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Control system for maximum use of adhesive forces of a railway vehicle in a tractive mode

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Abstract

The realization of maximum adhesive forces for a railway vehicle is a very difficult process, because it involves using tractive efforts and depends on friction characteristics in the contact zone between wheels and rails. Tractive efforts are realized by means of tractive torques of motors, and their maximum values can provide negative effects such as slip and skid. These situations usually happen when information about friction conditions is lacking. The negative processes have a major influence on wearing of contact bodies and tractive units. Therefore, many existing control systems for vehicles use an effect of a prediction of a friction coefficient between wheels and rails because measuring a friction coefficient at the moment of running vehicle movement is very difficult. One of the ways to solve this task is to use noise spectrum analysis for friction coefficient detection. This noise phenomenon has not been clearly studied and analyzed. In this paper, we propose an adhesion control system of railway vehicles based on an observer, which allows one to determine the maximum tractive torque based on the optimal adhesive force between the wheels (wheel pair) of a railway vehicle and rails (rail track) depending on weight load from a wheel to a rail, friction conditions in the contact zone, a lateral displacement of wheel set and wheel sleep. As a result, it allows a railway vehicle to be driven in a tractive mode by the maximum adhesion force for real friction conditions.

Keywords: Control system; Railway vehicle; Adhesive force; Torque; Slip

1. Introduction

Effective application of power, as well as the consumption of energy by railway vehicles, depends on how the adhesion process goes between a rail and a wheel during the mode of realization of tractive efforts. For railway vehicle development, it is necessary to give proper weight to design adhesion coefficients. However, real adhesion coefficients are quite different from design adhesion coefficients. For example, the difference for locomotives can reach $\pm 40\%$. It is shown that we have some reserves on the one hand, and we have some costs connected with slip and tractive loss on the other hand.

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The adhesion coefficient is complex phenomenon. During the last few years, many leading scientists such as J. Piotrowski, K. Knothe, M. Ertz, O. Polach, H. Chollet, F.D. Fisher, Yu. Luzhnov, A. Golubenko, etc. work on study of adhesion forces. The obtained results of their research were applied for the development of adhesion control systems. However, at the present time we do not have absolutely perfect systems, which are allowed to make a very effective realization and increase the adhesion coefficient.

In a review and analysis by Frylmark and Johnsson [1] in the field of adhesion control systems for railway vehicles, the adhesion control for anti-slip control systems can be described by means of several control strategies, which have quite a lot in common. Few of them use other signals than vehicle velocity and the adhesion as inputs. The differences lie more in how to interpret and process these signals. From obtained results of this work, it is possible to see that the best performance can be obtained from controllers used steepest gradient and fuzzy logic strategies.

The paper [2] proposes adhesion control system of electric motor coach using first-order disturbance observer constructed on torque feedback control strategy and the new torque command function $C(t)100$. As written by the authors in their scientific work, the proposed control method accelerates the driving wheel torque of electric motor coach stably and robustly on condition of large variation of adhesion force coefficient. But according to the work [1], the implementation of this controller was not successful because the slip curves used in [2] lacked a plateau after the peak and the proposed methods demands an excitation of the system.

Watanabe and Yamashita [3] investigated the one of questions of adhesion control, which is applied for slip detection without speed sensor by focusing on the current of each motor. The authors wrote that it is possible to presume adhesion force based on the behavior of motor current when a slip occurs. But this approach by our opinion, does not allow reaching the realization of maximum possible adhesion.

Matsumoto et al. [4] describes a control method based on adjusting the torque command for the motors according to the estimated adhesive forces between wheels and rails. The works contents information how to obtain information about realized adhesive forces, but as we know, the realized and maximum adhesive forces could be different.

Ryoo et al. [5] created the control system for Korean high-speed train with induction motor drive, which allows using a maximum adhesive effort and to improve tractive performance, adhesion characteristics. The proposed anti-slip control scheme is based on the conventional pattern control and the speed difference control. But, we think that applied method also is not optimizing by maximum adhesion criteria.

Ohishi et al. [6] presents control system for electric railway vehicle driven by inverted induction motors. This work is a continuation of their early research. The proposed system is based on the proposed high-order disturbance observer and sensor-less vector control and allows taking into account the vibration phenomenon of the actual bogie. The advantage of this scientific work is that the performed simulation was confirmed by real experimental results of re-adhesion control using tested bogie of electric commuter train.

Yamazaki et al. [7] studied the creation of adhesion control system for by using of beam model railway adhesion characteristics. In this work, the control system for braking mode was obtained via simulation. Herein is one important question, how to obtain maximum coefficient of adhesion in the beam model for running vehicles? The answer is that it is impossible to measure adhesion force directly, so they estimated adhesion force by using a disturbance observer. For correct work of the observer, the relation between wheel velocity and characteristics of tractive unit was used. Yamazaki et al. [8] continue their study in this field and present a control system for braking mode based on sliding mode control theory. The proposed system is more stable than the conventional controllers.

In case of the question about getting real adhesion coefficient, the work [9] is very interesting because the authors proposed to use to estimate the friction coefficient based on neural network estimation and computational methods. Unfortunately, we could not find information about the application of the proposed neural network estimation method for design of control systems.

The creation of adhesion control system with prediction of maximum adhesion coefficient by means of noise analysis was made by Ukrainian researches [10]. The control system based on steepest gradient method was introduced. Unfortunately, this work does not present full simulation results.

The experience of leading companies and research institutes that do research in this field shows that the application of microprocessor systems gives good results for the control of adhesion processes in tractive and