RAIL VEHICLE DYNAMIC SIMULATION
RESEARCH OF THE MODULAR VEHICLE FOR THE COMBINED RAIL-ROAD TRAFFIC

This paper presents the results of simulation studies of dynamic "Modular system combined transport" developed in IPS TABOR, used for the transport of semi-trailers. Due to the specific design of combined transport platforms is necessary to couple two of such vehicles. Otherwise it would not be possible to configure a train consisting of wagons, because of the survey was conducted just for this composition.

Learn how to conduct and results of studies relating to the stability of motion, the test line (operational) covering driving safety and ride quality of track loading gear. During the study of linear series of journeys made in a straight line and curve taking into account the actual measured track irregularities. Tests were carried out on the basis of the requirements of PN-EN 14363 [3] and UIC Code 530-2 [1].

Keywords: dynamic tests, driving stability, combined transport, simulation

1. THE OBJECT OF RESEARCH

The object of research is a platform for combined transport [2] (hereafter referred to as bimodal) (Fig. 1) designed to transport of the semi-trailer tractor unit. The design of the analyzed platform consists of six basic elements, which are shown in Fig. 2: three carriages 1, the platform under the trailer wheels 2, the frame under the trailer seat 3. The connecting element between the platform and the

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frame under the seat liaison element 4 is connected to the platform under the wheels of trailer 2 with ball joint 4a, and semi frame 3 with two pins 4b.

Fig. 1. Bimodal platform with a semi-trailer tractor unit

Fig. 2. View of bimodal platform without a semi-trailer

The semi-trailer is connected to the frame in five semi-socket points (Fig. 3) which form together a rigid connection between these elements.

Fig. 3. Place to connect trailers with frame; 1 – trailer mounting stud, 2 – vertical limiters, 3 – holes for the connecting bolts
The analyzed vehicle is equipped with three bogies (Fig. 4) based on 1.36 m, fitted with cast wheels with a diameter of 580 mm. The first stage of the suspension rubber spacers are located between 1 wheelsets and the bogie frame. These rubber spacers were used to achieve the desired stiffness of the driving wheelsets in the longitudinal and transverse directions. Due to the high value of the vertical rigidity, these elements do not affect considerably on the vertical dynamics of the vehicle. The secondary suspension are rubber-metal springs 2 (Fig. 4), these elements allow rotation of the bogie relative to the vehicle body. there is also a transverse damper in the secondary suspension. Traction and the braking force between the bogie and vehicle body is transferred by a rod 4 (Fig. 5). The vehicle is equipped with anti-yaw dampers installed between the frame of platform and the bogie.

Fig. 4. View of a bi-modal bogie; 1 – primary suspension conical rubber elements, 2 – secondary suspension rubber-metal springs, 3 – horizontal damper

Fig. 5. View of a bi-modal bogie; 4 – connection rot between the bogie frame and the platform
2. MECHANICAL MODEL

The mechanical model of the vehicle consists of rigid bodies connected by elastic elements represented by links between solids on Fig. 6. In order to ensure adequate accuracy of the semi-trailers body model, the platform under the wheel-trailer and bogie frames are divided into the appropriate number of rigid bodies to be able to introduce solids between the analyzed stiffness reflecting the real value of the susceptibility of these elements. Figure 6 shows the schematic interconnections of the vehicle kinematic rigid bodies.

Fig. 6. Diagram of a vehicle mechanical model

On the basis of the mechanical model of the analyzed vehicle a simulation model in SIMPACK was built, as shown in Fig. 7.

Fig. 7. View of the bimodal platform model with a semi-trailer in the SIMPACK

3. ANALYSIS OF THE WAVEFORMS

Examination of the stability of vehicle motion was made by observing the vehicle response on the track irregularities. The results given in Table 1 were analyzed in the first phase for empty semi-trailers. At a speed of 138 km/h,
the movement of the empty semi-trailers of the vehicle is stable. Since the
deflections of the wheelsets from the track axis (passing through prepared short
section of track) show disappearing vibration, results returning of the vehicle to the
track axis. The results obtained for the running speed of 145 km/h shows, that in
this case the motion of the vehicle is not stable. Similarly, the same table (Table 1)
shows the received waveforms transverse deflection of wheelsets for the
composition of the semi-trailers loaded at a speed of respectively 160 km/h and
165 km/h, the first of the listed vehicle running speed is still stable.

In order to verify the advisability of the use of anti-yaw dampers, additional
analysis of the stability of motion of the vehicle model without anti-yaw dampers
was carried out. The critical velocity of a vehicle without anti-yaw dampers is
100 km/h.

<table>
<thead>
<tr>
<th>Status</th>
<th>Speed [km/h]</th>
<th>The displacement of the lateral third of the first wagon wheelset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty semi-trailers with antiyaw dampers</td>
<td>138</td>
<td><img src="image1" alt="Graph" /></td>
</tr>
<tr>
<td>Empty semi-trailers with antiyaw dampers</td>
<td>145</td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>Loaded semi-trailers with antiyaw dampers</td>
<td>160</td>
<td><img src="image3" alt="Graph" /></td>
</tr>
<tr>
<td>Loaded semi-trailers with antiyaw dampers</td>
<td>165</td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>Empty semi-trailers without antiyaw dampers</td>
<td>100</td>
<td><img src="image5" alt="Graph" /></td>
</tr>
<tr>
<td>Empty semi-trailers without antiyaw dampers</td>
<td>105</td>
<td><img src="image6" alt="Graph" /></td>
</tr>
</tbody>
</table>
Another tests were carried out based on the guidelines contained in the PN-EN 14363, implementing scenarios of the measurement method.

These tests consist of three parts:
- running safety,
- track loading,
- dynamic running properties.

During the study were performed series of simulations with the full and the empty trailers, in four sections of the track, with measured on a real track characteristics.

Track parameters:
- track 1, a straight section of track,
- track 2, large radius curve (\( R = 800 \) m, cant 120 mm),
- track 3, small radius curve (\( R = 500 \) m, cant 150 mm),
- track 4, very small radius curve (\( R = 250 \) m, cant 150 mm).

Research on individual track sections made with the following speeds:
- track 1, 110% of \( V_{\text{max}} \) – 132 km/h,
- track 2, 122 km/h,
- track 3, 105 km/h,
- track 4, 72 km/h.

For rides made on the track 2, 3 and 4 are unbalanced lateral acceleration of 0.66 m/s\(^2\) (0.6 m/s\(^2\) + 10%, this corresponds to the cant deficiency of 99.6 mm).

Sample waveforms are shown in Table 2 and Table 3, the measuring points were shown at the in Fig. 8, the parameter names were taken in accordance with PN-EN 14363.

![Fig. 8. Arrangement of measurement points (\( a_1 \) – \( a_4 \)) for the first car, the measuring points of the remaining wagons are arranged similarly](image)
### Table 2

Results from the test track sections

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>Parameter [m/s²]</th>
<th>The recorded waveforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1</td>
<td>$a_{qst}$ = 0.66, $a_{\text{max}}$ = 1.72, $a_{\text{rms}}$ = 0.33, $a_{\text{max}}$ = 0.88, $a_{\text{rms}}$ = 1.08</td>
<td><img src="image1" alt="Waveform" /> <img src="image2" alt="Waveform" /></td>
</tr>
<tr>
<td>a2</td>
<td>$a_{qst}$ = 0.66, $a_{\text{max}}$ = 1.16, $a_{\text{rms}}$ = 0.25, $a_{\text{max}}$ = 0.50, $a_{\text{rms}}$ = 1.13</td>
<td><img src="image3" alt="Waveform" /> <img src="image4" alt="Waveform" /></td>
</tr>
<tr>
<td>a3</td>
<td>$a_{qst}$ = 0.65, $a_{\text{max}}$ = 0.83, $a_{\text{rms}}$ = 0.18, $a_{\text{max}}$ = 0.43, $a_{\text{rms}}$ = 1.13</td>
<td><img src="image5" alt="Waveform" /> <img src="image6" alt="Waveform" /></td>
</tr>
<tr>
<td>a4</td>
<td>$a_{qst}$ = 0.66, $a_{\text{max}}$ = 0.59, $a_{\text{rms}}$ = 0.18, $a_{\text{max}}$ = 0.56, $a_{\text{rms}}$ = 1.18</td>
<td><img src="image7" alt="Waveform" /> <img src="image8" alt="Waveform" /></td>
</tr>
</tbody>
</table>

### Table 3

Results from the test track sections

<table>
<thead>
<tr>
<th>Type of study</th>
<th>Parameters</th>
<th>Empty semi-trailers</th>
<th>Loaded semi-trailers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>max. value</td>
<td>limit</td>
</tr>
<tr>
<td>Driving safety</td>
<td>$Y_{\text{max}}$</td>
<td>16.8 kN</td>
<td>19.1 kN</td>
</tr>
<tr>
<td></td>
<td>$(Y/Q)_{\text{max}}$</td>
<td>0.63</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>$\Sigma Y_{\text{rms}}$</td>
<td>4.6 kN</td>
<td>8.9 kN</td>
</tr>
<tr>
<td>Track load</td>
<td>$Y_{\text{qst}}$</td>
<td>11.6 kN</td>
<td>60 kN</td>
</tr>
<tr>
<td></td>
<td>$Q_{\text{qst}}$</td>
<td>33.9 kN</td>
<td>145 kN</td>
</tr>
<tr>
<td></td>
<td>$Q_{\text{max}}$</td>
<td>30.2 kN</td>
<td>110 kN</td>
</tr>
<tr>
<td>Dynamic properties</td>
<td>$a_{\text{y qst}}$</td>
<td>0.72 m/s²</td>
<td>1.3 m/s²</td>
</tr>
<tr>
<td></td>
<td>$a_{\text{y max}}$</td>
<td>1.23 m/s²</td>
<td>3.0 m/s²</td>
</tr>
<tr>
<td></td>
<td>$a_{\text{y rms}}$</td>
<td>0.40 m/s²</td>
<td>1.3 m/s²</td>
</tr>
<tr>
<td></td>
<td>$a_{\text{z max}}$</td>
<td>3.68 m/s²</td>
<td>5.0 m/s²</td>
</tr>
<tr>
<td></td>
<td>$a_{\text{z rms}}$</td>
<td>0.88 m/s²</td>
<td>2.0 m/s²</td>
</tr>
</tbody>
</table>
4. SUMMARY AND CONCLUSION

The simulation studies were done on the basis of the requirements of PN-EN 14363. The track irregularities were taken from track measurement both straight and curve sections. The results obtained for ride safety meet the requirements of the norm [3]; the worse results were obtained during the passage of the curve, partly due to exhaustion of gap between the bogie frame and bump-stops, causing a large increase of the lateral stiffness. Analysis of the stability of vehicle motion carried out by observing the system response to impulse force and by analyzing the guiding force on wheelsets on the track showed that the vehicle does not tend to instable running to a maximum speed of 120 km/h (plus 10% required by the standard), estimated critical speed of the vehicle is 138 km/h. In the case of a vehicle not equipped with anti-yaw dampers, for the multimodal platform with empty trailers, maximum operational speed can be as low as 90 km/h due to the of instabile running at a speed of about 100 km/h.

The simulation results of the presented vehicle give the results fulfilling obligatory required with a large margin.

Simulations showed that the analyzed vehicle has sufficient running quality for maximum speed. The running safety in the curve are slightly inferior, the transverse clerance in the secondary suspension was exhausted.

In conclusion the analyzed bimodal model of the vehicle meets the requirements of PN-EN 14363 to the speed of 120 km/h (120 km/h + 10%).

REFERENCES

ANALIZA SYMULACYJNA DYNAMIKI MODUŁOWEGO POJAZDU DO KOLEJOWO-DROGOWEGO TRANSPORTU KOMBINOWANEGO

Streszczenie

Artykuł zawiera opis wyników badań symulacyjnych dynamiki pojazdu do kombinowanego transportu kolejowo-drogowego, prowadzonych zgodnie z normą PN-EN 14363. Analizowany pojazd skonstruowano w Instytucie Pojazdów Szynowych „TABOR” w Poznaniu. Składa się on z platformy kolejowej, wyposażonej w trzy wózki, na której można przewozić naczepę ciągnika siodłowego. Badano symulacyjnie stabilność ruchu pojazdu oraz bezpieczeństwo jazdy, obciążenie toru i spokojność biegu. Badania liniowe prowadzono na prostym odcinku toru i w łuku o dużym, małym i bardzo małym promieniu, z uwzględnieniem rzeczywistych nierówności toru. Badania symulacyjne wykazały, że analizowany pojazd w pełni spełnia aktualne wymagania europejskie co do właściwości biegowych.