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Assessment of the Passenger Ride Comfort for a Coach by Means of Simulation Computations

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Abstract: The ride comfort for passenger represents an important aspect of a rail vehicle dynamic analysing. The computational software utilisation helps to determine forces and accelerations in various positions through the body of a rail vehicle in order to predict ride properties or evaluate ideas for ride comfort in advance. This article is focused on the dynamic simulation of a rail vehicle running on a real track section. The rail vehicle model creation, computations performance and determination of accelerations badly needed for the ride comfort evaluation is performed in commercial software package.

Keywords: Ride comfort, passengers, rail vehicle, track section, computer simulation

1. Introduction

The ride comfort is one of the most important rail vehicle assessment standards. The ride comfort is given by several different adverse effects which passengers are subject on. These effects include mainly noise, air humidity, lighting, temperature, ventilation and vehicle vibration. The ride comfort is one of fundamental assumptions of a rail vehicle achievement and popularity for passengers and transport operators. For this reason a big emphasis is given on the rail vehicle analysis before its operation. For analysis computer simulations and detailed analysis of measured experimental values are widely used.

2. Ride Comfort for Passengers

The passenger ride comfort can be evaluated by the so-called indirect method [1]. For this method there is necessary to know acceleration values of the vehicle in analysed points. Acceleration values are filtered and weighted by functions that take into account the human sensitivity to the vibration in reference directions. Such modified values are statistically evaluated subsequently and comfort indices for the floor and for the standing or seated person standing and seated are numerically calculated. Acceleration inputs to the calculation can be obtained by measurement [2] or as a result of the simulation calculation [3-5].

During a wagon running dynamic movements of wagon body arise. These movements effect as vibrations. Passengers are subjected to these negative effects during a rail vehicle operation [6,7].

The ride comfort is the total sensation which is generated in the passenger body by the rail vehicle body movements. These rail vehicle body movements are to the whole passenger body transmitted in passenger – vehicle points [1] (Fig. 1) to the passenger position:

- standing position: floor – feet,
- seated position: headrest – neck, arm rest – arms, seat – hip, backrest – back, floor – feet.

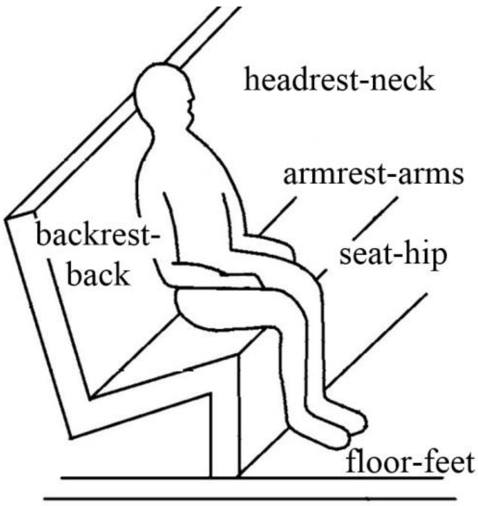

Fig. 1 Interfaces points. Source: [1]

Total sensation is classified as:

- average sensation – due to vibrations,
- immediate sensation – due to the immediate changing of the average sensation by the short effect [1].

Body accelerations are not only used in order to evaluate the passenger ride comfort but also to evaluate running properties and vehicle vibrations. Whereas comfort criterions are stricter as criterions for vehicle running properties in order to operation approval, there is to the ride comfort optimization concentrated at the rail vehicles dynamic analysis mostly, there through good running properties are achieved.

The passenger ride comfort is evaluated according to the EN 12299:2009 standard [1] based on the UIC 513. There is ISO 2631 standard also used, eventually the grade quality running W_z by

Sperling. Ride comfort criterions appear from the accelerations body measured namely in the vertical, lateral, eventually longitudinal direction.

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For the passenger ride comfort evaluation are the weighting filter used that deliberate the human body sensitivity by particular of frequency. These filters are different for vertical and lateral direction. Weighting filters accordance with EN 12299:2009 standard (measurement on the floor) for the lateral direction are consistent to the ISO 2631 filters, they are different for vertical direction a bit only. Compared with the older grade quality running W_z are particularly filters for lateral direction significantly different, therefore the different criterion can reach to different ride comfort quality results in spite of the same vehicle [1,8].

2.1 Ride Comfort Indices Calculation

The ride comfort indices calculation assumes the measurement of acceleration (m/s^2) in the *x*, *y*, and *z* direction (a_x, a_y, and a_z). Based on the sampling frequency f_n is determined by the number of samples that are recorded in the time interval of 5 sec. At the sampling frequency of 200 *Hz* during 5 sec. are obtained 1000 samples. Based on the condition of samples occurrence in 5 sec. intervals shooting time is divided into 5 sec. periods. Each of the sections has clearly established the start T_1 and the end T_2 in time. For the dataset at the each time interval is performed the fast Fourier transformation (FFT). For range of frequencies 0.4 Hz - 100 Hz is performed CAW calculation [8].

The weighting filter marked as *w* which takes into account the human body sensitivity at different frequencies is applied depending on the type of the evaluation – floor, standing position, seated position.

Weighting function modified acceleration values are statistically evaluated and summation functions in histograms are determined.

Result values of passenger ride comfort indices for the average comfort are calculated as follows [1]:

- floor

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

It can be sometimes useful depending on the application to calculate partial indices of the ride comfort:

$$N_{MVx} = 6 \cdot a_{XP95}^{W_d} \tag{2}$$

$$N_{MVy} = 6 \cdot a_{YP95}^{W_d} \tag{3}$$

$$N_{MVz} = 6 \cdot a_{ZP95}^{W_b} \tag{4}$$

- standing position

$$N_{VD} = 3 \cdot \sqrt{16 \cdot \left(a_{XP50}^{W_d}\right)^2 + 4 \cdot \left(a_{YP50}^{W_d}\right)^2 + \left(a_{ZP50}^{W_b}\right)^2} + 5 \cdot \left(a_{XP95}^{W_d}\right)^2 \tag{5}$$

- seating position

$$N_{VA} = 4 \cdot \left(a_{ZP95}^{W_b}\right)^2 + 2 \cdot \sqrt{\left(a_{YP95}^{W_d}\right)^2 + \left(a_{ZP95}^{W_b}\right)^2} + 4 \cdot \left(a_{XD95}^{W_d}\right)^2 \tag{6}$$

Analyses in this paper are focused on the N_{MV} index computation. To calculate this comfort index, it must input the accelerations in longitudinal (x), lateral (y) and vertical (z) direction of each point of interest.

The ride comfort calculation procedure is shown in Fig. 2.

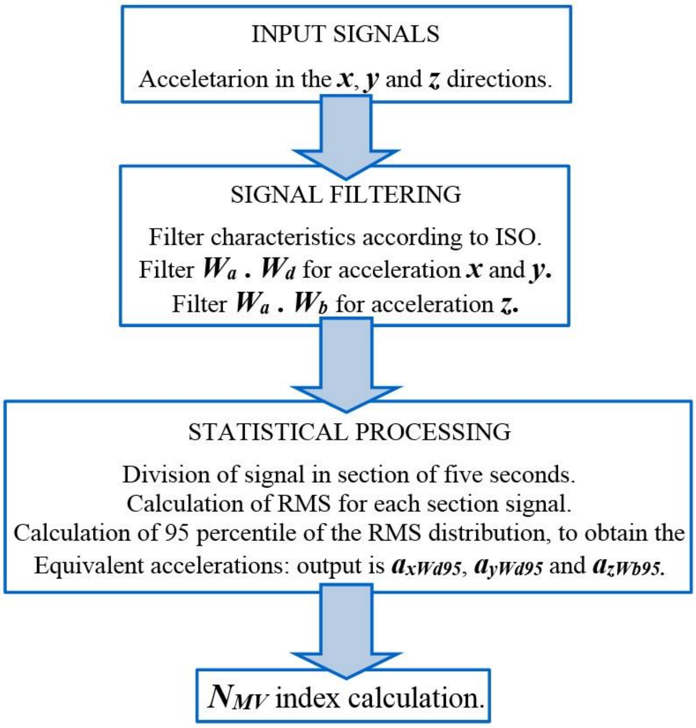

Fig. 2 Process of the N_{MV} comfort index calculation. Source: [1,8]

3. Ride Comfort Assessment by Using Computer Simulation

This section should include sufficient technical information to enable the experiments to be reproduced. In theoretical papers comprising the computational analyses, technical details (methods, models applied or newly developed) should be provided to enable the readers to reproduce the calculations.

In the development and manufacture rail vehicles process is given the care of a test and validation their static and dynamic properties. There is the main emphasis to the effective resources exploitation in a competition, therefore there are preferably used a lot of types of rail vehicle computer simulations as a mechanical system, its subsystems and its particular parts [9].

Generally is there an experimental process of data obtaining that are needed to optimization of new products designing and creating. The computer simulation is characterized by the real vehicle system replace computer model created especially for the specified conditions.

The dynamic analysis evaluates changes of rail vehicle behaviours as a mechanical system under the influence of equilibrium change.

Dynamic simulations of the rail vehicle running could be performed by using of a variety tools virtual reality [10,11]. For purposes of the rail vehicle model creation, dynamic simulation, processing of results and passenger ride comfort assessment has been used Simpack package.

Simpack allows modelling and analysis of rail vehicles and similar devices of every kind, from trams to high-speed trains but also from material handling systems to roller coasters.

3.1. Computer Model of a Passenger Car

Most parts of a rail vehicle model in Simpack are made with standard Modelling Elements, but the contact between rails and wheels uses specialized Modelling Elements. Calculation of ride comfort indices also requires the use of specialized Control Element (accelerometers).

The ride comfort was evaluated for a four – axle two bogies passenger car. The wagon is equipped with primary and secondary suspensions. The wagon model consists of several rigid bodies. Main parts of vehicle are:

- body of wagon,
- bogie frames,
- axle boxes,
- wheelsets.

The FASTSIM method was used for the rail/wheel contact calculation. This is the standard method for vehicle dynamics [12-14].

For the assessment of passenger ride comfort we had to determine accelerations in individual direction *x*, *y* and *z*. Therefore specialized Control Elements (167: Accelerometer) were defined into points as Fig. 3 shows.

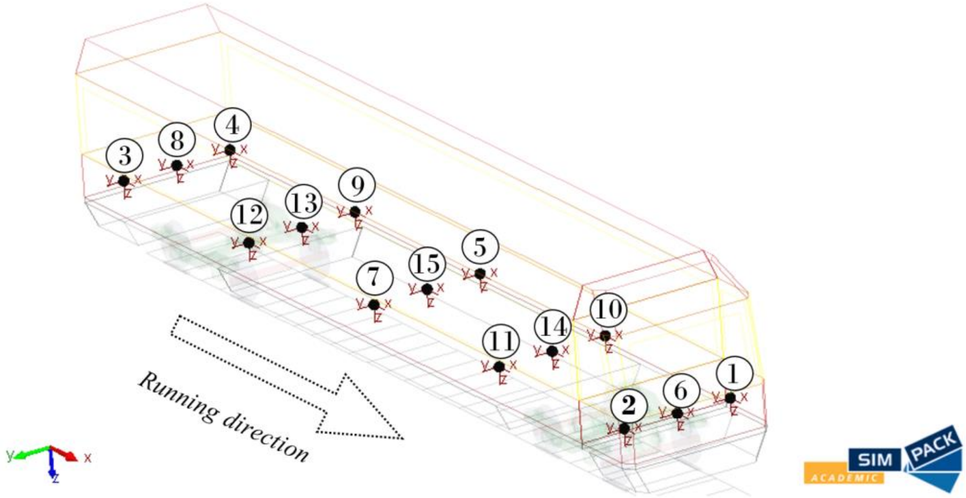

Fig. 3 Location of measured points for the assessment of a passenger ride comfort. Source: authors

The passenger wagon was run on the track model created from geometric parameters which correspond to the Slovak track section. The UIC rail profile and the S1002 wheel profile were used. The track model contains also measured track irregularities prescribed by discrete form.

The rail vehicle was run at the speed from 50 km/h to 110 km/h. Then, four speeds were selected for a calculation of ride comfort indices: 50 km/h, 70 km/h, 90 km/h and finally 110 km/h.

The computation of the passenger ride comfort index at wagon floor level for the Point 1 was performed using the algorithm built into the Simpack PostProcessor [15], which is based on the standard [1]. Outputs of procedures are frequency weighted RMS values of acceleration $a_{XP95}^{W_d}$, $a_{YP95}^{W_d}$ and $a_{ZP95}^{W_b}$, respectively, where a is RMS-values of acceleration; X, Y, Z refer to directions of acceleration, P indicates measurement position (floor), *95* means 95 percentile, W_d are weighting curve in *x*, *y* and *z* direction on the floor, respectively. The five-second RMS-values of the frequency weighted accelerations are calculated as:

$$a_{Xj}^{W_d}(t) = \sqrt{\left[\frac{1}{\tau} \cdot \int_{t-\tau}^{t} \left(\ddot{x}_{W_d}^{*}(\tau)\right)^2 d\tau\right]}, \tag{7}$$

$$a_{Yj}^{W_d}(t) = \sqrt{\left[\frac{1}{\tau} \cdot \int_{t-\tau}^{t} \left(\ddot{y}_{W_d}^{*}(\tau)\right)^2 d\tau\right]}, \tag{8}$$

$$a_{Zj}^{W_d}(t) = \sqrt{\left[\frac{1}{\tau} \cdot \int_{t-\tau}^{t} \left(\ddot{z}_{W_d}^{*}(\tau)\right)^2 d\tau\right]}. \tag{9}$$

From values of frequency weighted acceleration,**Chyba! Nenašiel sa žiaden zdroj odkazov.** N_{MV} indices for individual points according to the equation (1) were calculated.

Calculated indices of the passenger ride comfort allow objectify expected subjective discomfort during travelling.

Results of selected analyses are shown in Fig. 4 and compared with the scale in Tab. 1**Chyba! Nenašiel sa žiaden zdroj odkazov.**.

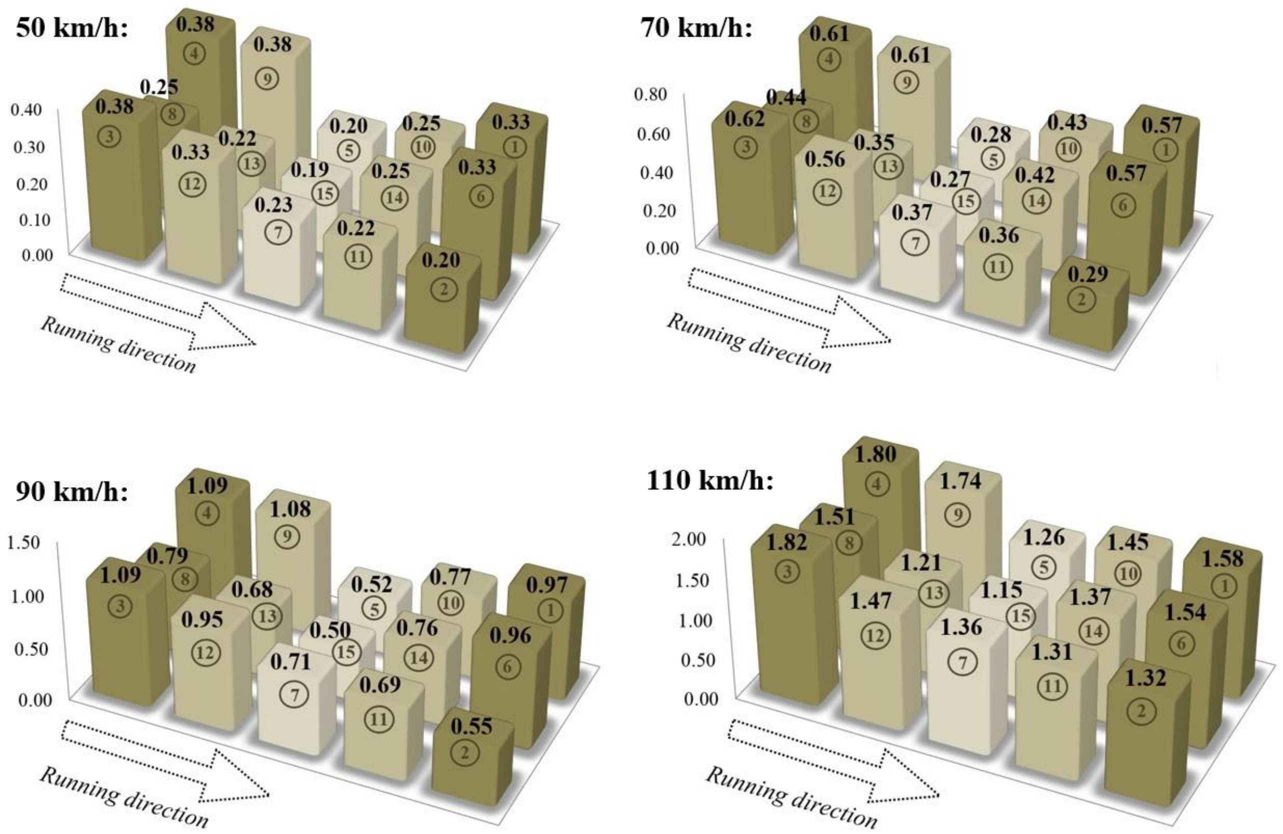

Fig. 4 Location of measured points for the assessment of a passenger ride comfort. Source: authors

Table 1 Comfort index evaluation scale. Source: [1]

$N_{MV} < 1.5$	very comfortable	$3.5 \leq N_{MV} < 4.5$	uncomfortable
$1.5 \leq N_{MV} < 2.5$	comfortable	$N_{MV} > 4.5$	very uncomfortable
$2.5 \leq N_{MV} < 3.5$	medium		

Let's have a look in Fig. 4. There are shown columns, which represent quantification of the quality of passenger ride comfort under running conditions. Generally, we can say, the quality of comfort gets worse decrease with running speed increasing. Moreover, position, which the passenger experiences the least influence of acceleration on the body in, is near to the centre of the wagon (centre of gravity). Areas, which the highest values of acceleration are generated in, are in front and rear locations of the passenger car.

Further, if we compare calculated ride comfort indices N_{MV} (Fig. 4) with the scale according to the standard [1] (Tab. 1), for the speeds of 50 km/h, 70 and also 90 km/h the wagon is classified as „very comfortable" (N_{MV} < 1.5). For the speed 110 km/h the situation is different. In this case, in nine of the fifteen points the wagon is classified as „very comfortable“ (N_{MV} < 1.5), but for five points in front and rear areas the wagon is evaluated as „comfortable“.

4. Conclusion

The passenger ride comfort is the criterion, whose assessment is the most actual today. The ride comfort is mainly from acceleration signals assessed. The EN, UIC and ISO standards states conditions, which assessment is performed. Signals are obtained by the measuring of accelerations at various vehicles body points. When neither the real vehicle nor measured acceleration data are available computer simulation tools allow obtaining these acceleration data. Through them we can perform computer simulations of the modelled vehicle on the track for various excitement values and assess vehicle properties based on prescribed parameters. Consistent with valid standards we can calculate then ride comfort indices for passengers based on the results of dynamic analysis model used.

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