Computation of Yaw Velocity Estimation For Railway Wheel set & Error Discrimination Based Upon Creep Coefficient For Slip

Zulfiqar Ali Soomro[1]

ABSTRACT:The railway wheelset of vehicle has enormous importance in its dynamics and modeling point of view. The knowledge of pertaining dynamics for proper running of railway wheels over railway tracks affected by the disturbances is very essential. Hence it is necessary to model the rail-wheel contact patches properly to avoid detrimental accidents due to improper adhesion level based to relation of creep analysis. The yaw motion is one of three degrees of freedom which varies with other two degree of freedom in longitudinal and lateral dimensions. In this paper, these generated disturbances are estimated by using kalman filter algorithm to control yaw velocity noise under various creep coefficient. Thus stability of rail wheelset model is investigated by error percentage estimation based upon creep to check adhesion level to avoid slip to protect railway vehicle and lives. This reflects the idea for acquiring the higher level of creep co efficient for stability of the railway wheelset as well as to reduce error ratio.

Keyword: Adhesion, creep coefficient, lateral speed, steering, error estimation, primary suspension

1. INTRODUCTION

The disordered running of a railway vehicle with wheelset having cylindrical solid body at steady longitudinal speed is observed by researchers in their work by inventing two basic types of speeds of vehicle. Where flange contact mingles at one railway track and other in which flange surface at both rail tracks transpire on it [1]. This is due to different rail track pavements like icy, wet, and contaminated due weather conditions which affect the adhesion level.

Almost all train drivers may reveal panic situation and controlling authority's failure to overcome situation. This cannot engender ample steering system, braking or throttle guidelines in emergency periods. Railway wheel spin constancy manage systems pay off train controller during fright state of affairs for creating compulsory counteractive yaw torques through active steering and braking control inputs system[2].

The yaw dynamic analysis existing on railway wheels by its patch surfaces in which the creeping forces can generate no torque by pure rolling. As creep forces stand-in on the wheels not together from the contacting forces are transferred by its basic suspension of bogie. When inertial forces become deserted, it should be affirmed that pure undulating assures none yaw movement is transmitted by bogie to railway wheels. A navigation plan holds the yaw moments can be premeditated on railway wheels. It should be well-known that state correspondent in avoiding the prime forward suspension in range of frequency is an active control scheme, where the railway wheelset get better its expected curving characteristics [3].

Railway wheelset is the fundamental module of the railway vehicle systems for secure and sound at ease haulage system to explore the rich dynamics associated with it [4]. The information is provided to kalman estimator for filtering the noise. Then values gained from Kalman filters is processed and assessed by detecting system to recognize the adhesion level from the dynamic variations of the railway vehicle wheelset. The expected estimated adhesion data is then supplied to the traction controlling system to regulate the throttle as a result [5]. The thrashing of spin solidity of a railway train can be caused by sudden spin turbulence as winding force aside, pressure loss by wheels or split braking [6].

The growth of computer has developed myriad applications of superior control technologies in the successful running railway industry. One of the noteworthy developments is active control system for railway vehicles on tracks. The oriented trains have remained successful in European countries and the respite of the world, and surely an active secondary suspension system will be used extensively. The research work has started in primary active suspensions for steering the railway wheelset by active control through stabilization and guidance of running [7]. A conservative railway wheelset consist on coned wheels connected through rigid axle together. The collection for compensation is of naturally central lining or curving paths, and if it is unimpeded also displays sustained fluctuation in the horizontal plane of train. This is prevailing over on predictable railway vehicles through springs coupled from the railway wheelset to the bogie or the body of the railway vehicle. However, this additional stiffness declines the capability of the wheels to curve on track and it may grounds severe wear of the railway wheelset and tracks. A variety of active ways to steer the solid-axle of railway wheels have been projected, where the major endeavor is to supply necessary stabilization control system without intrusive with the naturally curving system [8].

Using linear creep model derived for leading differential motion equations for bogie stirring on tangentially rails to learn the effects of bogie suspension distinctiveness and conicity of wheelset to the serious hunt velocity and matched the results with preceding researchers while in the study existing [9]. It was accomplished that horizontal direction and bogie spin frame and railway wheels are responsive to disparity of conicity and arithmetical values are a smaller amount with higher conicity as the absolute value of the creep coefficients is comparatively higher**.** Also an approach is kept on as long as guidance by creeping forces in combination with wheelset conicity, so that flange patches are usually ignored [10].

2. MATHEMATICAL FORMULATION

The railway frame has two wheels solidly attached with axle and arc of a circle denoted by radius r_o being solid body structure. Figure-1 denotes geometrical structure of the railway wheels for vehicle having three types of motion (DOF) consisting horizontal motion ‘y’ and spin motion, ‘z’ while another is longitudinal motion ‘x’ in planner directions. While rotational motions in corresponding directions are lateral rotation motion as ‘ξ’ and ‘ψ’ as yaw or spin rotational motion and rotation in direction of motion is denoted by ‘ϕ’. The formulae of movement for railway wheels are joined in the course of the nonlinearity of creeping force relationship. The ensuing regular forces occurred by wheelset and the rail track has horizontal constituent particularly through railway dynamics. Whereas ‘a’ is gauge length from centre of axle and k_1, k_2 as lateral and longitudinal spring stiffness [1,13].

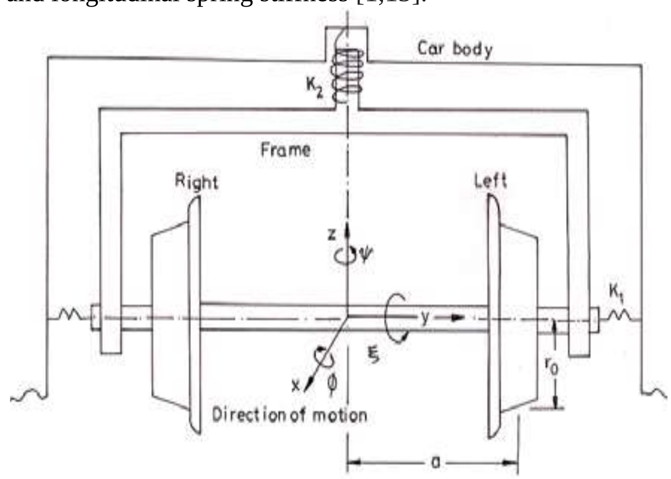

Figure-1 3-D motion of railway wheelset model [1].

The creepages concerned to the yaw velocities for wheelset are framed as a result can be represented as

$$\lambda_z = \frac{\Omega_1 - \Omega_2}{v} \quad (1)$$

Here v is vehicle speed and Ω_2 is real spin velocity while Ω_1 is the pure rolling speed of the wheels in the disappearance of the creep. The spin creepages at railway wheelset contact is related and formulated as under [11,12].

$$\lambda_{zR} = \left(\frac{v}{\dot{\psi}} - \lambda / R_o \right) \tag{2}$$

$$\dot{\psi} = \left(\frac{v}{\lambda_{zR} + \lambda / R_o} \right) \tag{3}$$

$$\lambda_{zL} = \left(\frac{v}{\dot{\psi}} + \lambda / R_o \right) \tag{4}$$

$$\dot{\psi} = \left(\frac{v}{\lambda_{zR} + \lambda / R_o} \right) \tag{5}$$

The maximum creep forces as determined by Kalker in shape of yaw moments are as follows

$$M_{zR} = f_{23} v_{yR} - f_{33}.\lambda_{zR} \tag{6}$$

$$M_{zL} = f_{23} v_{yL} - f_{33}.\lambda_{zL} \tag{7}$$

In above expressions M_{zR}, M_{zL} are spin moments, $v_{yR,}$ λ_{zL} lateral velocities for right and left wheels, $_{,}f_{23,}f_{33}$, are lateral and yaw creep coefficients ψ , $\dot{\psi}$ are the yaw motion and velocity.

Thus yaw motion for the railway wheelset is correlated through below formula.

$$I_w \ddot{\psi} = F_{xR} L_g - F_{xL} L_g - k_w \psi \tag{8}$$

$$I_w \ddot{\psi} = \frac{\mu_R N_R}{\sqrt{\lambda^2{}_{xR} + \lambda^2{}_{yR}}} [\frac{R_o \omega_{wR} - V_v}{V_v} - [\frac{L_g \dot{\psi}}{V_v} + \frac{\omega_{wR} \gamma (y_{lat} - z)}{V_v}]] L_g \tag{9}$$

$$- \frac{\mu_L N_L}{\sqrt{\lambda^2{}_{xL} + \lambda^2{}_{yL}}} [\frac{R_o \omega_{wR} - V_v}{V_v} - [\frac{L_g \dot{\psi}}{V_v} + \frac{\omega_{wR} \gamma (y_{lat} - z)}{V_v}]] L_g - k_w \psi$$

$$\dot{\psi} = \frac{\mu_R N_R}{\sqrt{\lambda^2{}_{xR} + \lambda^2{}_{yR}}} [\frac{R_o \omega_{wR} - V_v}{V_v} - [\frac{L_g \dot{\psi}}{V_v} + \frac{\omega_{wR} \gamma (y_{lat} - z)}{V_v}]]. L_g / I_w \tag{10}$$

$$- \frac{\mu_L N_L}{\sqrt{\lambda^2{}_{xL} + \lambda^2{}_{yL}}} [\frac{R_o \omega_{wR} - V_v}{V_v} - [\frac{L_g \dot{\psi}}{V_v} + \frac{\omega_{wR} \gamma (y_{lat} - z)}{V_v}]]. L_g / I_w - k_w$$

Above equation (10) is associated with coincity ‘γ’, L_g= a gauge length and and k_w is stiffness of spring, y_{lat} =lateral size, R_o= outer radius, ω_w=angular velocity of wheel, μ= adhesion, N= normal force, V_v as vehicle velocity, z=noise

Thus spin force for right wheel is linearised in above equation (11)

$$\Delta F_{zR} = g_{23} \Delta \lambda_{yR} + g_{33} \Delta \lambda_{zR} \tag{12}$$

Thus right wheel is represented by small signal model by sensors. Similarly, the lateral force for left wheel is linearised and converted by small signal model for kalman filter.

$$\Delta F_{zL} = g_{23} \Delta \lambda_{yL} + g_{33} \Delta \lambda_{zL} \tag{13}$$

3. KALMAN FILTER DESIGN

An Active steering system for an independently revolving railway wheels require some indispensable feedback signals like rail- wheel deflections for leading the railway wheels to pursue the rails. The direct measurement of feedback signals is not viable in put into practice even though state estimation tracts like Kalman filters may be utilized to estimate the prescribed signals. The update research has exposed tremendously complicated for observer’s work well for considerable parameter variations [7].

The control plan system for pertaining techniques can be established by optimal procedure, which permits crafty tough controllers by disciplined method with drawback of full feedback system. This dilemma existing over latest Kalman estimator is to filter the states by measuring methods [8].

In practice system is always affected by noise and if we assume that yaw rate is only available measurement with some noise then we can re-write the model as [9].

$$\dot{x} = Ax + Bu + w \tag{14}$$

$$z = cx + v \tag{15}$$

Where *w* is noise added o the system with zero mean and *Q* variance and *v* is measurement noise with zero mean and variance *R*, ignoring the affinity between processing and measuring noise.

Kalman filter is an essential tool widespread research and is applied specially in the area of assisted navigation and autonomous system. It is mathematical formulae to estimate the state of processes by well-organized computational and recursive methods to reduce the squared error. Kalman filter in shape of equations is described as under [10].

$$K = P_{k+1}C^T(CP_{k+1}C^T + R)^{-1} \quad (16)$$

$$\tilde{x}_{k+1} = \tilde{x}_k + K(z - C\tilde{x}) \quad (17)$$

$$P_{k+1} = AP_kA^T + R - AP_kC^TR^{-1}CP_kA^T \quad (18)$$

In equation (16) K is Kalman gain use to weight the measurement innovation in equation (17). Equation (18) is used to update the estimated state vector.

4. SIMULATION RESULTS

The yaw velocity disturbances are estimated by using kalman filter to measure the noise. Three different varieties of co-efficient of creep are manipulated to determine the behaviour of the actual and estimated parameters with each other. The Yaw velocity of the railway wheelset on the railway track has been shown in the figures 2 to 4. Here yaw velocity of the railway wheelset is testified to watch the performance of the railway wheelset.

The error percentage is also applied based on higher and lower creep co-efficient to check the stability of the system.

4.1 Yaw velocity of wheelset at different creep co-efficient

In figure-2, when co-efficient of the creep is taken at 10^7, we observe that yaw velocity of the railway wheelset moves with motion of 0.835 rad/sec initially in 05 sec with higher peaks 0.85 rad/s in 1.3, 3.3, 4.3 and 4.6 seconds respectively. Whereas lower limits to 0.75 rad/s in 1.5 sec and in 3 sec within 0.5 seconds respectively. Both curves move in chaos zigzag manner with time intervals from 0.5 sec up to 5 sec with increment of 0.5 seconds consisting upon actual and estimated parameters densely. Here actual values denoted by 'blue colour' moves along with the estimated values are denoted by 'green colour' in chaos manner. The peaks of these curves are nearly touching the bordering plane.

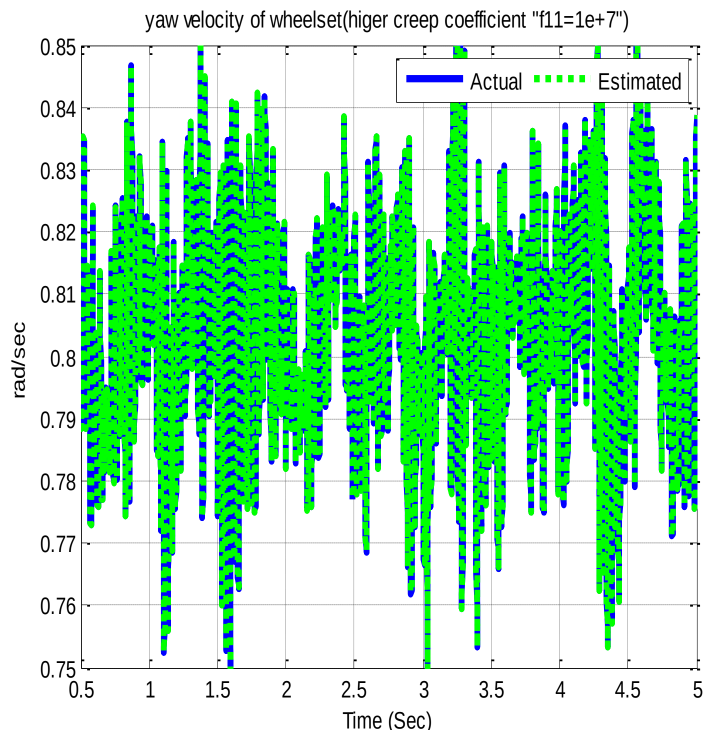

Figure-2 yaw velocity noise estimation based upon creep coefficient 10^7

In figure-3, when co-efficient of the creep is taken at 10^6, we observe that yaw velocity of the railway wheelset moves with motion of 0.835 rad/sec initially in 05 sec with higher peaks 0.85 rad/s in 1.3, 3.3, 4.3 and 4.6 seconds respectively. Whereas lower limits to 0.75 rad/s in 1.5 sec and in 3 sec within 0.5 seconds respectively. Both curves move in chaos zigzag manner with time intervals from 0.5 sec up to 5 sec with increment of 0.5 seconds consisting upon actual and estimated parameters densely. Here actual values denoted by 'blue colour' moves along with the estimated values are denoted by 'green colour' in chaos manner. The peaks of these curves are nearly touching the bordering plane.

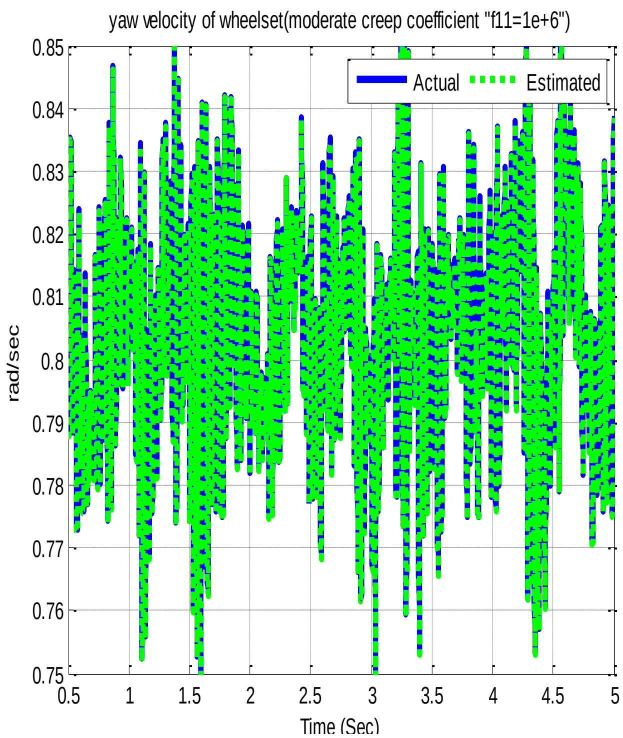

Fig-3 yaw velocity noise estimation based upon creep coefficient 10^6

In figure-4, when co-efficient of the creep is taken at 10^5, we observe that yaw velocity of the railway wheelset moves with motion of 0.835 rad/sec initially in 05 sec with higher peaks 0.85 rad/s in 1.3, 3.3,4.3 and 4.6 seconds respectively. Whereas lower limits to 0.75 rad/s in 1.5 sec and in 3 sec within 0.5 seconds respectively. Both curves move in chaos zigzag manner with time intervals from 0.5 sec up to 5 sec with increment of 0.5 seconds consisting upon actual and estimated parameters densely. Here actual values denoted by 'blue colour' moves along with the estimated values are denoted by 'green colour' in chaos manner. The peaks of these curves are nearly touching the bordering plane.

The results obtained from all above three diagrams 2 to 4, resemble with each other. This reflects the idea that in the analysis for computing the yaw velocity of wheeset, the adhesion is controlled and balanced on variation of the creep co-efficient if it is higher or lower, then both actual and estimated parameters overlap each other in same directions with nearly same values.

This should be noted that there is no any alteration on increasing and decreasing creep coefficient.

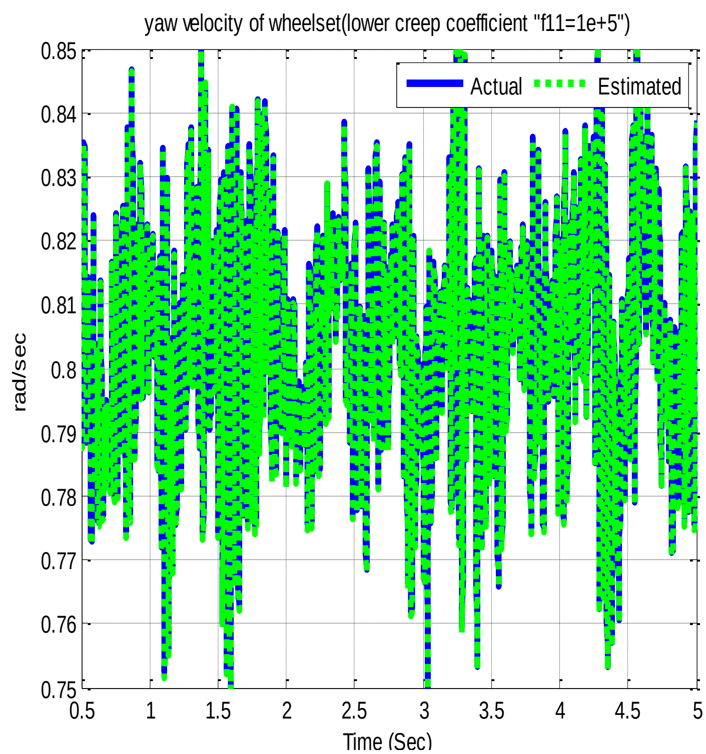

Figure-4 Yaw velocity of wheelset at 10^5 Creep co-efficient

4.2 Error estimation for yaw velocity of wheelset

The rail wheelset track dynamic parameters are estimated to analyse the error ratio through high creep coefficient by blue line and low creep coefficient by green line. The higher co-efficient of creep is selected as 10^7 and lower coefficient is taken as 10^6 for estimation of error value.

The higher and lower creep coefficient values of the mentioned are applied to estimate the error ratio for yaw motion of wheelset of the train in figure-5 as under. Here blue line representing high creep co-efficient travels in straight direction with lower noises from zero error with measured scale. This means that there is no error in constant adhesion level to occur any slip. While low creep coefficient denoted by blue line passes through -0.1 to 0.1, then it decreases in -0.005 to 0.006 and so on by vertical scale of error value in zigzag way with major disturbances to travel further above zero in 2.6 seconds shows improperly and insufficiency of adhesion. This also reflects that creep is increased with constant adhesion level, and position of slip occurrence.

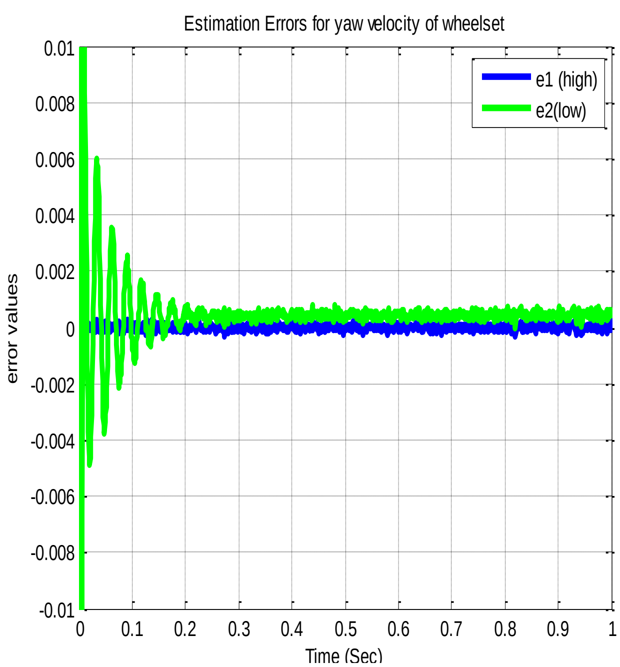

Figure-5 Error estimation for Yaw velocity of wheelset at 10^5

5. CONCLUSION

In above paper, the concerned dynamics of yaw velocity of the railway wheelset is enumerated. Then this dynamics is used for proper mathematical modelling and then in signal model for the implementation of kalman filter. The kalman filter is used to estimate the disturbance with respect to the actual parameters to observe their behaviour with each other. From this application, it is observed that the attitude of actual and estimated parameters is same on utilization of three different specimen of co-efficient of the creep. This displays the idea that yaw velocity always remains constant even though creep coefficient ratio is changed. Finally from the error percentage ratio, it can be concluded that adhesion level remains constant on zero error with increase of creepage on application of higher creep coefficient. Whereas, on lower creep coefficient, the adhesion value becomes unbalanced in zigzag manner then converted into straight path with smaller turbulence slightly above zero line on increase of creep. This chaos way shows little bit stability to avoid slip.

This infuses that error percentage at higher ratio becomes lower nearer zero at higher creep coefficient. But when creep coefficient is taken lower then percentage of error becomes higher to disable the railway system.

REFERENCES

[1] Nath, Y.& K. Jayadev. 2005. "Influence of yaw stiffness on the nonlinear dynamics of railway wheelset". *Communications in Nonlinear Science and Numerical Simulation* **10.2**, pp.179-190.

[2] T. Acarman. 2006. "An Advanced Driver Assistance System by Using State Dependent

Riccati Equation Technique", *IEEE Intelligent Vehicles Symposium*.

[3] Mei, T.X., and Roger M. Goodall. 2001. "Robust control for independently rotating wheelsets on a railway vehicle using practical sensors". *Control Systems Technology, IEEE Transactions* on **9.4**, pp.599-607.

[4] Abood, Karim H. Ali, and R. A. Khan. 2009 "Numerical Simulation Model to Study the Dynamic Behavior of Railway Single Wheelset on Tangent Tracks with Single-point and Two-point Wheel-rail Contact". *International Journal of Applied Engineering Research*. pp.4.9.

[5] Charles, Guy, R. Goodall, and R. Dixon, 2008. "Model-based condition monitoring at the wheel–rail interface". *Vehicle System Dynamics* **46**.S1,**.** pp 415-430.

[6] Guvenc, Bilin Aksun, Tankut Acarman, and L. Guvenc. 2003. "Coordination of steering and individual wheel braking actuated vehicle yaw stability control". *Intelligent Vehicles Symposium*. Proceedings. IEEE.

[7] Lee, Sen-Yung, and Yung-Chang Cheng 2005. "Hunting stability analysis of high-speed railway vehicle trucks on tangent tracks". *Journal of sound and Vibration* **282.3,** pp881-898.

[8] Pèrez, J., J. M. Busturia, and R. M. Goodall. 2002**.** "Control strategies for active steering of bogie-based railway vehicles". *Control Engineering Practice* **10.9**, pp1005-1012.

[9] Bruni, Stefano, et al. 2007. "Control and monitoring for railway vehicle dynamics". *Vehicle System Dynamics* **45.7-8**. pp 743-779.

[10] Wu, Y. H., D. D. Song, and Z. X. Hou. 2007. "A research on generalized predictive control for vehicle yaw rate". *Control Conference*.

[11] Soomro, ZA. 2014. "Adhesion Detection Analysis by Modeling Rail Wheel Set Dynamics under the Assumption of Constant Creep Coefficient". *Mechatronics, Electrical Power and Vehicular Technology* **5.2**, pp.99-106.

[12] Soomro, ZA. 2015. "Step Response and Estimation of Lateral and Yaw Motion Disturbance of Rail Wheelset". Journal of Engineering and Technology;**5.** pp 8-13.

[13] Yu-An Ku; Tesheng Hsiao; Yu-Yuan Chen, 2015, "Vehicle yaw motion control based on front-wheel lateral force tracking." *American Control Conference (ACC)*, pp. 3453 - 3458

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