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Modelling of secondary suspension for electric multiple unit

T. Michálek[a], F. Jeniš[b]

[a] *Department of Transport Means and Diagnostics, Faculty of Transport Engineering, University of Pardubice, Studentská 95, 532 10 Pardubice, Czech Republic*
[b] *Institute of Machine and Industrial Design, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, 616 69 Brno, Czech Republic*

The ride comfort is one of the most important aspects of railway vehicle dynamics from the point of view of railway users – the passengers. Increasing running speed and the requirements on barrier-free access into the vehicles, i.e. on low-floor high-capacity vehicles with traction equipment situated on the roof, make it more demanding to maintain the ride comfort at a high level. From the point of view of the railway vehicle design, the ride comfort is significantly influenced by the secondary suspension stage, i.e. the elastic and damping joints transmitting forces between the vehicle body and bogie frames and their parameters. A possible way, how to increase the ride comfort, is the application of modern technologies into the vehicle running gear, especially the actuators or semi-active dampers. Because of higher costs and demanding requirements on fail-safe function, the actuators are more complicated for application on the vehicle than the semi-active systems. However, the actuators are used nowadays in case of some locomotives in form of so-called active yaw dampers to help the individual bogies to steer into small-radius curves, and reduce the wheel/rail forces and wear in this way (see, e.g., [4]).

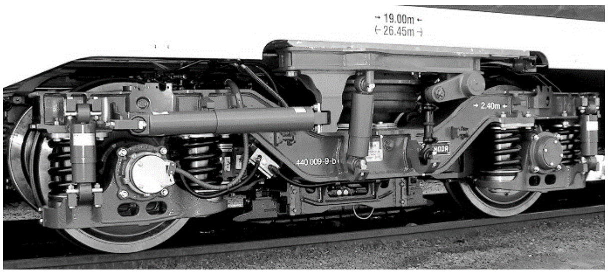

Fig. 1. Trailer bogie of a single-deck ŠKODA EMU

Potential benefits of semi-actively controlled secondary dampers – i.e. the second possible (and simultaneously cheaper as well as less demanding from the point of view of running safety and energy consumption) way to improve the ride comfort of railway vehicles by applying the innovative technologies – are investigated in framework of co-operation of Strojírna Oslavany (ST-OS), the Faculty of Mechanical Engineering of Brno University of Technology (BUT) and the Faculty of Transport Engineering of the University of Pardubice (UPCE) at solving an R&D project of the Technology Agency of the Czech Republic focused on improvement of the ride comfort of an electric multiple unit (EMU). An intermediate traction coach of the single-deck ŠKODA 10Ev EMU was selected as the object of the research work. This vehicle consists of a vehicle body and two two-axle bogies – one traction and one trailer bogie (see Fig. 1). The basic concept of both bogie types is the same – the primary suspension is realized by a couple of helical coil springs per axle box, the wheelset guiding within the bogie frame is ensured by vertical cylindrical plugs with rubber elements. The secondary suspension stage is realized by a pair of air springs with additional rubber springs per bogie and supplemented with vertical, lateral and longitudinal (yaw) dampers (a couple of each of them per bogie) and an anti-roll bar. The longitudinal force transmission between the bogie frame and the vehicle body is ensured by a central pivot and lemniscate mechanism. Lateral and yaw movements of the bogie relative to the vehicle body are limited by relevant bump stops. All the wheelsets are braked by web-mounted brake discs; in case of the traction bogie, the relevant wheelsets are driven individually and the torque of asynchronous traction motor is transmitted on the wheelset through a tilting coupling and an axle gear box.

For purposes of investigation of dynamic behaviour of the selected vehicle and optimization of the semi-active control of the secondary lateral and vertical dampers, a multi-body model of the vehicle was created in the SJKV simulation tool at the Faculty of Transport Engineering of the University of Pardubice. At the modelling, the most challenging task was the creation of the secondary suspension model including implementation of semi-active control of the dampers. As mentioned above, the secondary suspension consists of a couple of pneumatic springs, which are placed on the (emergency) rubber springs. In case of the investigated vehicle, two additional air reservoirs are connected to each air bellow to ensure a sufficiently soft characteristics of the suspension. Because of a pneumatical interconnection of the air springs on both bogie sides, a one-point support of the vehicle body on each bogie is achieved. Therefore, the stability of the vehicle body at the inflated air springs is ensured only by the anti-roll bars. For application into the multi-body vehicle model, the vertical and horizontal stiffness characteristics of the whole air spring system were estimated on basis of results of bench tests performed by manufacturer of the springs.

The secondary dampers, which are planned to be tested on the investigated vehicle in the mode of semi-active control, are being developed in co-operation of the Faculty of Mechanical Engineering of Brno University of Technology and ST-OS. Their design is based on previously developed semi-active yaw dampers with a short response time using the magnetorheological fluid (see, e.g., [3]). In this stage of the research, the control algorithm “Skyhook linear” (see, e.g., [2]) was chosen for implementation. Generally, the concept of “Skyhook control” is based on the idea that the vehicle body is connected with the inertial reference frame (i.e. the sky) by means of an ideal viscous damper to ensure a high level of the ride comfort during excitation of the vehicle by running on real track irregularities. Therefore, the “Skyhook damper” should work with the absolute velocity of the vehicle body. In practical application, the damper is able to switch (continuously) between its maximum and minimum $F-v$ characteristic and the so-called “Skyhook linear” algorithm is based on these conditions (see, e.g., [2])

$$F(v) = \begin{cases} F_{\mathrm{min}}(v) & \Leftrightarrow \dot{y}_{\mathrm{b}} \cdot (\dot{y}_{\mathrm{b}} - \dot{y}_{\mathrm{f}}) \leq 0 \\ \mathrm{sat}\left(\dfrac{\alpha \cdot F_{\mathrm{max}}(v) \cdot (\dot{y}_{\mathrm{b}} - \dot{y}_{\mathrm{f}}) + (1-\alpha) \cdot F_{\mathrm{max}}(v) \cdot \dot{y}_{\mathrm{b}}}{\dot{y}_{\mathrm{b}} - \dot{y}_{\mathrm{f}}}\right) & \Leftrightarrow \dot{y}_{\mathrm{b}} \cdot (\dot{y}_{\mathrm{b}} - \dot{y}_{\mathrm{f}}) > 0 \end{cases}$$

where $F_{\mathrm{min}}(v)$ and $F_{\mathrm{max}}(v)$ denote the minimum and maximum $F-v$ curves of the damper, $\dot{y}_{\mathrm{b}}$ is the velocity of the vehicle body in relevant direction (lateral vs. vertical), $\dot{y}_{\mathrm{f}}$ is the velocity of the bogie frame in this direction and the coefficient α is a tuning parameter (α = 0 belongs to the “Skyhook linear” algorithm and α = 1 to the simpler “ON/OFF Skyhook”). The response time of the magnetorheological dampers as well as the effect of stiffness of rubber bushing in the damper joints are considered in form of dependency of the time constant of the damper (see, e.g., [1]) on the velocity of damper deformation reflecting measurement results obtained with a damper prototype at BUT.

To demonstrate a potential contribution of the semi-active control of secondary dampers to the ride comfort improvement, a comparison of simulation results for the vehicle equipped with the original hydraulic dampers and with the semi-actively controlled lateral secondary dampers is presented in Fig. 2. The relevant simulations of vehicle running performance were performed in a straight track at speed of 160 km/h. In the left graph, time behaviour of lateral acceleration on the vehicle body and floating RMS signal (calculated in accordance with the requirements of EN standard on on-track tests with a window of 100 m) are presented. It is evident that the acceleration observed on the vehicle with semi-actively controlled lateral dampers (grey lines) reaches a lower level; the observed maximum RMS value in this particular track section is lower about approximately 30 % in comparison with the vehicle with passive damping (black lines). In the right graph in Fig. 2, corresponding working $F-v$ characteristics of one of the lateral dampers is shown. It should be noted that significantly lower damping forces and slightly higher velocities are observed on the semi-active damper in comparison with the passive one.

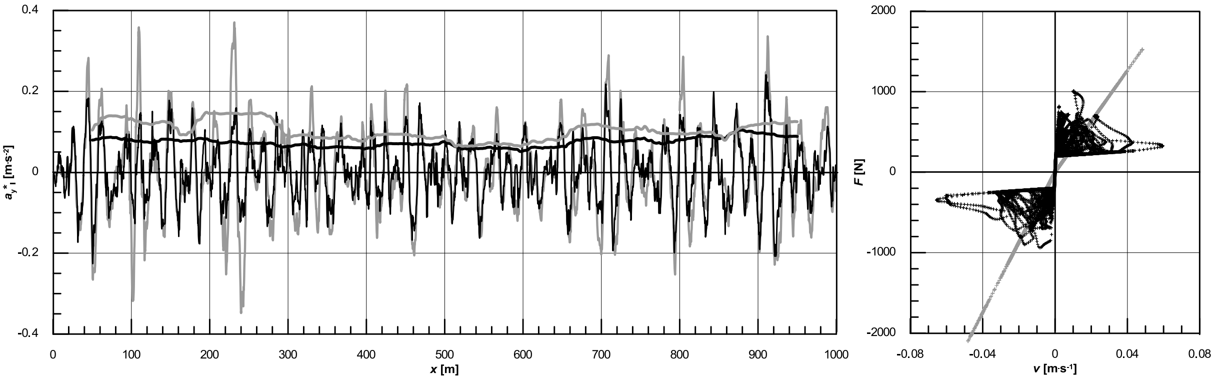

Fig. 2. Comparison of lateral acceleration (time behaviour and floating RMS) on the vehicle body (left) and working $F-v$ characteristics of a lateral secondary damper (right) at simulation of vehicle running on a straight track at 160 km/h with original passive (grey lines/dots) and semi-actively controlled lateral secondary dampers (black lines/dots)

In this contribution, selected simulation results of the initial stage of development of a semi-active damping system for a single-deck EMU are presented. In the next stage, the described simulation model will be used for optimization of efficiency of the semi-active damping system. Verification of the simulation results by on-track tests is expected to be realized in 2024.

Acknowledgements

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