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Observer Based Slip Measurement Technique of DC Motor Mounted on Railway Wheel-set

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Abstract: The paper proposes the technique of detection and estimation of slip by using parameters of motor such as torque and current for a locomotive system. The motor is used for controlling wheel-set motion mounted on each axle of the rail. As the track condition changes (due to decrease in adhesion/friction), the parameter of motor considerably varies resulting slip occurrence. By utilizing inertial mounted sensors (such as tachometer) in order to measure the velocity of the train, slip can be detected. Furthermore, the estimation of motor parameters is carried out using Kalman filter, which minimizes the usage of additional sensors. In this regard, the proposed method offers a cost effective, accurate and robust solution for the slip issue in order to avoid accidents in locomotive systems. The technique is validated using simulation results in this paper.

Keywords: Locomotive, Slip, Detection, Estimation, Kalman Filter, Rail.

I. INTRODUCTION

Low adhesion (friction) problem has been spotted a vital parameter to be considered from the beginning of railway transportation for the designing and operation of railway vehicles [3]. The weather effect especially autumn drastically disturbs the adhesion level in which decomposed leaves are crushed by the wheels of the train. In this condition, applying a higher force on the track by the wheel cause wheels-slip during traction and it is subjected to slide while braking, which may be responsible as the damage of track and wheels itself. Various techniques are adopted around the world to overcome this issue, the few of them used (temporarily)are as: (i) vegetation, (ii) sandites (iii) water jetting management [2]. Hence from these methods, the designers still could not get the comprehensive results in order to reduce the adhesion because of the highly non-linearity of adhesion variations most of the time. Therefore, it is difficult to monitor and calculate it exactly and it may certainly desire some level of technical expertise to introduce a solid and appropriate technique to deal with this problem.

In this paper, a wheel-set model is under observation and assessment is made on the basis of comparison between its dynamics under stable condition and slip condition. The information of slip can be acquired from motor parameters such as torque/current connected with each axel of rail as shown in Figure 1. In addition, Kalman filter is used in order to get the accurate estimation of torque/current. Once torque/current is estimated we can ultimately measure that how much slip is occurred during traction.

The remaining paper such as section II comprises of rail wheel-set. Section III presents the modeling of system dynamics. Section IV states the details of estimation of slip using Kalman filter. Section V shows the simulation results. Finally, section VI concludes the proposed method.

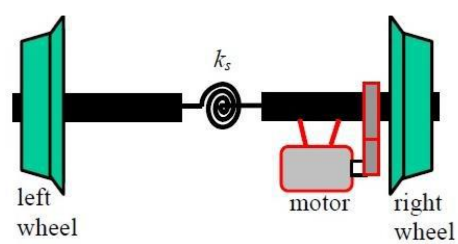

Figure 1. Motor mounted wheel set: Courtesy to [9]

II. RAILWAY WHEEL SET

The essential element of the railway transport is wheel-set rolling on the railway track. Its dynamics highly affect the transport comfort, the wear of rails and the life time of both wheels-set and track [1]. Wheel-set dynamics are highly affected by the variations in adhesion level between wheel and track due to different contact conditions [7].

These contact conditions are highly nonlinear regarding creep forces produced at wheel-rail interaction. Figure 2 gives that how adhesion coefficient varies with respect to creep forces. It also marks the presence of any kind of contamination, e.g. autumn felled leaves, icing, liquid (water/oil) etc. This causes considerable rise and fall in the friction level between wheel and track. In order to have proper traction and braking performance, the minimum level of adhesion must be kept (i.e., 0.25 for traction and 0.1 for braking) [5].

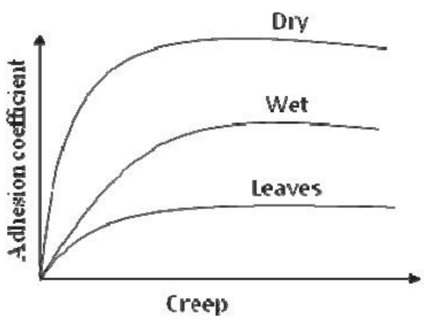

Figure 2. Adhesion Curves: Courtesy to [3]

III. MODELING OF SYSTEM DYNAMICS

A. Bogie Configuration

Bogie configuration is a mechanical configuration commonly found in rails. In this regard, each bogie consists of two wheel-sets [6]. Those wheel-sets are designed in such a way that both wheels are rigid in a single axel, so that can rotate at same angular velocity.

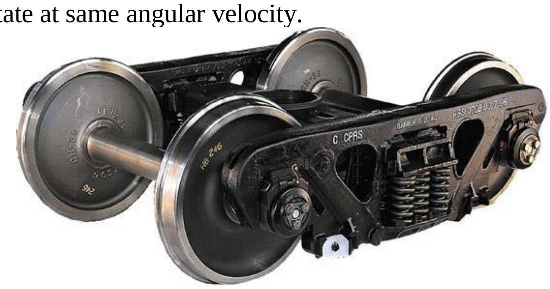

Figure 3. Wheelset arrangement in a bogie: Courtesy to [5]

B. Dynamic Equation of Wheel-Set

Motor drives the right wheel by applying torque which is denoted as Tt, the other rotational dynamics can be given as:

$$I_R\,\dot{\omega}_R = T_t - T_K - T_R \tag{1}$$

$$I_L\,\dot{\omega}_L = T_k - T_L \tag{2}$$

$$\dot{\theta}_K = \omega_R - \omega_L \tag{3}$$

Where, $\dot{\omega}_R$ is right wheel angular velocity, I_R is right wheel moment of inertia, T_R is the tractive torque of right wheel, T_k is torsional torque produced by axle stiffness, I_L is moment of inertia of left wheel, T_L is the left wheel tractive torque, $\dot{\omega}_L$is left wheel angular velocity, $\dot{\theta}_K$ represents the torsional angle of the axle.

$$T_R = r_0 f_{11} \lambda_{XR} \tag{4}$$

$$T_L = r_0 f_{11} \lambda_{XL} \tag{5}$$

r_0, is the wheel radius, $f11$ is available adhesion

$$\lambda_{XR} = \frac{r_0\omega_R - v}{v} \tag{6}$$

$$\lambda_{XL} = \frac{r_0\omega_L - v}{v} \tag{7}$$

Replacing T_R and T_L in equation 1 and 2 yield following wheel set equation.

$$\begin{bmatrix}\dot{\omega}_r\\ \dot{\omega}_L\\ \dot{\theta}_s\end{bmatrix} = \begin{bmatrix}-\frac{{r_0}^2 f_{11}}{vI_r} & 0 & -\frac{k}{I_r}\\ 0 & -\frac{{r_0}^2 f_{11}}{vI_L} & -\frac{k}{I_L}\\ 1 & -1 & 0\end{bmatrix}\begin{bmatrix}\omega_r\\ \omega_l\\ \theta_s\end{bmatrix} + \begin{bmatrix}\frac{1}{I_R}\\ 0\\ 0\end{bmatrix} T_t \tag{8}$$

From Above mentioned state space model, it can be observed that the wheel-sets dynamics depends on the available adhesion and vehicle speed. Therefore, these factors cannot be ignored when we are considering stability, ride comfort and safety of the vehicle. Low adhesion level can cause slip during traction and slide during breaking.

IV. DETECTION AND ESTIMATION OF SLIP

A. Detection of slip through motor torque/current

Proposed technique for slip detection through motor torque estimation is a versatile and cost-effective, eliminates need of extra sensors. With the help of internal mounted sensor for finding vehicle velocity, slip can be observed by transforming linear velocity into angular velocity of the wheel.

Armature control DC motor provides a great assistance to control the speed of train, especially where high starting torque is required [4]. Typically motor is installed on one side of axel as shown in Figure 4, connected on right wheel so it acts as driving wheel while the left wheel moves by the torsional torque of the axel rigidly fixed with right wheel (see Figure 1).

In armature control DC motor,

$$T \propto i_a \tag{9}$$

In this situation, when slip occurs, wheels rotate freely, as a result significantly the load from motor reduces hence motor torque and current falls down. We can easily measure motor current /torque consequently we can estimate wheel slip indirectly.

B. Kalman Filter Design for Estimation

Kalman filter can be used when the process of obtaining the optimal estimate from the noisy/corrupt data including the elimination of unwanted signal, which in proposed system are noise variables. It processes observations to produce an estimate of a variable of interest, which optimizes the results based on a certain criterion. So, a proper estimate of the system parameters is needed to obtain the desired information and then improve it. Kalman filter is ideal for linear stochastic systems that are why it is of our interest for the proposed approach [8].

DC motor model considered in the equation below can be written in the subsequent standard forms

$$X(t) = Ax(t) + Bu(t) + w(t) \tag{10}$$

$$Y(t) = Cx(t) + Du(t) + V(t) \tag{11}$$

where *x(t)*, is the state matrix, *u (t)* is input vector, *w (t)* is the process noise applied by the track irregularities *v(t)* is the inertial noise or noise level of the sensor, *y(t)* is the output matrix. Sensor already mounted in the vehicle in order to measure velocity of the train, can offer satisfactory results for the Kalman filter designing as input from the system (Model).

$$\frac{d}{dt} = \begin{bmatrix} \dot{\theta} \\ i \end{bmatrix} = \begin{bmatrix} -\frac{b}{j} & \frac{k}{j} \\ -\frac{K}{L} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} \dot{\theta} \\ i \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} V + w(t) \tag{12}$$

$$y = [1 \quad 0] \begin{bmatrix} \dot{\theta} \\ i \end{bmatrix} + v(t) \tag{13}$$

Here the process noise is considered that it has no relation with measurement. The equations for Kalman filters are given as

$$\hat{x}(t) = A\hat{x}(t) + Bu(t) + K[Y(t) - C\hat{x}(t)] \tag{14}$$

$$k = PC^T R^{-1} \tag{15}$$

$$\dot{P} = AP + PA^T - KRK^T + Q \tag{16}$$

In above equation *-1* superscript indicates matrix inversion and subscript *T* shows transposition of matrix. $\hat{x}$ shows the state vector estimated values and *K* is gain of Kalman filter, in order to weight the measurement changes $Y(t)-C\hat{x}(t)$. Where *P* is taken as the estimation error covariance which depends on the selection of measurement noise covariance *R* and the process noise covariance *Q* and *R* can be calculated by the following equations

$$Q = E[ww^T] \tag{17}$$

$$R = E[vv^T] \tag{18}$$

Q =0.001
R=0.00000000001*eye(2)
is taken.

V. SIMULATION RESULTS

A. Simulation of Wheel-Set

The simulation results shown in Figure 4 given below are for wheel-set model and taken for 10 secs. For initial 5 secs, the adhesion level of surfaces supposed to be dry. So that, it can be observed that the speed of both wheels remains nearly constant but the vehicle velocity is increasing linearly. After t=5sec, the situation is changed now the wheel rail contact condition is altered from dry case to poor case (due to contaminated leaves) causes occurrence of slip. As a result, wheels move freely, makes significant change in speed of left and right wheel ab. On other hand, after 5 secs, vehicle speed remains almost constant.

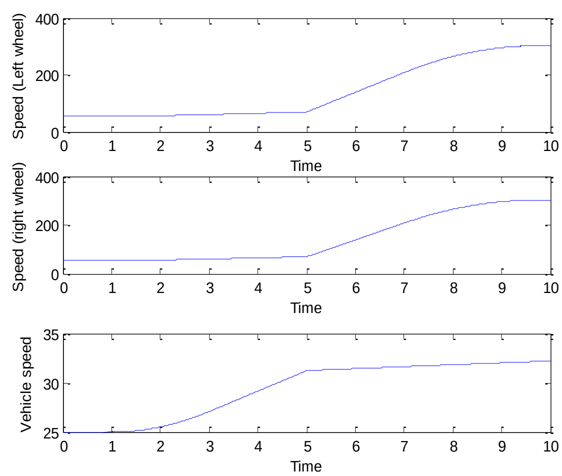

Figure 4. wheel set simulation Results

B. Simulations on the Effect of Slip on Motor parameters

Motor Torque and RPM variations can be observed in favor of previously mentioned time for each track condition as per applied tractive effort from the Figure 5 to 8 below. As after the time considered above i.e. t= 5 secs, the track conditions change from dry to poor condition, forcing slip to occur. Load on the motor reduces consequently making the current to decrease. On the other side, RPM of motor increases significantly because the slip causes motor rotates freely with higher RPM.

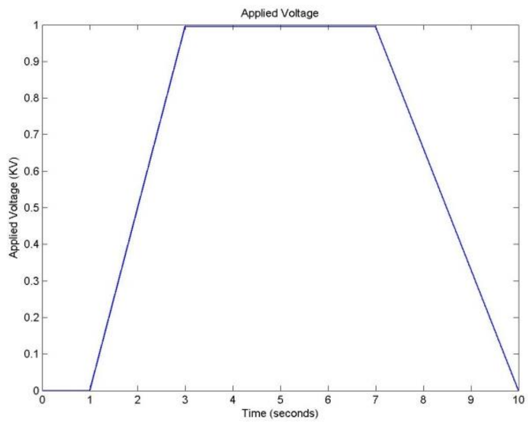

Fig.5 Tractive Effort

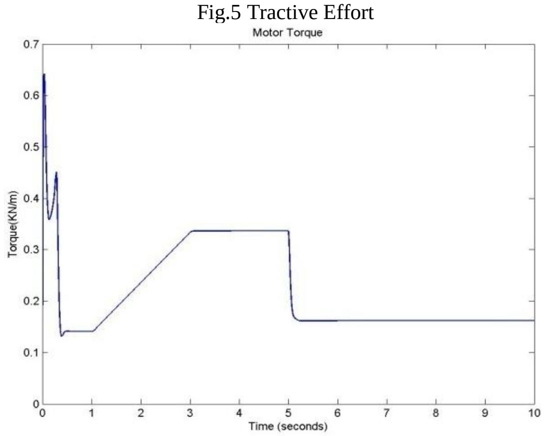

Fig.6 Motor Torque

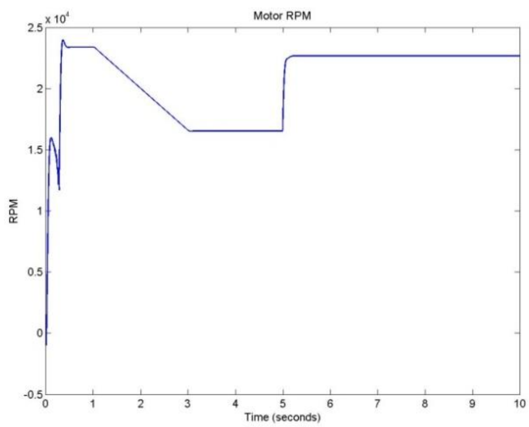

Fig.7 Motor RPM

C. State Estimation

By fine-tuning the process noise covariance matrix Q, the performance of the Kalman filters can be evaluated thoroughly. The determination of the process noise covariance is a more difficult process, so a trial and error approach is applied to find an optimal value at any specific operating point (Q=0.001).

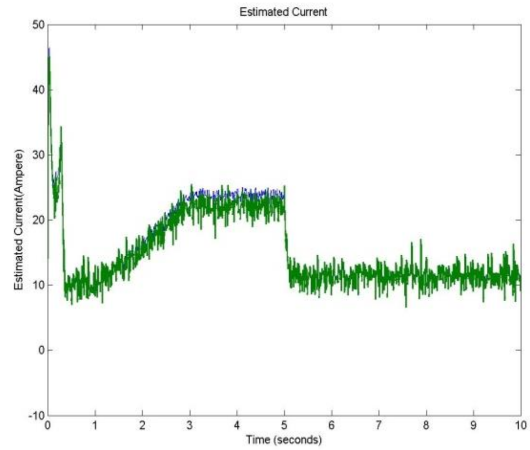

Fig.08: Estimated Current

It can be observed that error for estimated current and real error value are very small approximately negligible, which shows a correctly tuned filter can provide a better estimation for detecting slip using motor parameters.

VI. CONCLUSION

As the adhesion level reduces, consequently the motor parameters (current consequently torque) changes by accessing change in these parameters of motor, slip is estimated indirectly using Kalman filter. This technique not only provides detection of slip also proves to be a cost effective by eliminating use of extra sensors. Mainly the research deals with technical aspects of slip detection and its estimation, justification of cost effectiveness is only analyzed due to less use of extra sensors compare to other existing techniques. Cost effectiveness of the proposed technique can be proved in future work.

REFERENCES

[1] I. Hussain, Mei T.X, R. T.Richings, "Estimation of wheel–rail contact conditions and adhesion using the multiple model approach" International Journal of vehicle System Dynamics, vol. 55,no. 1, 2013.

[2] Mei T.X, I. Hussain, "Detection of wheel-Rail Contact condition for improved traction control" proceeding of 4th international conference on railway traction system, Birmingham, UK, 2010.

[3] I. Hussain, I. A. Halepoto, W. Kumar, K. Kazi, "Anti-slip Traction Control of Railway Vehicle Based on Estimated wheel-rail Contact Condition" Sindh Univ. Res. Journal,vol. 45. No. 2, pp. 373-378, 2013.

[4] P.A.Adewuyi, "DC Motor Speed Control" International Journal of multidisciplinary Sciences and Engineering, vol.4, no.4, May2013.

[5] Ward, Christopher P., et al. "Adhesion estimation at the wheel–rail interface using advanced model-based filtering." Vehicle System Dynamics, vol. 50, no.12, 2012.

[6] C.P ward, R.M. Goodall and R. Dixon "Detection of low adhesion in railway vehicles wheel/rail interface: assessment of multi-bodied simulation data" UKACC International Conference on control UK,3-5 September 2012

[7] C.P Ward, R.M Goodall, R.Dixon and G.Charles "Use of real time creep force estimation data for assessment of low adhesion in wheel/ rail contact" 2011.

[8] N. Fahmedha, P.Chaitanya, P.Anand and RachanaR"Estimation of System Parameters Using Kalman Filter and Extended Kalman Filter"International Journal of Advanced Technology and Engineering Exploration, vol. 2, no. 6, May-2015.