Locomotive Longitudinal Velocity Estimation

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Abstract. For reaching locomotive maximal tractive effort it is needed fully utilize available adhesion conditions on a track. For the purpose are exploited slip controllers. The controllers are based on many types of algorithms and some algorithms has common feature that the algorithms needed to know the locomotive longitudinal velocity. Measuring of the locomotive longitudinal velocity on driven wheels without any additional devices cannot be done. Therefore there are some methods for estimation of the train velocity. The paper proposes an adaptive nonlinear filter that is used for the locomotive longitudinal velocity estimation. The filter is described and simulation results in Matlab software based on measured wheel velocity are presented.

Keywords

Slip control, train, velocity measurement.

1. Introduction

The train tractive effort is transition between wheels and rails is possible via an adhesion coefficient. The adhesion coefficient has relatively small value and for tractive effort maximal value reaching it is needed to get maximal value of the adhesion coefficient. When the maximal value of the coefficient is required there is a risk of unprompted wheel slip that increase wheel and rail wear and can cause locomotive or track damage. Therefore the locomotives are equipped by slip controller that control slip velocity to appropriate value.

There are many types of slip control algorithms. Some of the algorithms need to know the train velocity to its proper work [1]. The train speed is typically determined from a locomotive wheels speed. The wheel speed is higher than the train velocity about the slip velocity. Therefore it is difficult to determine true train velocity. The train velocity is unmeasurable by wheels velocity on driven wheels. The methods that are used for the train velocity determination do only the velocity estimation [2]. There are other methods for measurement of the train velocity like GPS or using Doppler radars [2], [3] for the velocity estimation. But the methods are not widely used.

In the paper is described an adaptive nonlinear filter that is used for the train velocity estimation. The filter description and its simulation in Matlab software are done. The simulation is based on measured data from a locomotive.

2. Train Velocity

It is problematic to determine the train speed from the wheels speed. Because the wheel speed is higher above a slip velocity in accelerating or smaller above slip velocity in braking. The relation between train speed and wheels speed is given by (1)

\[ v_T = \frac{v_W}{1+s} \]  

Where \( v_T \) is a train speed, \( v_W \) is a wheel speed and \( s \) is a slip. The slip is defined as difference between wheel velocity and train velocity.

The second problem is caused by wheels diameter. The incremental encoder does not measure the longitudinal wheel velocity but it measure the wheel angular velocity. The relation between the angular velocity and longitudinal velocity is through wheel diameter. Every wheel has different diameter because of different wear. Another wheel diameter difference is caused by its conical shape that enables train run through curve. The wheel shape causes a hunting movement of a train. During hunting movement the train oscillates from side to side according equilibrium. The oscillation causes gradual changes of wheel diameter. The wheel diameters are different when the train goes through a curve. The diameter is therefore changed every time when the train runs.

3. Wheel Velocity Measurement

The locomotive speed is typically derived from wheel speed. The wheel speed is measured by an incremental encoder that is mounted on wheelset or on motor shaft. The position of incremental encoder depends on type of electric drive. Locomotives with DC motors typically have the incremental encoder mounted on wheelsets but locomotives with induction motors have the incremental encoders mounted on the motor. This variant was chosen because of vector control of the induction motor. Mounting the incremental encoder on the different places has some advantages and some disadvantages. When the incremental
encoder is mounted on the motor rotor than between wheels and the encoder is the gearbox placed. In this variant the motor angular speed is higher than the wheel angular speed therefore the encoder can provide higher resolution. On the other hand the gear box damps some dynamic motions that occur on wheelsets. The main dynamic motion is torsional vibrations between wheels. The vibrations could be used in some specific slip control methods to detect the maximum value of the adhesion characteristic.

The velocity calculation is done by a microcontroller. The microcontroller is connected with the incremental encoder output and the microcontroller count the number of edges that are produced by the incremental encode during the shaft rotation. From the number of pulses and time is the speed calculated. The calculated speed is filtered to remove some noise that can occur on mechanical parts of the electric drive. There are many variants of the microcontroller software implementation and some microcontrollers have some special unit that simplifies the measurement. An example of measured speed is shown in Fig. 1. The speed shown in Fig. 1 is filtered. In the figure is shown some noise that is caused by electric drive dynamic motion. From speed waveform that is shown in Fig. 1 is clear that any signal processing has to be robust. It is difficult to calculate some derivation of the signal.

The second problem is with high value of slip velocity. In the case the wheel velocity has disproportionately higher velocity than train and even the train velocity can decrease when the high value of the slip occur on more wheelsets simultaneously.

4. Adaptive Nonlinear Filter

The adaptive nonlinear filter is used for estimation of the train longitudinal velocity. The filter uses only measured wheel velocity for estimation. According [4] the adaptive filter has low error when the filter is used for car longitudinal velocity estimation. The filter could be described as:

\[ \dot{v}(t) = -R_g \cdot \text{sign}(v(t) - r \cdot \omega) \] (2)

\[ v(t = 0) = v_0 \] (3)

Where \( \omega(t) \) is wheel angular velocity, \( v(t) \) is an estimated train velocity, \( R_g \) is an adjustment parameter of filter sensitivity. The sign function is defined as:

\[ f(x) = \text{sign}(x) = \begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{cases} \] (4)

The train velocity \( v(t) \) will converge to the wheel velocity \( r \dot{\omega} \) in steady state. This feature could cause some inaccuracy because the train velocity is smaller about slip velocity than wheel longitudinal velocity when the wheels transit a force to a rail. Value of \( R_g \) limits speed of change of the train velocity \( v(t) \). The train velocity is \( v(t) \) and change of \( v(t) \) represents the adhesion value change[4].

Equation (2) uses a sign function. The function can cause numeric oscillations [5]. Therefore the sign function is replaced by saturation function that eliminates the oscillations:

\[ \dot{v}(t) = -R_g \cdot \text{sat}(v(t) - r \cdot \omega, d) \] (5)

Where \( d \) is saturation function parameter. The sat function is defined as:

\[ f(x) = \text{sat}(x) = \begin{cases} 1, & x > d \\ -1, & x < d \\ x, & \text{else} \end{cases} \] (6)

5. Simulation results

For simulations were a measured data as the filter input. The data was measured on locomotive that hauls a freight train. As filter input data is used a wheel velocity measured by an incremental encoder. The measured data contain noise caused by some dynamic motions, high slip velocity caused by bad adhesion conditions. These high values of the slip velocity cause the main problem of estimation because the high value of the slip increases the filtered train velocity. The train velocity was measured by GPS. The adaptive filter cannot reach the actual train velocity but only an approximation of the velocity could be reached. The estimated velocity is closer to the wheel velocity. The measured data, filtered data with sign function and filtered data with saturation function and
velocity measured by GPS are shown in Fig. 2, Fig. 3 and Fig. 4. For Fig. 2 and Fig. 3 has the \( R_g \) variable the same value \((0.5 \, \text{kph} \cdot \text{s}^{-1})\) The value is little higher than a haul train acceleration. For Fig. 4 has the \( R_g \) variable value \(1 \, \text{kph} \cdot \text{s}^{-1}\). The value is higher than train acceleration but the high acceleration is set because of saturation wide filter band. The filtered data has some oscillations around actual value. The oscillations are numerical oscillations caused by sign function. In Fig. 2 is shown filtered data for low saturation threshold \((d = 1)\). The saturation filter output with saturation function has some oscillations that are close to the sign function filter. In the Fig. 2 it is shown that neither filter does not filtered true velocity during wheel slip. The disadvantage could be mitigated by proper filter parameters as it is shown in Fig. 3. In the Fig. 3 is saturation filter threshold wider \((d = 5)\). The oscillations are lower and influence of high value of the slip velocity is lower too. In Fig. 3 the velocity is lower than the wheel velocity but the velocity is still higher than the velocity measured by GPS. The output signal is more stable but more deformed than signal from Fig. 2. In Fig. 4 is saturation threshold the same as in Fig. 3 \((d = 5)\) and \( R_g \) has value \(1 \, \text{kph} \cdot \text{s}^{-1}\). In the Fig. 4 the output of the saturation filter is closer to the wheel measured velocity. The sign filter has higher oscillations. In all figures the sign filter has the same the settings. The results are summarized in Tab. 1.

<table>
<thead>
<tr>
<th>Filter</th>
<th>( d )</th>
<th>( R_g )</th>
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<tr>
<td>sign</td>
<td>1</td>
<td>0.5</td>
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<td>sat</td>
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<td>sat</td>
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Tab. 1. Filter setting summarizing

6. Conclusion

The paper presents simulation results of adaptive filter that is used for train longitudinal velocity estimation. The two types of filter are used. First type contains the sign function and the second contains the saturation function. The filter with sign function can cause numerical oscillations. The filter with saturation function can be set to have similar behavior as sign filter by setting narrow band of the filter. But the filter could be set to eliminate the oscillations and have more smooth output by setting the
wider band. In the case it is appropriate to set the maximal acceleration higher than for the narrow band.

The adaptive filter could be used for the train velocity estimation but the estimation has some inaccuracy. The inaccuracy is caused by the filter properties. The filter property could be changed by the filter settings as it is shown in the Fig. 2 and Fig. 3. In both figures it is shown that the filter difficulty deals with high value of the slip velocity. This problem could be influenced by the filter setting e.g. to make the filter more robust at the cost of the output signal deformation.

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References


About Author

Petr PICHLÍK was born in Písek, Czech Republic in 1985. He received his bachelor and bachelor degree in Faculty of Electrical Engineering from CTU in Prague in 2008 and 2011 respectively. In 2011 he joined Department of Electric Drives and Traction at Faculty of Electrical Engineering at CTU in Prague as a PhD student. His research is focused on slip control and readhesion control of railway traction vehicles especially on electric locomotives. He vindicates his technical study at topics Slip Control Strategies of Railway Traction Vehicles in 2013. Now his research deals with slip control strategies of locomotives.