22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

ESTIMATION OF PRIMARY SUSPENSION PARAMETERS FROM LATERAL DYNAMIC RESPONSE OF A WHEELSET

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Abstract: *Globally, maintenance tasks for railway vehicles have generally calendar based schedules. However, apparent changes may occur in vehicle structure and environment. Suspension malfunction and substantial change in adhesion conditions can be given as an example for such situations. Since these kinds of changes may affect especially safety, necessary actions must be taken as soon as possible without waiting schedule. This is possible with condition monitoring systems, which lead vehicles to be smarter, as they can inform decision makers for actions. Dynamic response of a vehicle, which includes information about changes in vehicle's structure and environment, can be used for condition monitoring. In this study, a condition monitoring scheme is proposed to identify primary lateral suspension parameter from dynamic response of a wheelset. Identification is based on the well-known model based filtering method, namely unscented Kalman filter.*

Keywords: Condition Monitoring, Wheelset Dynamics, Unscented Kalman Filtering, Wheel-Rail Contact, Parameter Estimation.

1. Introduction

Wheelset is the most important part of a railway vehicle which interacts with rails and has a highly nonlinear dynamic structure. In order to provide better and safer ride, wheelset is connected either to a bogie or a vehicle body with suspension elements in practice. These suspension elements provide the stability of vehicle during run. Especially, the primary suspension system has greater importance such that a problem in this system can cause lack of safety during ride.

Several studies consider the parameter estimation problem by using the dynamic models of railway vehicles. These studies can be divided into two groups. One group of studies focus on the adhesion estimation whereas the second group focus on estimating suspension parameters. (Ward et al., 2012) and (Hussain et al., 2013) are the examples of studies related with the estimation of adhesion. They are using the Kalman filtering scheme to estimate adhesion conditions by considering the lateral dynamical response of the vehicle. Kalman filtering method can only be used for systems which can be modelled and represented in linear state space form. Therefore, (Ward et al., 2012) choose to estimate firstly the creep forces and moments since they can be represented in linear state space form. Whereas (Hussain et al., 2013) choose to linearise the system around operating point and then estimate adhesion conditions by using a post processing method in conjuction with Kalman filtering method.

The second group of studies investigate the applicability of model based filtering methods for estimation of suspension or wheel/rail contact parameters. A literature review, which describes the advances in the related area up to 2007, can be found in (Bruni et al., 2007). (Li et al., 2004) and (Li et al., 2007) propose a filtering scheme that combine particle filter and Kalman filter for estimation and compare the results with the extended Kalman filter case. It is a well-known fact that particle filters are effective tools in identification of highly nonlinear, non-Gaussian systems. However, particle filters require excessive computational power. When the dynamic model of the system is described exactly and

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the initial conditions are selected carefully, (Zhongshun et al., 2014) show that extended Kalman filter can be applied for identification. However, the extended Kalman filter, which is the nonlinear version of the Kalman filter, suffers from the problems due to linearisation of the models.

In this study, possibility of estimation of primary lateral suspension parameters by using an unscented Kalman filter is presented. However, unlike the previous studies, this study inlcudes a detailed wheel/rail contact model which reduces the error due to modelling in estimation. Furthermore, unscented Kalman filter, which is considered here, is advantageous with respect to particle filter and extended Kalman filter. Details and advantages of unscented Kalman Filter can be found in (Julier & Uhlmann, 2004).

2. Methods

The overall methodology is given in Fig. 1. Necessary explanations can be found in the text.

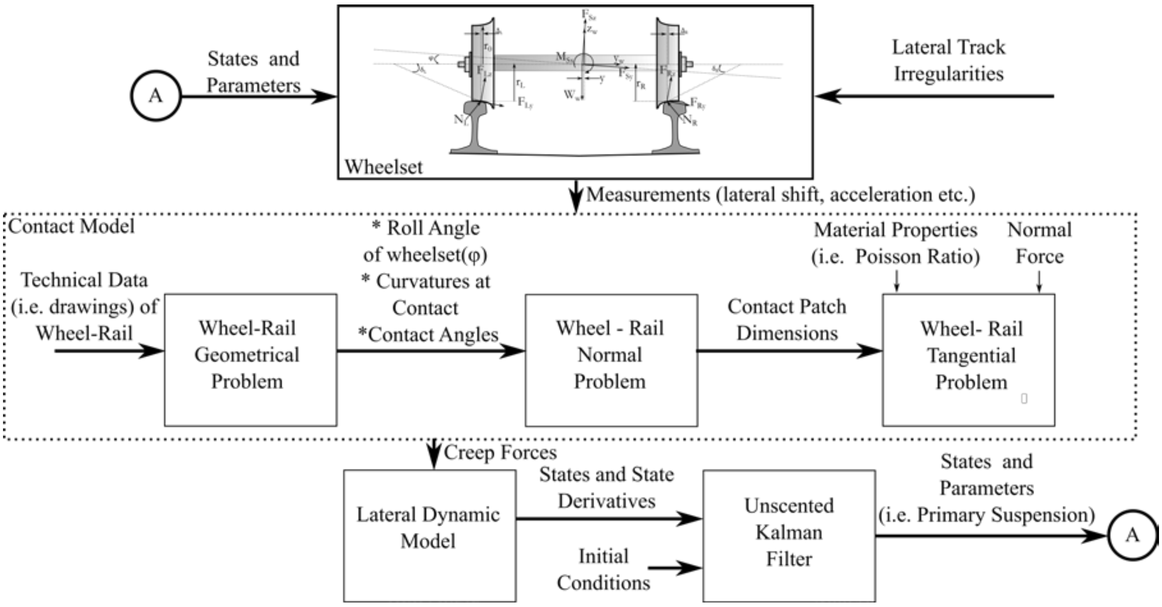

Fig. 1: General Scheme for Estimation.

2.1. Solution to geometrical, normal and tangential contact problem

The wheel/rail pair considered in this study is theoretical S1002/UIC60E1, where the details of these profiles can be found in related European standards. Firstly, by considering these profiles, geometrical problem, normal problem and tangential problem must be solved with respect to the lateral shift of the wheelset due to track irregularities. For the details of the methods to solve geometrical problem and normal problem considered in this study, readers are referred to read (Onat et al., 2015a). However, different from (Onat et al., 2015a), in this study, solution of normal problem is corrected by using the method given in (Piotrowski & Kik, 2008). (Piotrowski & Kik, 2008) converts the actual contact patch area into an equivalent ellipse whose length and width is equal to the length and width of penetration area. Due to the fact that contact area cannot be greater or equal to the penetration area, another penetration term is introduced, namely equivalent penetration, and this penetration is intentionally expanded by a factor. Therefore penetration area remains consistent. The corrected shape of the equivalent ellipse is given as

$$a_c = \sqrt{\frac{\delta_0}{A}}, b_c = \sqrt{\frac{\delta_0}{B}}, \tag{1}$$

where a_c and b_c are the corrected Hertzian contact patch dimensions in meters, δ_0 is the penetration in meters, A and B are the Hertzian curvatures in 1/meter. For all details of the method and explanations readers are refferred to read (Piotrowski & Kik, 2008).

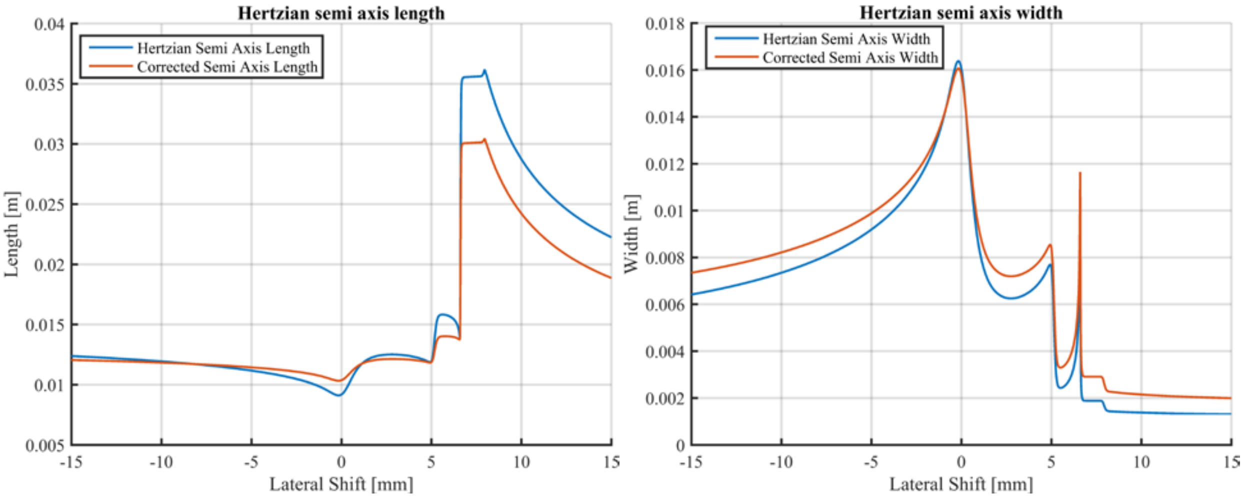

Fig. 2: Corrected width and length of contact patch.

For the solution of the tangential problem the well-known and experimentally validated creep force model of Polach, which is also mentioned in (Onat et al., 2015b), is used.

2.2. Wheelset dynamics and estimation

Details of the lateral dynamic model, which is considered here, can be found in (Onat et al., 2015b). On the other hand, instead of a rigid bogie assumption considered in (Onat et al., 2015b), bogie is modelled as a laterally suspended mass in this study. The lateral suspension force acting on the wheelset is given as

$$F_{sy} = -2k_y\left(y - y_m\right) - 2b_y\left(\dot{y} - \dot{y}_m\right), \qquad (2)$$

where F_{sy} is the force due to lateral suspension in Newtons, k_y spring constant of a spring in lateral suspension in Newtons per meter, b_y is the damping coefficient of a damper in lateral suspension in Newton-seconds per meter, $y, \dot{y}$ and $y_m, \dot{y}_m$ are the lateral shift of the wheelset and bogie and their derivatives in meters and in meters per second, respectively. The estimation is based on the fact that change in lateral suspension parameters affects the dynamic response of the wheelset. Track measurements, which are taken from a 3 km track section between Choceň-Dobřikov (CZ), are used to excite the dynamic system. The longitudinal velocity of wheelset is taken 40 m/s. Parameters, which are considered here for wheelset, can be found in Table 1 of (Onat et al., 2015b). Different from that of (Onat et al., 2015b), in this study, the normal force per wheel is 50 kN and the lateral spring stiffness is equal to the 3x10^6 N/m.

Continous dynamic system is discretized and by using a Runge-Kutta integration method, solution to the differential equations are obtained. System can be expressed as

$$\begin{aligned} x_k &= f\left(x_{k-1}, u_{k-1}, k-1\right) + q_{k-1} \\ y_k &= h\left(x_{k-1}, k-1\right) + r_k \end{aligned} \qquad (3)$$

In Equation 3, x represents vector of states, which are lateral shift, yaw angle, lateral velocity and yaw rate of the wheelset. In the same equation, q and r vectors represent the process and measurement noises, respectively. In this case of application, the input to the system is lateral alignment irregularity, but measurements (all states) are assumed to be taken from wheelset, so that the system becomes output only. A non-augmented joint unscented Kalman filter (i.e. additive noise case) is considered for parameter estimation problem. In order to understand methodology used here, readers are referred to read the study in (Matzuka et al., 2012). (Matzuka et al., 2012) explain the application of unscented Kalman filter for parameter estimation in details and give examples for simple dynamic systems.

In order to test estimation scheme, firstly spring constant of lateral suspension is tried to be estimated statically, i.e. by having a distant initial guess of the parameter. Afterwards, it is assumed that a step change occurs in spring constant of primary suspension. In the first case, it is assumed that the initial guess for the spring constant of lateral suspension is 4x10^6 N/m, whereas the real value is 6x10^6 N/m. For the second case, it is assumed that real value of the total lateral spring value drops to the $4x10^6$ N/m from $6x10^6$ N/m after 20 seconds. Estimation results are fairly good and can be seen in Fig. 3.

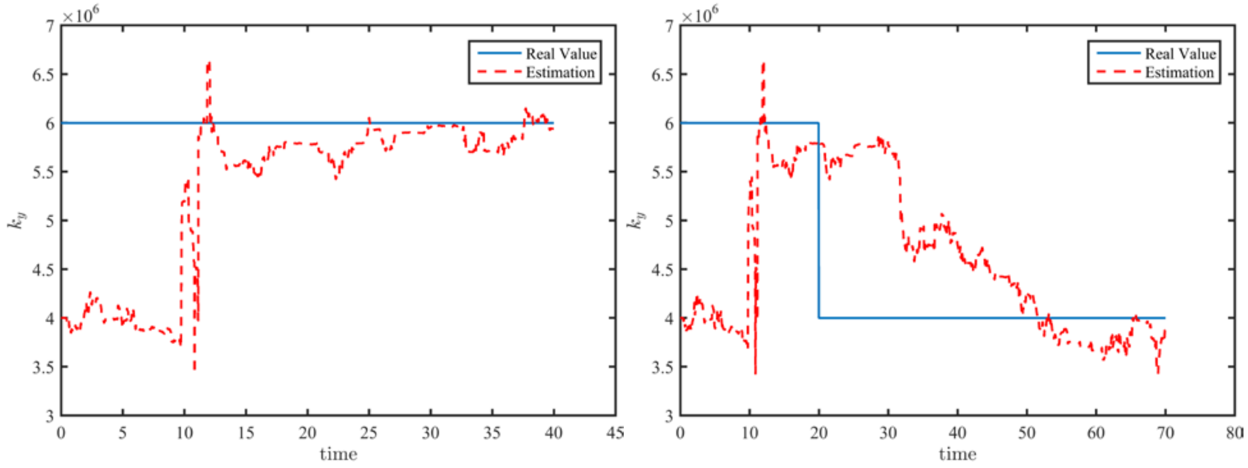

Fig. 3: Static estimation case (left), a step change in spring constant of lateral suspension (right).

3. Conclusions

In this work, a model based filtering scheme to identify primary lateral spring constant of a railway vehicle is investigated. Unlike the previous studies, a detailed model for the wheel/rail contact is considered in the estimation. Furthermore, the advantages of unscented Kalman filter with respect to the previously mentioned methods are used.

Additionally, use of real track irregularity measurements shows that the overall scheme may be appropriate for using the measurements from a real vehicle. By using this approach, if dramatic changes occur in suspension parameters before scheduled maintenance, necessary actions can be taken so that safety issues can be prevented.

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