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THE SOPHISTICATED CONTROL OF THE TRAM BOGIE ON TRACK

Summary. The paper deals with the problems of routing control algorithms of new conception of tram vehicle bogie. The main goal of these research activities is wear reduction of rail wheels and tracks, wear reduction of traction energy losses and increasing of running comfort. The testing experimental tram vehicle with special bogie construction powered by traction battery is utilized for these purposes. This vehicle has a rotary bogie with independent rotating wheels driven by permanent magnets synchronous motors and a solid axle. The wheel forces in bogie are measured by large amounts of the various sensors placed on the testing experimental tram vehicle. Nowadays the designed control algorithms are implemented to the vehicle superset control system. The traction requirements and track characteristics have an effect to these control algorithms. This control including sophisticated routing brings other improvements which is verified and corrected according to individual traction and driving characteristics, and opens new possibilities.

ZAAWANSOWANE STEROWANIE PRZEBIEGIEM JAZDY WÓZKA TRAMWAJOWEGO PO TORZE

Streszczenie. W artykule zajęto się problematyką algorytmów sterowania nowej koncepcji wózka tramwajowego. Głównym celem tych działań badawczych jest zmniejszenie zużycia kół i torów kolejowych, redukcja strat energii napędu oraz zwiększenie komfortu jazdy. Wykorzystano do tego badania eksperymentalne pojazdu tramwajowego ze specjalną konstrukcją wózka, zasilanego przez akumulator trakcyjny. Pojazd ten ma wózek obrotowy z kołami obracającymi się niezależnie, napędzanymi przez silniki synchroniczne z magnesami trwałymi i stałymi osiami. Mierzone są siły oddziaływania na koła w wózku za pomocą dużej liczby różnych czujników umieszczonych na badanym eksperymentalnie pojeździe tramwajowym. Obecnie projektowane są zaimplementowane algorytmy do systemu sterowania, będące rozszerzeniem dla tego pojazdu. Wymagania i właściwości trakcyjne mają wpływ na algorytmy sterowania. Kontrola w tym przebiegu jazdy wózka ulepsza sterowanie, parametry są weryfikowane i korygowane w zależności od indywidualnej przyczepności kół oraz właściwości jezdnych, co otwiera nowe możliwości.

1. INTRODUCTION

The present development of technology has also an effect on development and progress of transport and transport infrastructure, the requirements of transport companies and regional administrations. These requirements may represent availability and capacity of transport, transport speed, comfort and convenience transportation as well. Therefore it is necessary for the other research of transport management and technology, research of various modes of transport and transport means. The tram vehicles are one of the transport means used for mass urban transport. Their operation has some different characteristics in comparison with other rail vehicles. For example the tracks are led through the streets and have very small radius curves and steep rises. The new conceptions of these trams lead to the usage of tram design with part low-floor or full low-floor conception. A tram conception with a full low-floor conception is based on a bogie conception without solid axle which is solved by an electronic way represented by a connection between a right and a left wheel. This enables to optimize the mode of driving vehicle on rail track [1, 2]. The mechanical characteristics of this bogie conception are different from the standard conception with solid axle. The behavior difference between solid axle and the independent rotating wheels is shown in Fig. 1.
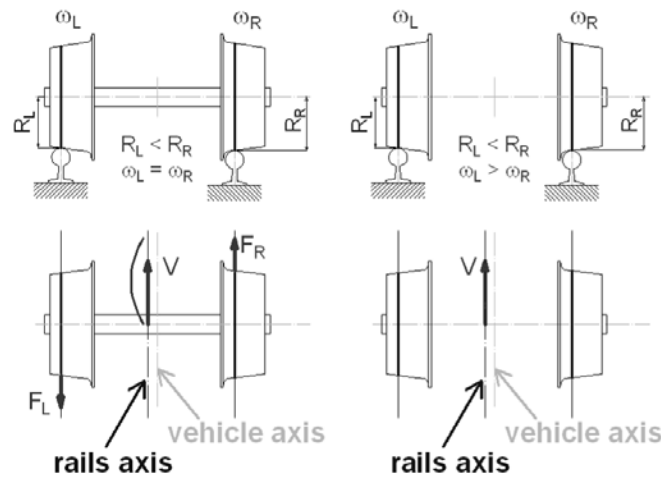

Fig. 1. The behavior of solid axle and independent rotating wheels on track
Rys. 1. Zachowanie stałej osi i obracających się kół niezależnych na torze

The bogie with independent rotating wheels is characterized by enlarged force effects between the wheels and rails during vehicle run on the rail track. In particular, raised wear of wheels and rails then also surface cracks are the result. The sophisticated synchronized torque control of individually driven wheels of the bogie (on left and right side) is one of the possible solutions for this mentioned problem. The driving characteristics of this bogie are very different at a straight track or a curve track. For this reason these control algorithms are also necessary adapted according to a vehicle position on the rail track. The determining of running curve radius by tram vehicle and feedback to the control of the individual wheel drive of the bogie is the key problem of this routing as well. The possibility of routing on the rail track is shown in Fig. 2. The M_B is a routing torque creates an action force for achievement of a bogie ideal position on a rail track [3].

The M_B is created by an additional wheel torque ΔM. The torque on the left side is added to the required torque and the torque on the right side is subtracted from the required torque. The request for a motor torque is calculated by the following equation

$$M_i = M_D + \Delta M_i \tag{1}$$

where M_i is a torque on a wheel, M_D is a required torque from driver and ΔM_i is an additional wheel torque.

Further the equation (2) has to be valid
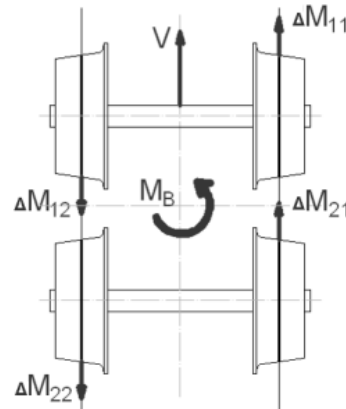
$$\sum_i \Delta M_i = 0 \qquad (2)$$

Fig. 2. The creating of the routing torque M_B
Rys. 2. Tworzenie od momentu trasowania M_B

Meet the requirement of this equation is necessary for keeping of constant tractive force to avoid affecting of drive characteristics. The magnitude of the additional wheel torque is limited by the available operation torque of traction drive. It follows that the maximum request for tractive force will not be a reserve for additional torque - at this point, there will be limitation of additional wheel torque only on the available torque of the motor. The several control algorithms for evaluating of the track parameters were considered in the framework of the research in progress where the control algorithm is based on the usage of GPS signals and processing of these signals by the superset control system of the vehicle [4] in the context of the function of adaptive algorithms of synchronized control of wheel drives of bogie is developed at Department of Electrical and Electronic Engineering and Signalling in Transport (DEEEST), University of Pardubice. The Škoda Transportation is a producer of tram vehicles with full low-floor conception. Their vehicles are already operated in mass urban transport in Prague, the Czech Republic or Riga, Latvia. The operation of these tram vehicles under different operating conditions, locations and tracks provides the large number of operation significant data. Although these tram vehicles are operated for a few years, there are still other options to optimize and improve their characteristics. The existing rail vehicles with the bogie with independent rotating driven wheels do not use the advanced algorithms for synchronized torque control of wheel drives. The DEEEST in cooperation with Research Institute of Railway Rolling Stock (VÚKV) and ŠKODA ELECTRIC deals with the research of the implementation possibilities of the advanced control algorithms.

2. THE TESTING EXPERIMENTAL TRAM VEHICLE

The testing experimental tram vehicle with the mentioned conception was constructed at the DEEEST. This research involves the evaluation of theoretical assumptions and verification of the results of mathematical models and the advanced control algorithms. This vehicle has the bogie with independent rotating wheels allows further wide research in the field of rail vehicles with the advanced conception, Fig. 3.

Fig. 3. The testing experimental tram vehicle
Rys. 3. Badania eksperymentalne pojazdu tramwajowego

This research is providing new knowledge they can be applied to both new and current conceptions of these tram vehicles. The vehicle was designed for a testing track with narrow gauge of 600 mm. This testing track is represented by Industry Rail Track with length of 11 km, it has not the regular operation and provides wide spectrum of various radius of curves, different type of rail track and steep rise up to 35 ‰. The vehicle has a solid axle and a rotary bogie. The solid axle, which is mounted on the main frame, is not driven and it is used only for distribution of the vehicle weight of 2 140 kg. The rotary bogie, which is created by two frames located under the main support frame of the vehicle, is equipped with four independent rotating wheels driven by permanent magnet synchronous motors (PMSMs) without gearbox, Fig. 4.

Fig. 4. The rotary bogie with independent rotating driven wheels
Rys. 4. Wózek obrotowy z niezależnymi wirującymi kołami napędzanymi

The main vehicle electrical equipment consists of four converters, four PMSMs, a superset controller and a power supply system [5]. The wheel drive unit is represented by a converter and a PMSM. The control of drive converters is done by designed implemented algorithm of vector control including field weakening mode in drive controllers [6, 7]. The superset controller (cRIO) calculates the optimal control of the vehicle drives (for each wheel) for vehicle leading and bogie routing in rail channel of track, the wheel slip control of this vehicle and analyzes the records of electrical and mechanical data obtained from the sensors and the drive controllers. This controller by feedback adjusts new wheel torque for individual wheels according to the track character. The power supply vehicle system is created by traction batteries with nominal voltage of 96 V and capacity of 150 Ah. The block diagram of the vehicle is shown in Fig. 5.
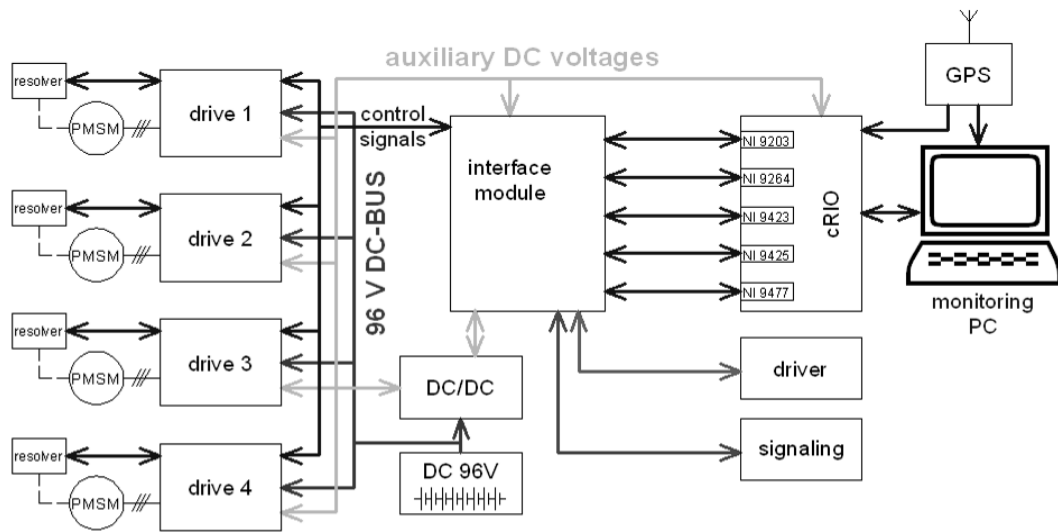
Fig. 5. The block diagram of the vehicle
Rys. 5. Schemat blokowy pojazdu

3. THE TESTING CONTROL ALGORITMS

The research activities in progress are focused on the design, implementation and testing of synchronized control with algorithms, their adaptation depends on the parameters of the running track. The testing control algorithms are used data of track characteristics (e.g. curve radius). For location of right position and related track characteristic is used also information from the GPS signals. This control algorithm evaluates the bogie optimal routing in rail track by comparison of the speed of each wheel in the bogie [8, 9]. The control structures based on this information generates the routing effort so that the bogie will be the most centred in rail track and thus the guiding force causing the increasing of the wear will be minimized, The management philosophy is shown in Fig. 6, where ω_{11} to ω_{22} are the instantaneous values of the each wheel speed of bogie, M_{11} to M_{22} are the setpoint torque of wheel drives assigned to the four drive controllers. The speed controller ω_m operates as a speed limit. The control quality is evaluated by measuring of the series of variables providing information about the quality of bogie routing in the rail track. The values of ω_{11} and ω_{12} correspond to two opposite wheels in the bogie, the value of ω_{21} and ω_{22} correspond to the remaining two opposite wheels, Fig. 7.
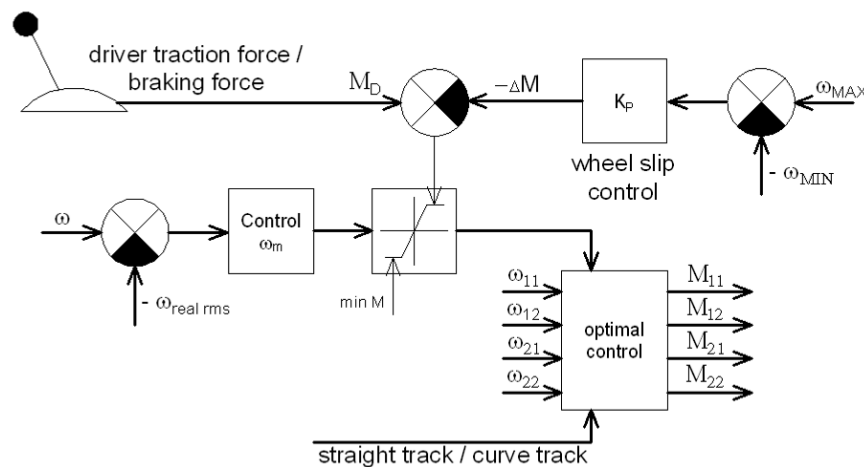

Fig. 6. The control structure of optimal routing on rail track
Rys. 6. Struktura kontroli optymalnej trasy na torze kolejowym
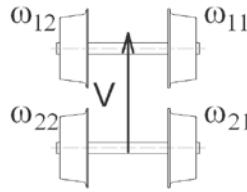
Fig. 7. The wheel signing in the bogie
Rys. 7. Oznaczenie koła w wózku

Nowadays two main algorithms of optimal routing are developed at the DEEEST. The first algorithm is based on the usage of linear controller. The calculation of the controller in the straight track is applied according to

$$\Delta M = b_1 \cdot \left(\frac{\omega_{11} + \omega_{21}}{\omega_{12} + \omega_{22}} - 1 \right) + b_2 \cdot \left(\frac{\omega_{11} + \omega_{22}}{\omega_{12} + \omega_{21}} - 1 \right) \tag{3}$$

The value of ΔM is added to traction torques of left and right wheels in the bogie. The unbalance of needed torque in a curve track is determined according to

$$\Delta M = b_3 \cdot \int_{curve} \left(\frac{\omega_{11}}{\omega_{12}} - \frac{\omega_{21}}{\omega_{22}} \right) dt \tag{4}$$

In the above mentioned equations the values b_1 to b_3 represent routing parameters. The usage of one or other equation is given by the fact that the vehicle runs in a straight track or a curve track. The magnitude of parameter b_3 is also adapted according to the running radius of the curve track. The equation 5 must be observed for keeping of vehicle constant tractive force

$$\left| \Delta M_{11} \right| = \left| \Delta M_{12} \right| = \left| \Delta M_{21} \right| = \left| \Delta M_{22} \right| = \Delta M \tag{5}$$

The necessity of good knowledge of the each wheel speed in the bogie ω_{11} to ω_{22} is the problem for this linear controller. The differences of these speeds are given by degree of wheel taper. The differences are very small (from tenths to units of percentage). For this reason the second algorithm of optimal routing is tested which is based on the usage of fuzzy controller, Fig. 8. This controller has a small discrete number of possible positions of bogie on rail track.
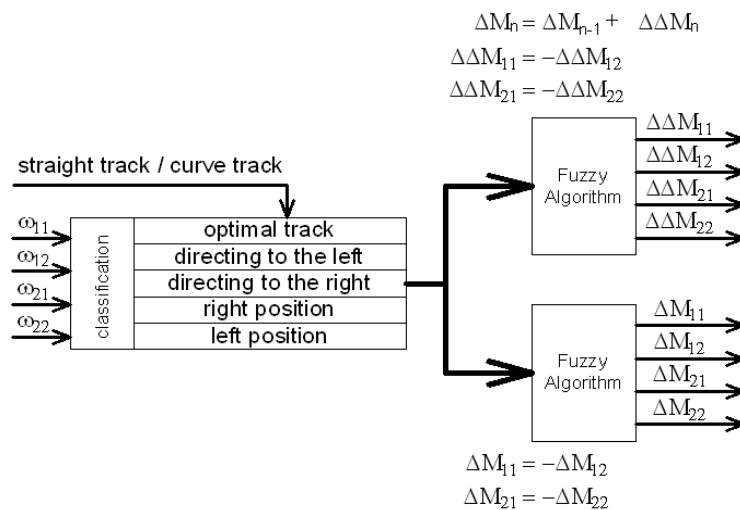

Fig. 8. The fuzzy controller algorithm of optimal routing on rail track
Rys. 8. Rozmyty algorytm regulatora optymalnego ułożenia na torze kolejowym

Due to the complexity of mechatronic system of described detection of vehicle trajectory, it was decided to use a geodesic mapped rail track and its characteristic for control solution of testing experimental tram vehicle. Then it is possible from tabulated maps and characteristics of rail track to read the necessary data by GPS system and to assign the parameters of the track section. For accuracy improvement of calculation of the exact position of this vehicle and also bogie is used both information by a GPS receiver and information by speed sensors located at the vehicle wheels. The prognostic mathematics of calculation in real time based on the geometric method of calculating chords and tangents is used for the location. The Navilock NL-402U is utilized as GPS receiver. The accuracy is further improved by using of precise digital railway maps and data postprocessing [10 - 12]. The better characteristics of the GPS receiver have not been chosen intentionally because the testing experimental tram vehicle compared to the real tram vehicle runs significantly slower. The real tram vehicle reaching higher operating speeds will use more accurate and faster GPS receiver, so that the distance between the position points (i.e. accuracy) was the same as at the testing experimental tram vehicle. For this research stage the algorithm of position evaluation is not implemented in the cRIO because of the possibility of more flexible testing without driving of the testing experimental tram vehicle. The SW created in LabView is used for monitoring PC as well. The curve radius is calculated by the monitoring PC based on the obtained corrected position by the GPS receiver. Then the other parameters of the rail channel, which are necessary for the input parameters of the algorithm ensuring of routing optimization of bogie on rail track, are determined from the knowledge of the position.

4. THE VERIFICATION OF THE ALGORITHMS

The independent user interface in the monitoring computer was created for the purpose of measuring and testing the characteristics, Fig. 9 and Fig. 10. This interface lists the main status chains of the GPS receiver and also decodes the received data for selected required parameters (vehicle and wheel speed, run distance from the starting set point, and so on). For testing purposes, this interface provides data storage of run position, plotting of the exact position of the run rail channel in the coordinate system and tested methods for calculating of the track radius.
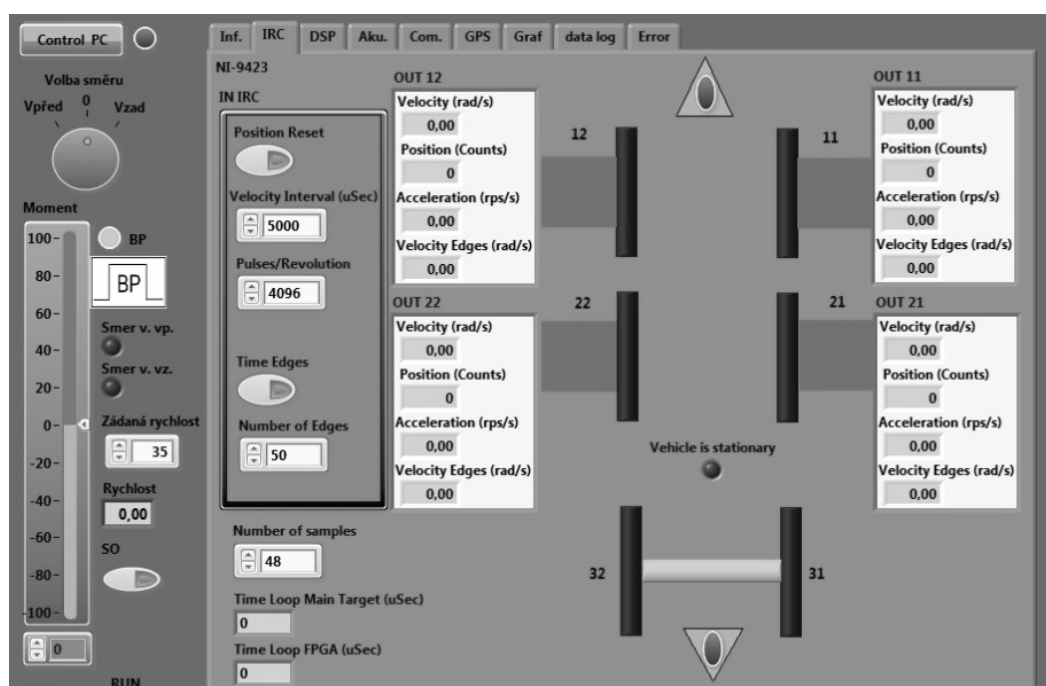

Fig. 9. SW in the monitoring computer
Rys. 9. Oprogramowanie do monitorowania komputera

Fig. 10. The interface in the monitoring computer
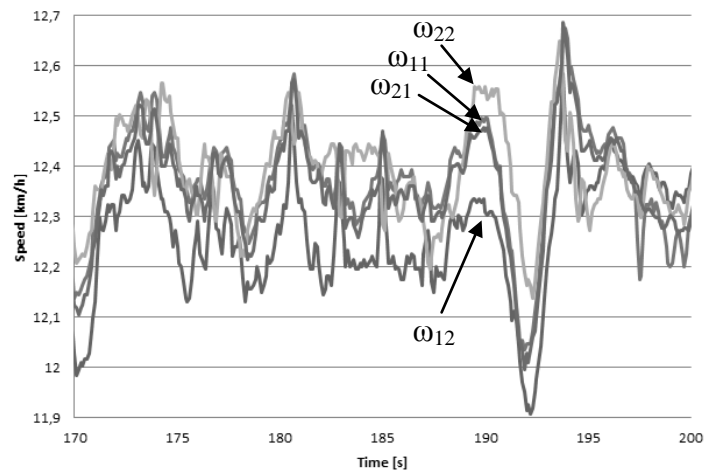Rys. 10. Interfejs do monitorowania komputera

Fig. 11. The record of the wheel speed in the bogie
Rys. 11. Rekord prędkości koła w wózku

5. CONCLUSION

The paper was intended to provide information on the progress of research work performed on the sophisticated superset control system of the testing experimental tram vehicle. This superset control system utilizes sensors information on the vehicle board to determining of right vehicle position and bogie routing in rail channel on rail track. Data for control of individual wheel drives are obtained on the basis of the calculation in the superset control system. The wear reduction of wheels and rails during a run of tram vehicles without solid axles of bogies, reduction of traction power losses and increasing of running comfort are main efforts of these research activities. Last year, the algorithms of vehicle position were also tested without feedback to the drive control system including electronic differential. Nowadays the other algorithms and methods are prepared and implemented for other improving. These methods are in testing process. After finishing of this testing of the whole structure of control for the optimized routing of the bogies with independent rotating wheels on rail track by the testing experimental tram vehicle these methods will be implemented to the real tram vehicle as tram 15T.

Acknowledgment

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