Seasickness or motion sickness (kinetosis) is not only an issue at sea, but on rails as well. Unlike vibration discomfort, no clear guidelines exist for assessing motion sickness. Recent developments such as tilting technology and increased passenger demands regarding comfort have led to higher requirements for rolling stock equipment and infrastructure. This article presents a tool for assessing train design with respect to motion sickness at the engineering stage.

**WHAT IS MOTION SICKNESS**

Motion sickness is a phenomenon usually experienced by persons exposed to a moving environment with low frequency accelerations. The most common symptoms of seasickness are nausea and vomiting. It is evident from tests that the vestibular, visual, and somatosensory system play a role in the onset of motion sickness. Psychological factors are also involved [6]. However, there is no agreement in the scientific community on why the human body has developed these symptoms. The most widely accepted hypothesis is the sensor conflict theory. This theory states that our brain collects information from the human sensors and tries to correlate the information to body movement. If the brain is not able to correlate the information properly, it may develop the symptoms known as motion sickness.

**MODELS USED TO CHARACTERIZE MOTION SICKNESS**

One of the first studies characterizing the effect of various frequencies with the symptoms of motion sickness was carried out in 1974 [8]. O’Halon and McCauley determined that the most motion sickness-provoking frequencies are found around 0.2 Hz. They defined the “motion sickness incidence” (MSI) as the percentage of people who experienced emesis (vomiting). Similar to the frequency-weighting curves used for comfort assessment, M. J. Griffin and Lawther [1] defined a frequency-weighting curve for kinetosis based on laboratory tests with humans. This frequency-weighting curve can be found in the International Standard ISO 2631-1 [2] and is named $w_f$. The weighting function is displayed in Fig. 1. Based on this frequency-weighting filter, the motion sickness dose value is introduced as the square root of the integral of the frequency weighted accelerations over time. The full mathematical description is as follows:

$$MSDV_f = \sqrt{\int a_f^2 \cdot dt}$$

Based on the motion sickness dose value, the vomiting incidence ($VI$) is given as a percentage. The illness rating ($IR$) can be estimated from the following formulas:

$$VI = \frac{1}{2} \cdot MSDV_f^2$$

$$IR = 100 \cdot MSDV_f$$

The values obtained for the illness rating allow one to judge motion sickness accordingly as shown in Table 1. As the motion sickness dose value is the integral over time of squared accelerations,
This Wiederkehr, Friedhelm Altpeter, Helbling Technik AG, Aarau | CUSTOMER APPLICATION
the dose value will never decrease over time. This is a weakness of the model as the human body is able to recover from the effects of motion sickness. Two models that overcome this weakness are Oman’s (developed by Charles Oman at MIT [9]) and the net dose model (developed by the Swedish National Road and Transport Research Institute VTI [10]). Oman’s model attempts to model the neural behavior of the human body with respect to motion sickness. This model is therefore the most complete one available but, also the most difficult to apply.

The net dose model was used to analyze a tilting train on a specific track in Sweden [10]. Passenger surveys were carried out in addition to the acceleration measurements. Since the passenger rating was used to fit parameters of the model, it cannot be easily transferred to judge other acceleration histories.

New frequency filters have recently been published which extend the application of the motion sickness dose values to horizontal (lateral) [4] and roll motions [3]. The latter are of particular importance in the case of railway vehicles [5]. For now, the simplicity of application and clear rules make the motion sickness dose value the preferred method for assessing motion sickness.

**APPLICATION USING SIMPACK**

In order to judge a given train design with respect to motion sickness, a multi body simulation model is created. This model simulates the vehicle on a given track and calculates the respective numbers characterizing motion sickness from the simulation results. SIMPACK is well-suited to perform this simulation, as it comes with the important features for railway dynamic simulations such as rail-wheel contact and track setup. As the most provoking frequencies for motion sickness are around 0.2 Hz, it is essential to use a representative track course (Fig. 2) with its curvature and super-elevation. The track under observation consists of a fairly straight section and segments with curves to the left- and right-hand sides.

Once the simulation is complete, the post-processing SIMPACK tool evaluates the motion sickness dose value from the accelerations (Fig. 3) using the frequency filter $W_f$. As the frequency filters for lateral motions are not yet integrated in SIMPACK, the results are exported as MATLAB® readable data for further processing. The results of the motion sickness dose value for vertical and lateral motions are displayed in Fig. 4.

### Table 1: Values obtained for illness rating to judge motion sickness

<table>
<thead>
<tr>
<th>IR</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>I felt all right</td>
</tr>
<tr>
<td>1</td>
<td>I felt slightly unwell</td>
</tr>
<tr>
<td>2</td>
<td>I felt quite ill</td>
</tr>
<tr>
<td>3</td>
<td>I felt absolutely dreadful</td>
</tr>
</tbody>
</table>

**Fig. 1: Frequency weighting function for motion sickness**

“As the most provoking frequencies for motion sickness are around 0.2 Hz, it is essential to use a representative track course with its curvature and super-elevation.”

**Fig. 2: Representative track course**
Based on the results of the motion sickness dose value, vehicle design assessment is possible. The results show that the straight part of the track does not cause the MSDV to increase markedly. However, the lateral accelerations, which result from the curved part of the track, do increase the MSDV, and thus, the symptoms of motion sickness.

CONCLUSION

The method presented in this article allows for the assessment of a given railway vehicle design with respect to the passengers’ feelings of motion sickness primarily by considering the frequency-weighted lateral and roll accelerations. The presented method can be applied to vertical, lateral and roll motion separately. However, it ignores the effect of phase angles between roll and lateral accelerations which have proven to be important [11]. While acceleration measurements are available from existing vehicles, multi-body simulation contributes to a more comfortable train design during the engineering stage. This can be accomplished by using SIMPACK for parameter studies.

REFERENCES


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