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EVALUATION OF THE IMPACT OF THE DISCRETIZATION ORDER OF THE PASSENGER WAGON BODY MODEL ON RIDE COMFORT

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Abstract

Passenger wagons are important transport means, which ensures transportation of large numbers of passengers every day. These transport means should meet strict criteria from several points of view. Passenger ride comfort is an important factor influencing the choosing the right wagon. From the mechanics point of view, a level of mechanical oscillation lead to deterioration of passengers' ride comfort. Nowadays, the quality of running properties of a rail vehicle is very often investigated by means of modern computer simulation methods. The presented research is also focused on an application of numerical simulations to analyse passenger's ride comfort using a commercial simulation software. A standard approach considers either a rigid body as a one component of a wagon body model or a flexible wagon body. In comparison with that, this study includes a wagon body as a system of discrete components interconnected by torsional springs. Then, the wagon body is modelled as a torsional system. Its simplified mathematical model is also included in the study. Totally, four orders of wagon body discretization's are investigated. Individual parts of the discrete wagon body have defined the corresponding mass and moments of inertia together with a position of the centres of gravity. Fifteen points are chosen in the wagon body to evaluate ride comfort for every order of discretization. An average speed of 80 km/h was defined for the wagon running along the track. A real section of the railway track was modelled. Excitation of the wagon mechanical system was caused by irregularities. The achieved results showed, that higher number of discrete elements representing the wagon body caused lower values of the ride comfort index, i.e. higher level of ride comfort. These findings correspond with known results for a flexible body. However, lower demands on modelling complexity and computational time are needed.

Keywords: rail vehicle, ride comfort, dynamics, MBS model, discretization

1 Introduction

Passengers usually travel for shorter and middle distances by railways or by roads transport. The current trend is, that even long distances are overcome by land transport, namely by railway transport [1-3]. Railway are considered a sufficiently fast, comfort, reliable as well as environmentally friendly kind of transport [4-6]. Increasing running speed, stricter demands on safety and reliability of transportation systems lead to design modern and robust rail vehicles, which also meet criteria of ride comfort for passengers. It is possible to state, the criterion of ride comfort for passengers that this criterion is as important as the criterion of safety. Actually, the ride comfort quality is a key factor for users to choose a particular rail vehicle to use. This is engineers' motivation to design comfort passenger wagons, that satisfy the passengers' demands for comfort together with reliability and efficiency of transportation [7].

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Computer simulations are widely and actively employed in the design and analysis of rail vehicles. There are several approaches to evaluate running properties of rail vehicles. The presented research is based on multibody modelling. The main goal is to investigate, how the discretization order of the passenger wagon body model influences to assessed ride comfort for passengers. A section 2 includes a theoretical background to the ride comfort assessment, a section 3 brings a description and details of the solved multibody model and the achieved results together with discussion are presented in a section 4.

2 Ride comfort assessment

Ride comfort for passengers is evaluated in rail vehicles by means of two methods. The first method is a direct method, when passengers are in a rail vehicle and they evaluate own subject feeling during rail vehicle running on a railway track in a real time. The second method is an indirect method, which is based on simulation computation. The indirect method requires to create a suitable simulation model. Subsequently, simulation computations are performed on a railway track model. The main outputs values are acceleration signals, which are processed and evaluated based on procedures prescribed in a corresponding standard, such as EN 12299:2009 [8]. This standard includes a description of a methodology, which should be applied for evaluation of ride comfort for passengers [9, 10]. There are included the details of several methods depending on required evaluated running conditions, such as a standard method – the total comfort, a standard method – the continuous comfort, a method for discrete events, and others. Every of these methods has defined a procedure of processing of the acceleration signals and subsequent calculation of the resulting ride comfort index [8, 11]. The presented research is focused on evaluation of ride comfort for passenger on a wagon body floor. This ride comfort is characterized by the N_{MV} ride comfort index. The calculation of the N_{MV} ride comfort index is based on the following formulation:

$$N_{MV} = 6 \cdot \sqrt{\left(a_{XP95}^{W_d}\right)^2 + \left(a_{YP95}^{W_d}\right)^2 + \left(a_{ZP95}^{W_b}\right)^2} \tag{1}$$

where the expressions $a_{XP95}^{W_d}$, $a_{YP95}^{W_d}$ and $a_{ZP95}^{W_b}$ indicate accelerations in x, y and z directions processed, respectively. These accelerations signals are weighted by the weighting functions W_d and W_b and the 95-percentage is determined. Finally, the calculated value of the ride comfort index is compared in the limit values, which are in the following ranges: N_{MV} = (0 to 1.5) – very comfortable, N_{MV} = (1.5 to 2.5) – comfortable, N_{MV} = (2.5 to 3.5) – average comfort, N_{MV} = (3.5 to 4.5) – uncomfortable, N_{MV} = (4.5 to ∞) – very uncomfortable [8]. The examined passenger wagon includes 15 measured points, which the acceleration signals are evaluated in. These points are shown in figure 1b. A distribution of ride comfort level in a wagon body is illustrated by means of a column graphs. These research results are presented in section 3.

3 A multibody simulation model of the passenger wagon

As it is mentioned above, the presented research is based on simulation computations. The multibody dynamics approach is applied for creation of a simulation model of a passenger wagon and for performing simulation computations. The Simpack multibody software was used to set-up the passenger wagon. This software represents a robust and quite widely spread simulation tool, which allows to perform realistic simulation of means of road transport, rail transport as well as any other mechanical systems [12-14].

Regarding to rail vehicles simulations, this software is popular among researchers and scholars, because it includes a special modelling elements to set-up the wheel-rail contact [15], force elements and calculation algorithm for post-processing the output signals including the acceleration signals in order to calculate the N_{MV} ride comfort index directly after simulations are done [8]. The passenger wagon model consists of three main substructures in the used software, namely two bogies and the wagon body. The created multibody model of the passenger wagon is depicted in figure 1a.

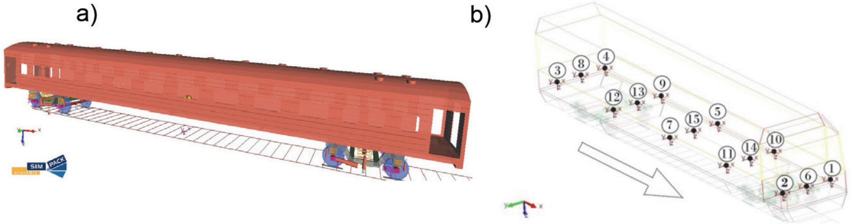

Figure 1 a) The created multibody model of the investigated passenger wagon, b) a location of 15 points for evaluation of ride comfort for passengers by means of the N_{MV} ride comfort index

As the research is focused on evaluation of the impact of the discretization order of the passenger wagon body model on ride comfort for passengers, four versions of the wagon body substructure were set-up. These versions are as follows:

- the wagon body as a rigid body (without the defined torsional stiffness), the version A, figure 2a
- the wagon body consisting of two rigid bodies (with the defined torsional stiffness), the version B, figure 2b
- the wagon body consisting of three rigid bodies, the version C, figure 2c
- the wagon body consisting of four rigid bodies, the version D, figure 2d.

The created multibody model of the passenger cars includes relatively high number of degrees of freedom. These movements are described by differential-algebraic equations, which are derived automatically by the used software, and they are hidden form the user. However, the wagon body movements regarding to the longitudinal axis (in the running direction) can be derived and written in a quite simple way. Depending on the discretization order, a calculation dynamic scheme of the wagon body will be as shown in figure 2.

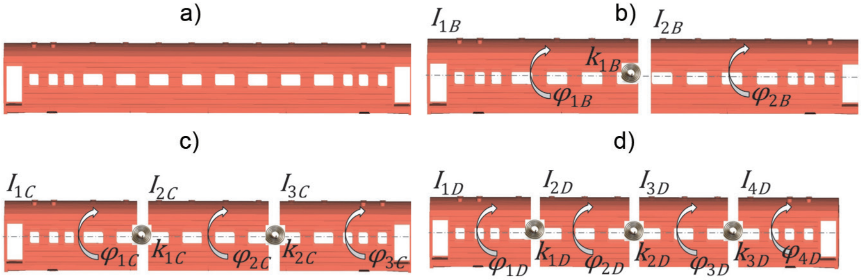

Figure 2 An illustration of various level of discretization of the wagon body model: a) version A, b) version B, c) version C, d) version D

When the relative angular coordinates Ψ_{ij} and the torsional stiffness k_{ij}, i = 1, 2, 3, j = B, C, D are considered, the equations of motion of torsional oscillation of individual versions of the wagon body discretization valid for free oscillations are as follows:

$$\ddot{\Psi}_{1B}+\frac{k_{1B}\cdot\left(l_1+l_2\right)}{l_1\cdot l_2}\cdot\psi_{1B}=0 \tag{2}$$

for the model depicted in figure 2b:

$$\begin{aligned}&\ddot{\Psi}_{1C}+\frac{k_{1C}\cdot\left(l_1+l_2\right)}{l_1\cdot l_2}\cdot\psi_{1C}-\frac{k_{2C}}{l_2}\cdot\psi_{2C}=0\\&\ddot{\Psi}_{2C}-\frac{k_{1C}}{l_2}\cdot\psi_{1C}+\frac{k_{2C}\cdot\left(l_2+l_3\right)}{l_2\cdot l_3}\cdot\psi_{2C}=0\end{aligned} \tag{3}$$

for the model shown in figure 2c, and finally, for the model illustrated in figure 2d:

$$\begin{aligned}&\ddot{\Psi}_{1D}+\frac{k_{1D}n\left(l_{1D}+l_{2D}\right)}{l_{1D}nl_{2D}}n\psi_{1D}-\frac{k_{2D}}{l_{2D}}n\psi_{2D}=0\\&\ddot{\Psi}_{2D}-\frac{k_{1D}}{l_{2D}}n\psi_{1D}+\frac{k_{2D}n\left(l_{2D}+l_{3D}\right)}{l_{2D}nl_{3D}}n\psi_{2D}-\frac{k_{3D}}{l_{3D}}n\psi_{3D}=0\\&\ddot{\Psi}_{3D}-\frac{k_{2D}}{l_{3D}}n\psi_{2D}+\frac{k_{3D}n\left(l_{3D}+l_{4D}\right)}{l_{3D}nl_{4D}}n\psi_{3D}=0\end{aligned} \tag{4}$$

Equations 2 to 4 include relative angular coordinates, which are as follows:

$\Psi_{1B}=\varphi_{2B}-\varphi_{1B}$, $\Psi_{1C}=\varphi_{2C}-\varphi_{1C}$, $\Psi_{2C}=\varphi_{3C}-\varphi_{2C}$, $\Psi_{1D}=\varphi_{2D}-\varphi_{1D}$, $\Psi_{2D}=\varphi_{3D}-\varphi_{2D}$, $\Psi_{3D}=\varphi_{4D}-\varphi_{5D}$.

The solved passenger wagon is equipped with two two-axle bogies. The suspension system includes a primary suspension system and secondary suspension system. Both suspension levels consist of coil springs and hydraulic dampers with defined characteristics. Simulation computations were performed for the running speed of 80 km/h. A real track section in the Slovak Republic was chosen for simulations. It is a section with the total length of 5, 800 m. The wagon overcomes this section in 261 s. The sampling frequency for calculations was defined of 250 Hz. This value meets the requirement of the minimal sampling frequency of 200 Hz when ride comfort is evaluated. The chosen railway track section includes several curves with various radii. The excitation of the mechanical system of the examined model of the passenger wagon is caused by the track irregularities [16-20]. In the solved case, the track irregularities are defined for both left and right rails in vertical and lateral directions. They are defined as a deviation from the ideal track geometry [21]. The track irregularities are prescribed by the input file in a for of measured irregularities with the incremental step of 0.5 m. The Fastsim wheel/rail contact model was defined for the multibody model [22, 23]. This is the most widely used wheel/contact model, and it is the most suitable for this type of performed simulation computations [24, 25]. The subsequent section presents the results of the performed research.

4 Results and discussion

The achieved results of the performed research are presented in a form of column graphs depicted in figure 3. The results correspond to the discretization order of the wagon body model presented in a section 3, figure 2. The numbers of columns reflect their distribution on a body floor shown in figure 1b. As it can be seen, the highest values of the ride comfort indices N_{MV} are achieved for the wagon body, the version A. At the same time, the highest values of ride comfort (i.e. the lowest level of comfort) can be recognized in the end parts of the wagon body (dark blue colour). These values are of 1.70 to 1.73 (figure 3a). Further, the highest ride comfort quality is evaluated in the middle part of the wagon body, where the N_{MV} index reaches the values of 1.15 to 1.22 (figure 3a). When the wagon body model consists of two individual bodies connected by a torsional spring (figure 2b), the ride comfort index reaches lower values. The highest values are of 1.59 to 1.65 and the lowest values are of 1.08 to 1.18 (figure 3b). The higher level of the wagon body discretization leads to decreasing the values of the N_{MV} index. This is possible to recognize in figure 4c. In this case, the wagon body model includes three bodies connected by two torsional springs (figure 2c). Finally, the highest level of the ride comfort index N_{MV} is detected in figure 3d, which corresponds to the discretization of the wagon body model consisting of four individual bodies (figure 2d). In this case, the highest values of the N_{MV} index are achieved again in the end parts of the wagon body and they are from 1.40 to 1.45. The lowest values of the ride comfort index N_{MV} are identified in the middle of the wagon body. These values are from 0.85 to 0.92 (figure 3d).

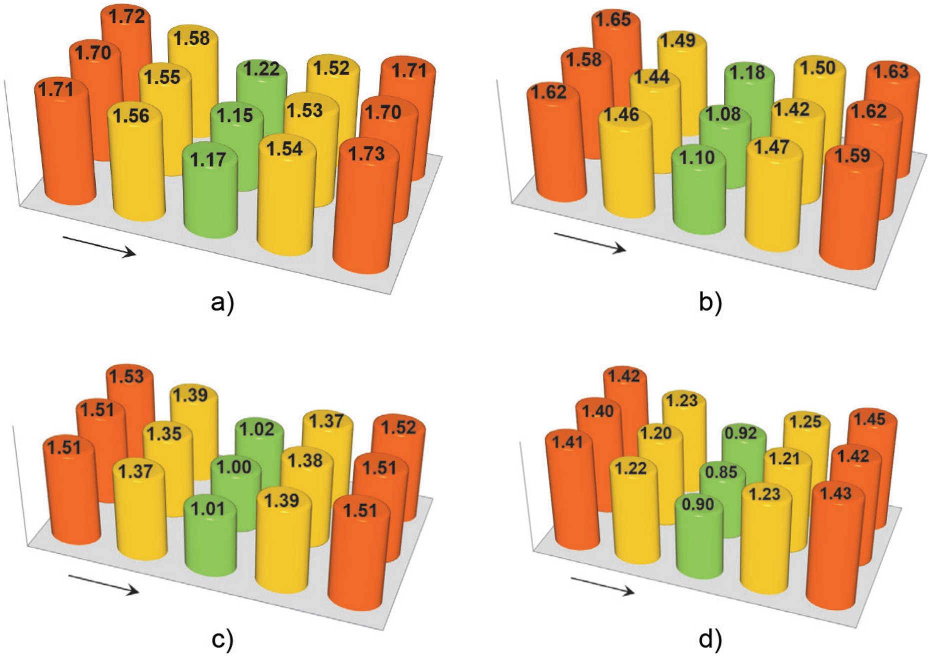

Figure 3 The results of the simulation computation for various level of discretization of the wagon body model: a) version A, b) version B, c) version C, d) version D

The values of the N_{MV} ride comfort index can be also evaluated regarding to limits presented in the section 2. The ride comfort level “very comfortable” (valid for the values up to 1.5) is for all cases in the middle part of the wagon body. This comfort level is also achieved for the wagon version D for all measured points (figure 3d). Further, the ride comfort level for the versions A to C in the end parts of the wagon body is evaluated as “comfortable” (values up to 2.5). Finally, other points located on the wagon body floor are evaluated as “very comfortable” of “comfortable” depending on the discretization level of the wagon body. The main findings of the performed research is a fact, that the level of the wagon body understood that the torsional stiffness of the wagon body (with defined partial damping) helps to decrease arising oscillations of the wagon body and subsequently also its accelerations in the measured points.

At the same time, it is revealed, that the resulting differences are not so significant, mainly in a case, when low level of discretization is applied in a multibody model. Higher level of discretization requires to set-up a slightly complicated model and higher computing time. The future research will include to assess more running conditions, such as different running speeds, different railway track profiles, etc. to the output parameters. It is considered the aim of investigation of an implementation of a flexible wagon body to the multibody wagon model [26, 27].

5 Conclusion

This research addressed an investigation of an influence of the level of discretization of the wagon body model to the ride comfort for passengers. The research was based on simulation computations of a passenger wagon. The theoretical background of the evaluation of ride comfort for passengers included important information about the used method N_{MV} applied in the study. Simulation computations were performed by means of the commercial multibody software Simpack. Fifteen points on the wagon body floor were defined fin order to evaluate the ride comfort level for the defined running properties. Running speed of 80 km/h and a real track section with prescribed track irregularities were chosen for the simulations. Four variants of the wagon body model were created differing in the level of the discretization. It was found out, that torsional stiffness defined in the model helps to reduce oscillations and vibrations of the wagon body during movement on a track. Therefore, a higher level of discretization of the wagon body model leads to higher ride comfort for passengers.

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3

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