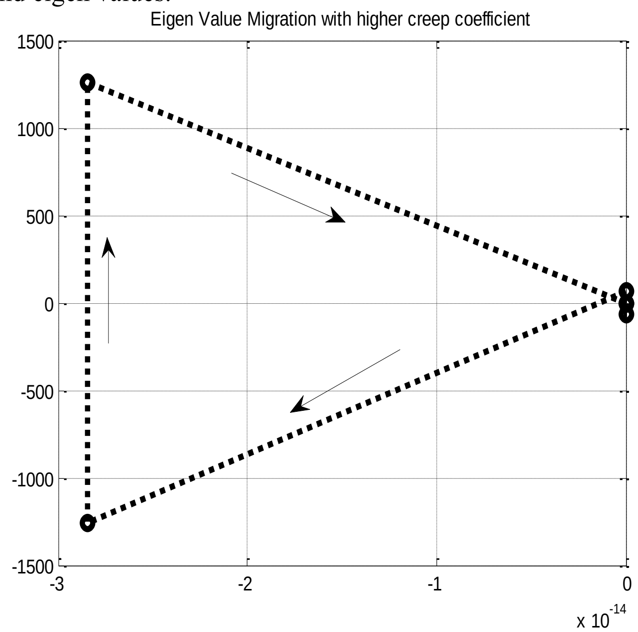

Fig. 1: Non linear migration of eigen values at higher creep coefficient.

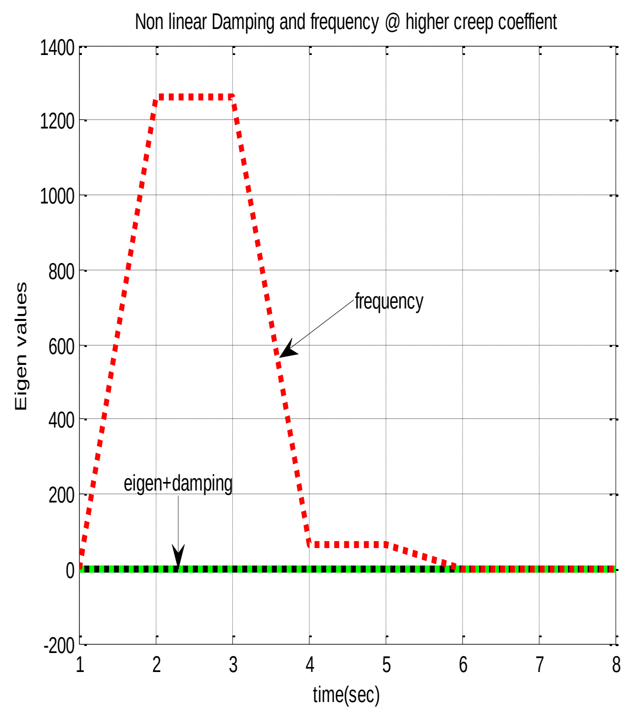

Fig. 2: Damping and frequency behavior of eigen values on higher creep coefficient

In Fig 3, the co-relationship of eigen values with respect of damping and frequency is denoted within required of time. Here wavelength denoted by black color travels on straight line of zero while velocity displayed by red color makes smaller inclined line over wavelength line. While frequency denoted by dotted blue line makes trapezoidal shape on 0 to 1250 of eigen value vertically and 1-4 major points and minor 2-3 sec of time on horizontal to end by making small deflection before reaching zero. This line then travels in straight path on zero with damping and eigen values. This sketch of frequency used for wavelength has same size points for the frequency of wheels used by eigen value in Fig 2.

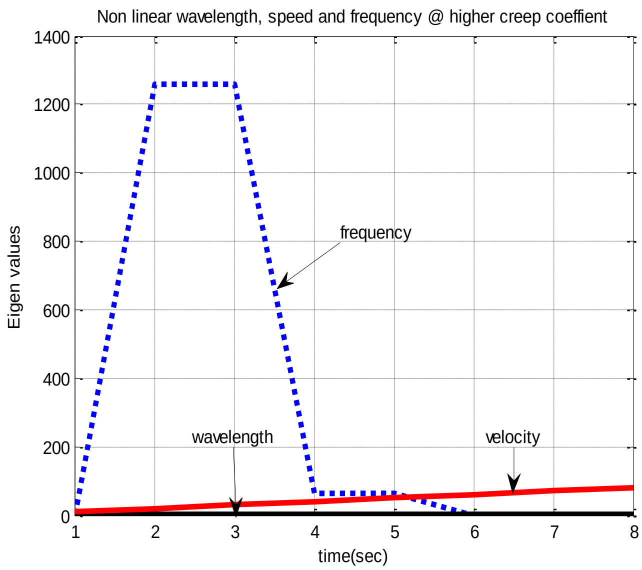

Fig. 3: Wavelength attitude with frequency and velocity

Behavior of eigen values at lower creep coefficient

In Table-2, the frequency has almost same values like eigen values even it may be like imaginary values of eigen values. While frequency is almost inverse to that of damping values or overall it may be higher than that of damping values.

Table 2: Non-linear parameters with lower creep coefficient

Eigenvalue	Damping	Freq. (rad/s)
-9.65×10^{-016}	$1.00\times10^{+000}$	9.65×10^{-016}
$1.42\times10^{-014} + 3.77\times10^{+002i}$	-3.77×10^{-017}	$3.77\times10^{+002}$
$1.42\times10^{-014} - 3.77\times10^{+002i}$	-3.77×10^{-017}	$3.77\times10^{+002}$
$0.00\times10^{+000} + 6.44\times10^{+001i}$	$0.00\times10^{+000}$	$6.44\times10^{+001}$
$0.00\times10^{+000} - 6.44\times10^{+001i}$	$0.00\times10^{+000}$	$6.44\times10^{+001}$
$0.00\times10^{+000}$	$-1.00\times10^{+000}$	$0.00\times10^{+000}$
$0.00\times10^{+000}$	$-1.00\times10^{+000}$	$0.00\times10^{+000}$
$0.00\times10^{+000}$	$-1.00\times10^{+000}$	$0.00\times10^{+000}$

In Fig 4, the migration of non linear eigen values for higher creep coefficient based upon kinematic and yaw stiffness has been shown. This shapes like equilateral triangle whose one side starts from -80 to 0 crossing on vertical side. This curve then upwards nearly 400 inclined on vertical plane. This then goes down to touch nearly -400 shows the cycle of eigen migration to end on -80 of smaller vertical plane to complete in triangular shape.

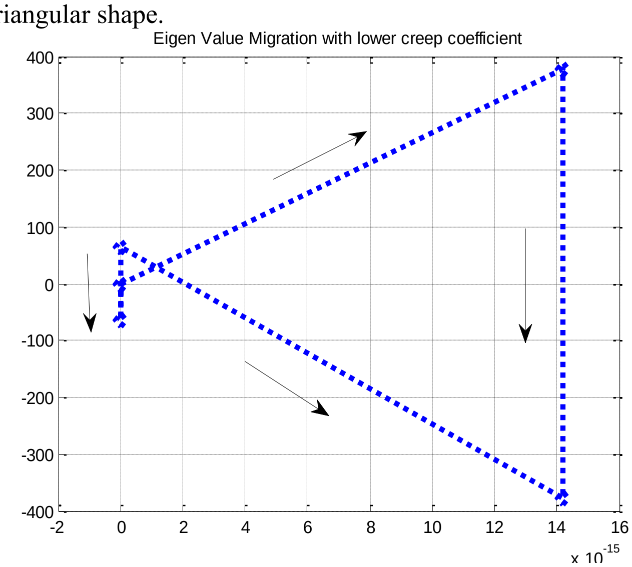

Fig. 4: Non linear migration of eigen values on lower creep coefficient

One obvious can be observed here that this figure is opposite to the figure-1 due to dimensional sides and structure point of view.

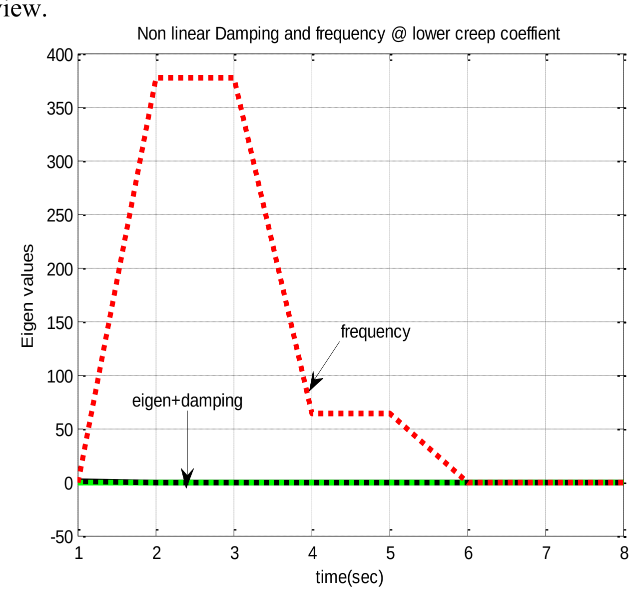

Fig. 5: Relation of frequency with damping and eigen values on lower creep coefficient

The Fig 5 represents the image for the relation of eigen values with respect to damping and frequency is graphed within fixed span of time. Here damping denoted by green color and eigen values shown by black color travel overlapping each other on straight line of zero. While frequency denoted by dotted red line makes trapezoidal shape on 0 to 380 of eigen values vertically and 1-4 major points and minor points 2-3 sec of time on horizontal to end by making smaller deflection before reaching zero. This line then travels in straight path on zero with damping and eigen values. This figure resembles to that of Fig-2 with different values on vertical side. In Fig 6, the correlation ship of wavelength with respect of velocity and frequency is denoted within fixed length of time. Here wavelength denoted by black color travels on straight line of zero while velocity displayed by red color makes smaller inclined line over wavelength line on zero. While frequency denoted by dotted blue line makes trapezoidal shape on 0 to 380 of wavelength vertically and 1-4 major points and minor 2-3 points as sec of time on horizontal to end by making small deflection before reaching zero. This line then travels in straight path on zero with velocity and eigen values. This sketch of frequency used for wavelength has same size points for the frequency of wheels used by eigen values in Fig 5. This figure is also little bit similar to that of Fig 2, only with difference of more depart inclination o end on 80 of vertical side of eigen values.

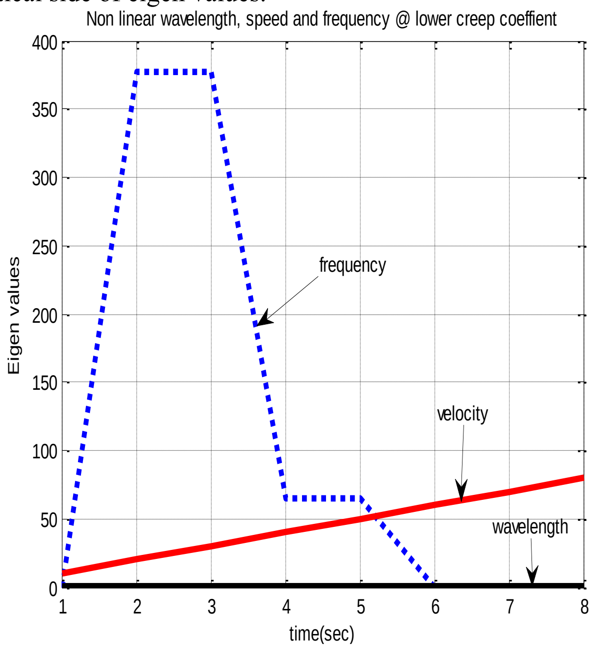

Fig. 6: Relation of wavelength velocity and frequency

Behavior of bogie wavelength at various creep co-efficient

Fig 7 shows the bogie wavelength used for higher and lower coefficient of creep. Here lower creep coefficient bogie wavelength has greater inclination ranging from 0.025 to 0.15 with some bullet values. While higher creep coefficient bogie wavelength has smaller inclination than that used for lower creep coefficient ranging from 0 to 0.05 with some bullet value inside whereas constant bogie wavelength line shows nothing any alteration. The mentioned tables have been generated by them by their major experimental heads of creep coefficients through eigen values having real and imaginary values ('i' showing as so small) and concerned graphics by computer simulations. This research paper consists on bogie attitude on variation of creep co-efficient.

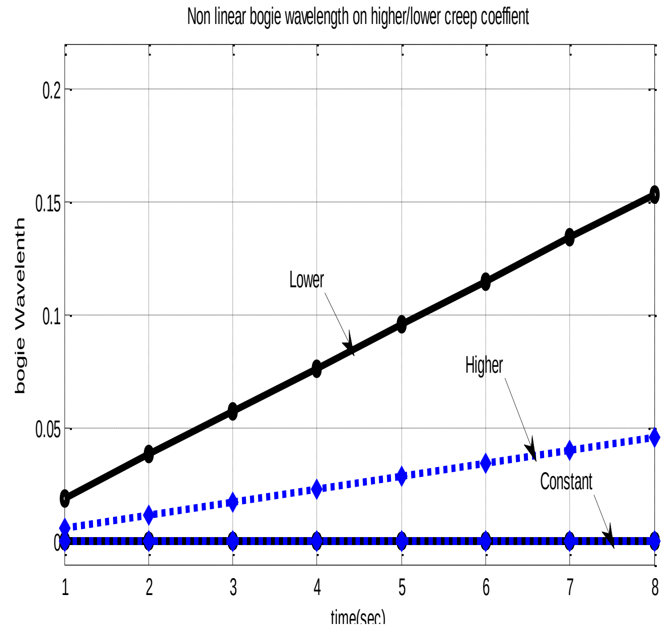

Fig. 7: Lower and higher Bogie wavelength relationship

Conclusion

From generated tables and simulated results it can be concluded that attitude of both tables as well as for eigen values for damping and frequency is different. The procured frequency values in both tables are almost same as imaginary parts of eigen values. The relation analysis of eigen values in both different cases is same in nature but in opposite directions through simulated sketches. While the behavioral denotation for frequency and damping is almost same with different values and with same structure. The wavelength for eigen values with respect to frequency and velocity is also same in both concerned simulated images with different values and slightly changed design. Thus it can be observed that natural design of frequency remains same for all different creep coefficient values along with same sketched wavelength with different attitude of velocity. Based upon these wavelengths, bogie wavelength is drawn that perceives final concept that lower wavelength shows greater inclined value while the greater valued wavelength shows the lower bogie wavelength and in rest it shows no any reaction. The higher creep co-efficient is preferred on $f_{11}=10^7$ and lower creep coefficient as $f_{11}=f_{22}=10^5$ as used in generated Tables.

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