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The conception of the experimental rail vehicle

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ABSTRACT

Purpose: The article deals with the advance configuration and the installation of vehicle components to the experimental rail vehicle powered by the traction battery. Particularly the paper focus on the research problems of the construction of the experimental rail vehicle (bogie), the structure of electrical equipment of experimental rail vehicle (traction drive, control system, power supply system and the research problems of the influence between the different systems placed on the experimental rail vehicle are mentioned as well.

Design/methodology/approach: The design of the experimental rail vehicle which has a foursome mechanically independent drives and each drive has own DSP controller, is specific. The mentioned configuration ensures the coordination of the traction forces between traction drives, which create one bogie with independently rotating wheels, provides the necessary energy flows. For the reason of the effects of the control to running characteristics the experimental rail vehicle has a lot of sensors and the other measuring devices.

Findings: The problems of EMC - influence elimination of traction drive with PMSMs, control and measurement are solved. The sophisticated structure of the conception of the vehicle, which is expected to minimization of influence to the sensitive precision measuring equipment from, was designed during the development of the experimental rail vehicle (the minimization was achieved by LCD and LC filter modules).

Research limitations/implications: The vehicle with four PMSMs form the whole traction vehicle drive with the total nominal power of 5 kW because of the budget is limited.

Originality/value: The special conception of rail vehicle, which is mechanically designed by Rolling Stock Research Institute, is constructed at the JPTF for the purposes of experimental research on vehicles with independently rotating wheels.

Keywords: Conception; Low-floor tram; Traction drive; Control; Experimental rail vehicle

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

At the present, the requirements for passenger and freight transport, both road and rail transport are changing significantly. Most of these changes are evident in the public transport where a large number of electronic systems used for example to the increase of the passenger safety or information systems for passenger. These changes cause the changes in the construction of these vehicles or vehicle units as well. Many of these changes are associated with the improving of running characteristics of vehicles, but many of them deal with the increasing of the availability of these vehicles for the group of people with limited movement. Besides the height of vehicle board limits possibility to use the different levels and the structures of the platforms. For these reasons the operators of public transport already very often require the new vehicles or vehicle units with full low-floor conception from the manufacturers. Currently the full low-floor vehicles meeting these conditions are not a large number. Except mentioned requirements these vehicles have to have the high reliability and efficiency during the whole life cycle of the vehicle. For those purpose the materials and metallurgical technologies or for example vibration monitoring are important as well [1,2,21-23]. ŠKODA Pilzen is one of these manufacturers offering a full low-floor rail vehicle (15T ForCity) for urban traffic. The characteristic parameters of this tram are: length is 31 400 mm; number of units is 3; number of bogies is 4; number of wheels is 16; number of traction drives is 16; total power is 752 kW; maximum torque of traction drive is 2170 Nm; maximum speed is 80/100 km/h; level floor above top of rail is 350/450 mm. This manufacturer produces the full low-floor vehicles due to independently rotating wheels which are not connected to a fixed mechanical axle. This conception of the tram with fully rotating bogie has each wheel driven by own permanent magnet synchronous motor (PMSM). During the short operation of this tram in Prague the new questions and the suggestions for further research in the field of this vehicle with the goal to improve its running and operating characteristics arise. For this purpose of this research the special experimental rail vehicle which will allows further research in the field of rail vehicles with the advanced design conception is built at Jan Perners Transport Faculty (JPTF), University of Pardubice in cooperation with ŠKODA ELECTRIC and Research Institute of Railway Rolling Stock (VÚKV Prague). The aim is to improve the contemporary knowledge.

2. The experimental rail vehicle

2.1. The conception of the vehicle

The special conception of rail vehicle, which is mechanically designed by Rolling Stock Research Institute, is constructed at the JPTF for the purposes of experimental research on vehicles with independently rotating wheels. The designed dimensions of the vehicle: total length of 3 400 mm; width of 1 900 mm; height of 2 527 mm and the total weight of the vehicle without operating staff is almost 2 ton. These vehicle characteristics are designed from reason of testing on the chosen narrow gauge track of 600 mm located in Mladějovské industry rail track with length 11 km. This track has not the regular operation and provides wide spectrum of various curve, different radius and steep rise up to 30 ‰ as well. The proposed mechanical design is different from the previously vehicle mounting due to mechanical design of the mounting of the wheels including drives which is designed to the measurements of the forces in all axes of all wheels. The vehicle is designed with one rotary bogie (which is created by two frames located under the main support frame of vehicle, Fig. 1) fitted with four independently rotating wheels driven without gearless by PMSMs (four PMSMs form the whole traction vehicle drive) with the total nominal power of 5 kW because of the budget is limited. These motors with the integrated resolver are prototypes produced by Kollmorgen.

The characteristic parameters of motors: rated idling torque is 52.5 Nm; rated torque at nominal speed is 37.6 Nm; maximum torque (for 5 s) is 106.0 Nm; number of pole is 44. Except of the rotating bogie - Fig. 2, this vehicle has another solid non-driven axle located on the main support frame of the vehicle that replaces the second rotating bogie. This non-driven axle is inserted to facilitate the modeling of the mechanical running characteristics of the rail vehicle.

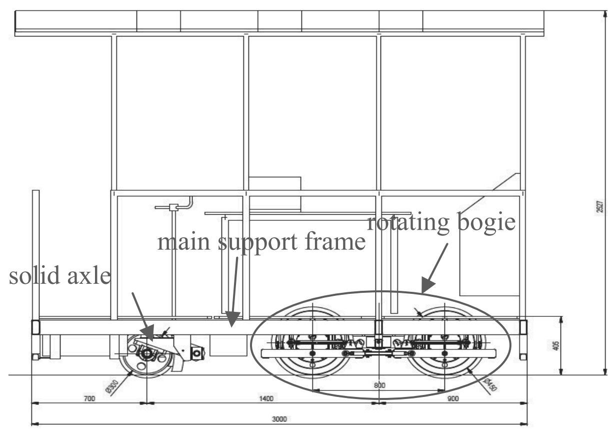

Fig. 1. The experimental rail vehicle

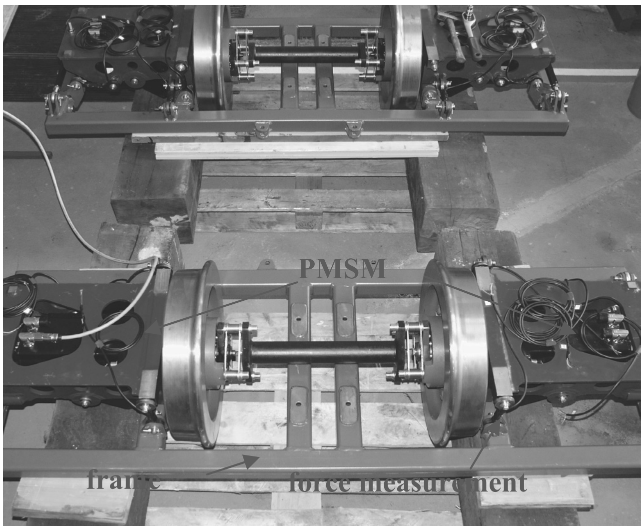

Fig. 2. The active bogies

2.2. The stucture of the electric equipment

The power supply system of this vehicle is created by 8 lead-acid batteries 12 V with total capacity 150 Ah located under the board of the vehicle. The usage of traction voltage 96 V was chosen on the basis of unification and decreasing of currents and also losses of drive units, Fig. 3.

Fig. 3. The power supply system

This voltage is in accordance with voltage constant of used traction motors. The battery capacity corresponds to the length of testing track and requirements of measuring during testing process [3-4]. The higher battery capacity was not chosen from the reason of increase of vehicle weight which could bring increasing of wheel pressures. These batteries were also selected for the reason of the possibility of efficient braking by recuperation and for the reason of the research needs of energy flows, the balances and the optimizations. The vehicle except these batteries has not the other source of the energy. From these batteries, the traction drives and also the control and the measuring systems are powered supplied, as a real vehicle supplied by the trolley line. Plenty of the precise sensors which are used for the evaluation of vehicle running are not at a real vehicle (for example 80 pc. of resistance strain gauges for the measuring forces on the rotating bogie located a few centimeters from traction drives and their measurement signals are in units of mV).

The converters of traction motors base on IGBT modules including suitable exciters by SEMIKRON. The selected exciters provide galvanic separation of controller control signals from power module and also protection of power IGBT elements. The designed converters are in standard configuration with voltage DC-bus, current and voltage sensors based on Hall probes by LEM with galvanic separation. The control of converters is done by designed implemented algorithm of vector control in controllers with DSP processor 2812. This designed algorithm is adjusted for traction requirements of rail vehicle and also modified to supplying of traction drive by the batteries. The whole structure of this controller including controller for decreasing of magnetic flux of drive (field weakening) based on the separated control of the flux and the torque component. At the present this control structure is known, Fig. 4.

The designed algorithm of control of convertor works in the mode of the torque loop in the selected configuration of traction drives and superset controller which calculates the necessary torque for each traction motor of bogie according to designed algorithm [5-8]. Currently this algorithm is tested and optimized. The other circuit of the traction converter is the coupling interface and the R/D converter.

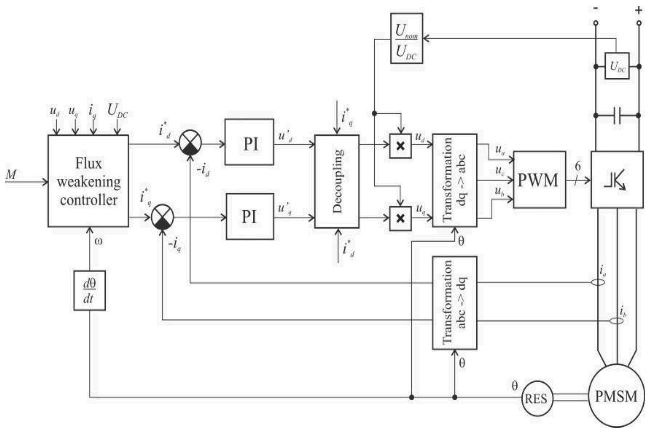

Fig. 4. The control structure

The superset controller for drive controller was chosen the CRio system by National Instrument. The controller will execute the calculations of the optimal control of the vehicle in rail channel, the calculations of anti-wheel slip control of this vehicle and analyze records of electrical and mechanical data obtained from the sensors and the controllers. This configuration brings the usage of analog and digital signals of the different systems use various power supply systems. The main task of this system working with operating system in real time is to control the whole vehicle according to the programmed algorithm. This represents adjustment of torque commands for individual wheels depending on the track character (curved line or direct line) [9-10].

The main block diagram of the whole experimental rail vehicle is shown in Fig. 5.

2.3. The theoretical analysis

The designed and constructed vehicle is unique due to its conception. During the design, it was necessary to deal with the problem of the vehicle arrangement of electric equipment and the structure of used different systems and their coupling from the viewpoint of the influence. During construction of this design were utilized EMC standard methods and principles. The main construction of the experimental rail vehicle is made from the metal structure and the vehicle is operated on the metal rail track, but on the basis of the detail analysis it is necessary to regard this for the isolated system. Insulation of the electric equipment from the metal construction is very important and necessary by reason of safety. There are a large number of analogous problems related to control and measurement of traction drive in [11-16], but they are not applicable for this mentioned case. Because in most of these cases the quite different conditions of built space for implementation of the mechanical arrangement or availability of the quality ground point is valid. During the mentioned analysis the quite complicated problem occurs related to the shielding of the individual coupling of the power supply systems and the couplings of the wiring arrangement and the influence between the parts of systems at the vehicle operating.

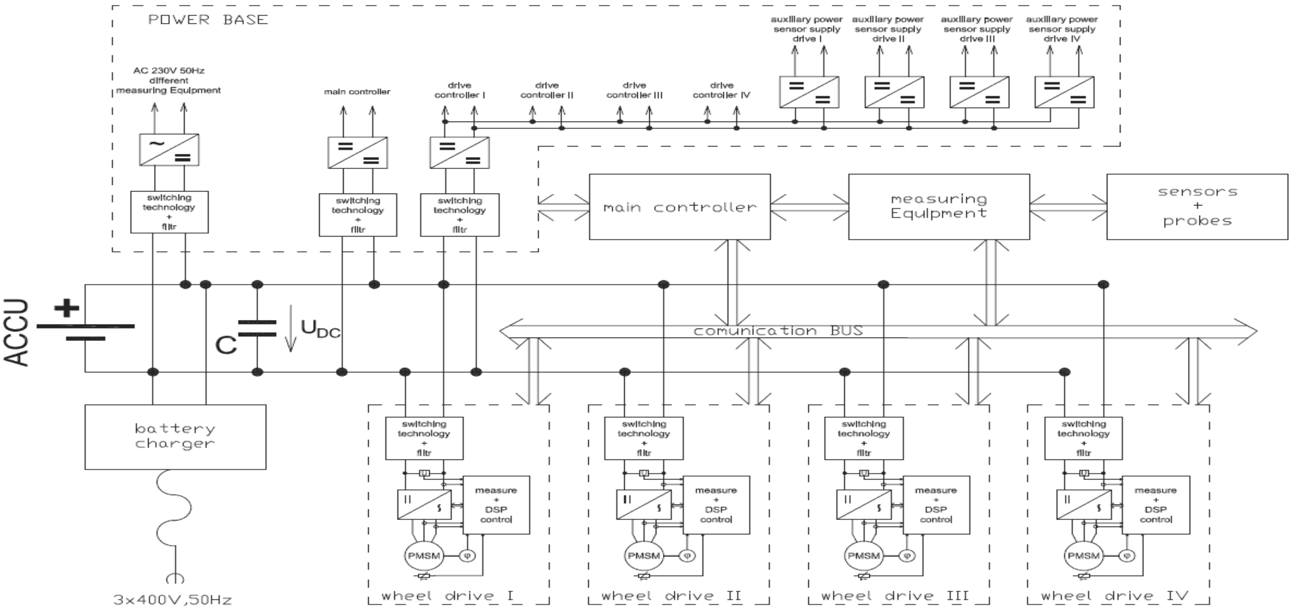

Fig. 5. The maim block diagram

3. The realized solution

The separation of the major and the minor parts of the system including shared sub-parts was performed on the basis of the analogous solutions and the study of the literature during of the development phase. This separation was done by both the digital and the analog variables and the possibilities of separation of these signals by using of digital communication bus. Five main components - four DSP drive controller, the superset controller which are further proposal taken as a single virtual node - were chosen during the proposal. The analog signals shared for the measuring systems were separate due to this proposal and the fast digital communication bus used for monitoring of the whole system and for system adjustment is used for the connection of measuring systems with the other pars of the vehicle systems. Usage of five main components which are not original modified for connection of two signal systems “digital an analog” brings the troubles, because the main connection is close to the near the CPUs. The conductive connection between the power and the signal systems is created by the system of LCD and LC filter modules for elimination of this connection which is a potential source of interference. These filters are designed to reduce possible oscillatory transients spread this connection. The fact that the motors operate with low sampling frequency and generating (units of kHz) and the measuring system records the slower process, represent by mechanical variables describing running characteristics (units of Hz), was the facilitating aspect for the design of these filters. The remaining subsystems (such as individual converters or evaluation units of mechanical variables) are located in close these above mentioned main components [17-20]. Knowledge of significant harmonic and subharmonic components in current spectrums of traction drive was utilized for design of these filters. The example of this spectrum is shown in Fig. 6. The question of the power supply system for the vehicle was solved during design of conception of the experimental rail vehicle. The vehicle systems are not designed for the lower voltage than the voltage of battery. The solution of DC/DC converters divide voltage to the separation subsystems is also used. The original design contains for each subsystem its own DC/DC converter. These individual subsystems were further connected to the main systems. From this reason the final conception was chosen the common DC/DC converters (six converters with total nominal power over 500 W) and the separation subsystems by LCD filters.

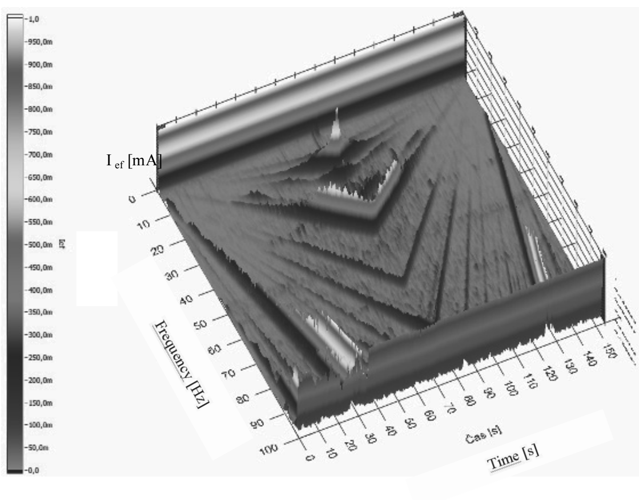

Fig. 6. The measured spectrum of the traction drive

4. Conclusions

At the present the design of the suitable configuration and the installation of vehicle components to the experimental vehicle are finishing at this research stage. The construction of experimental rail vehicle according to drawing documentation by Research Institute of Railway Rolling Stock is completed. The major part of construction of vehicle is being built up and also HW of traction converter and auxiliary electronics and circuits are being designed. During of this current research stage the problems of EMC - influence elimination of traction drive with PMSMs, control and measurement are solved. Most of these problems are discussed at the stationary applications with enough space and without limits for the weight, power and drive. At the mobile applications such as the transport means, this problem is very complicated especially if this application used several of the same types of power converters, controllers and precision measuring equipment which share the inputs of sensors. In this case it is very difficult to determine the best conception of the analog and the digital technology and coupling between them. The sophisticated structure of the conception of the vehicle, which is expected to minimization of influence to the sensitive precision measuring equipment from, was designed during the development of the experimental rail vehicle. This minimization was achieved by applicable choice of coupling LCD and LC filter modules.

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