Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 192 (2017) 695 – 700

Procedia Engineering

www.elsevier.com/locate/procedia

TRANSCOM 2017: International scientific conference on sustainable, modern and safe transport

Dependence of locomotive adhesion force estimation by a Kalman filter on the filter settings

Petr Pichlík[a]*, Jiří Zděnek[a]

[a]*Department of Electric Drives and Traction, Czech Technical University in Prague, Faculty of Electrical Engineering, Technická 2, 166 27 Prague, Czech Republic*

Abstract

A locomotive needs a slip controller to achieve the maximal tractive effort. Many types of methods are used for this purpose. Some methods use a Kalman filter or other type of estimation. These methods can work precisely and reliably. The Kalman filter provides a filtration of an output signal to eliminate the output signals noise when the Kalman filter inputs are noisy, and a filtration level is required. There is a relation between the Kalman filter filtration level and its delay. The Kalman filter delay can reach over 100 milliseconds. The locomotive slip controller has to react in the order of tens of milliseconds to provide an appropriate function. The high level of filtration and low delay are contradictory demands. The key is to find a relation between the Kalman filter delay and filtration through its covariance matrixes. In the paper is investigated the relation between the filtration level and the time delay. The simulations are made in the Matlab software and based on measured data.

Peer-review under responsibility of the scientific committee of TRANSCOM 2017: International scientific conference on sustainable, modern and safe transport

Keywords: Slip control; Kalman filter; adhesion; locomotive; railway

1. Introduction

Reliability and efficiency requirements increase in railway transport today. Furthermore, parameters of newly developed locomotives increase too. Among main locomotive parameters are the maximal tractive effort and the maximal speed. The tractive effort value and locomotive ability to transfer the tractive effort depends on an adhesion

* Corresponding author. Tel.: +420-2-2435-2136; fax: +420-2-3333-9972.
E-mail address: pichlpet@fel.cvut.cz

Peer-review under responsibility of the scientific committee of TRANSCOM 2017: International scientific conference on sustainable, modern and safe transport
doi:10.1016/j.proeng.2017.06.120

conditions. The conditions change suddenly and unpredictably when the train runs the track. When the adhesion conditions are bad, the wheels can have a big value of slip velocity that increases wear of wheels and rails and causes undesirable mechanical effects in locomotive electric drives and other mechanical bogie parts.

Locomotives are equipped with slip controllers that limit slip velocity and enable maximal tractive effort reach. During past decades were developed many types of slip controllers that have a different level of efficiency and reliability. Effective slip controllers determine a slope of current adhesion-slip characteristic. These slip controllers require knowing an adhesion force or adhesion coefficient value. For this purpose are used a disturbance observers [1, 2, 3] or Kalman filter [4]. The slip controllers have to react as quickly as possible. Therefore the adhesion force estimation has to be fast. The rate of adhesion force estimation depends on the estimator settings. If the input signal is noisy, the estimator requires a higher level of filtration and the overall estimation time is increased. This issue is too taken into account in the papers. The Kalman filter time delay is studied in the paper because the Kalman filter has emerged as a possible method for the slip control purpose [5].

Basic principles of an adhesion phenomenon are firstly described in the paper. Next follows a description of a Kalman filter and its application for slip control purpose is done. The paper covers a Kalman filter description, its parameters explanation and a model of locomotive electric drive. For slip control, the overall time delay of the filter is important. Finally, simulation results are presented. The simulations are based on measured data that were measured on a freight train.

2. Adhesion

An adhesion force can be transmitted between wheels and rails only if some slip velocity is presented. The slip velocity is defined as a difference between a wheel circumference velocity and its longitudinal velocity. More often is used a term slip instead of the slip velocity. The slip is defined as a ratio between the wheel slip velocity and the wheel longitudinal velocity:

$$s = \frac{v_C - v_L}{v_L} \tag{1}$$

Where s is a slip, v_C is a wheel circumference velocity, and v_L is a wheel longitudinal velocity.

A slip velocity or slip is needed for a force transition between wheels and rails. The adhesion force is defined as:

$$F_A = \mu \cdot N \tag{2}$$

Where F_A is an adhesion force, μ is an adhesion coefficient, and N is a normal force applied to the wheel.

The normal force has a constant value only in a static state. In a dynamic state, the normal force changes and therefore the adhesion force changes too when a train runs. The first reason of the adhesion force change is locomotive dynamical motions. The second parameter is an adhesion coefficient. Dependence between the adhesion coefficient and the slip is called an adhesion-slip characteristic. Examples of the adhesion-slip characteristics are shown in Fig. 1. The figure describes dependence for dry rails, wet rails and for the case when on the rails is oil. The oil can get to the rail e.g. by rail lubrication in a curve. The adhesion-slip characteristic changes with rail conditions and a train velocity. If the required force rises, the slip velocity rises too. The slip starts rising quickly when the adhesion coefficient exceeds the adhesion-slip characteristic maximal value. In the case, a slip controller has to react and decrease the required force. An ideal slip controller has to avoid this situation.

3. Kalman filter

The Kalman filter needs a system model for its proper work. The used model is based on three mass model that was developed in [5]. The model was reduced to two mass model for this paper. The two mass model is simpler for calculation and the three mass is not needed. The reduction was done because a speed sensor is placed on one wheelset. The second wheel is unobservable without an additional speed sensor. The system is shown in Fig. 2.