Influence of Kink Protection Systems on a Tram Passing Through Curve

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Existing system of kink protection for a tram

Bombardier Transportation
Rail vehicle with articulated joint – WO98/42557

- Control elements are provided to detect the angle of rotation between the wagon bodies and their corresponding bogies, and the angle of articulation at the articulated joint as well as controllable actuators for influencing the angle of articulation depending on the control elements.
- The angle of articulation is regulated to a control value, said control value being the sum of the current angle of articulation measured and the bending angle, in order to be able to minimize the clearance required whilst the railway vehicle is travelling dynamically.

Fig. 1
Existing system of kink protection for a tram

Liebherr
Track-guided vehicle, in particular a rail vehicle for the transport – DE 19936565 A1

Steering rule is realized according to equation: \( \alpha_1 k_1 = k_3 \alpha_3 + k_5 \alpha_5 + \ldots + k_n \alpha_n \)

\( \alpha_i \) – relative rotation angle between carbody and corresponding bogie
\( k_i \) – gain factor
Existing system of kink protection for a tram

Liebherr
Track-guided vehicle, in particular a rail vehicle for the transport – DE 19936564 A1

Steering rule is realized according to equation: \( \alpha_i = k_i \cdot (-1)^n \cdot \alpha_n \)

- \( \alpha_i \) – relative rotation angle between carbody and corresponding bogie
- \( k_i \) – gain factor
MBS Model of tram:

- Complete analyzed model with trailer, motor bogies and intercar connections (each carbody is supported by one bogie).
- Motor bogie model include all kinematic connections, flexibility, stiffness and damping characteristics.
- Defined sensors for measuring of position in three dimensions for each marker located on cross sections relative to the Isys (required for swept envelope evaluation).
- Two kind of kink protection system are modeled:
  - Steering system applied for two bogies (named 2xB)
  - Steering system applied for three bogies (named 3xB)
- All bogies with independent wheels.
MBS Simulation: Kink protection for two bogies steering system

Steering system applied for two bogies (named 2xB)

- Two hydraulic actuators for each bogie (additional yaw moment for controlling relative angle between carbody and bogie).
- Each actuator is connected between carbody and corresponding bogie with in series stiffness–damping element.
MBS Simulation: Kink protection for two bogies steering system

Steering system applied for two bogies (2xB) – gear

Steering rule is realized according to equation $\alpha_1 = -\alpha_3$
MBS Simulation: Kink protection for three bogies steering system

Steering system applied for three bogies (named 3xB)

- Two hydraulic actuators for each bogie (additional yaw moment for controlling relative angle between carbody and bogie).
- Each actuator is connected between carbody and corresponding bogie with in series stiffness–damping element.
**MBS Simulation: Kink protection for three bogies steering system**

Steering system applied for three bogies (3xB) – differential mechanism

Based on equations as follow

\[ \alpha_1 = \frac{\alpha_2}{2} - \Delta \alpha \]
\[ \alpha_3 = \frac{\alpha_2}{2} + \Delta \alpha \]

steering rule is realized according to equation \( \alpha_1 + \alpha_3 = \alpha_2 \)
MBS Simulation: On track case

Track radius 25m, cant 130mm, velocity 20 km/h

On track position [m]

Cant [m]

Curvature [1/m]
Example of results: Comparing the results

<table>
<thead>
<tr>
<th>Type of steering system / Gain factor (stiffness)</th>
<th>Maximum lateral displacement of carbody 1 relative to reference value [m]</th>
<th>Maximum lateral displacement of carbody 2 relative to reference value [m]</th>
<th>Maximum lateral displacement of carbody 3 relative to reference value [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2xB / K1</td>
<td>-0.030</td>
<td>-0.013</td>
<td>+0.002</td>
</tr>
<tr>
<td>2xB / K2</td>
<td>-0.071</td>
<td>-0.050</td>
<td>-0.028</td>
</tr>
<tr>
<td>2xB / K3</td>
<td>-0.069</td>
<td>-0.038</td>
<td>-0.019</td>
</tr>
<tr>
<td>3xB / K4</td>
<td>-0.064</td>
<td>-0.077</td>
<td>-0.038</td>
</tr>
<tr>
<td>3xB / K5</td>
<td>-0.080</td>
<td>-0.063</td>
<td>-0.042</td>
</tr>
<tr>
<td>3xB / K6</td>
<td>-0.069</td>
<td>-0.079</td>
<td>-0.050</td>
</tr>
<tr>
<td>3xB / K7</td>
<td>-0.078</td>
<td>-0.078</td>
<td>-0.053</td>
</tr>
<tr>
<td>3xB / K8</td>
<td>-0.089</td>
<td>-0.079</td>
<td>-0.049</td>
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<tr>
<td>3xB / K9</td>
<td>-0.095</td>
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<tr>
<td>3xB / K10</td>
<td>-0.078</td>
<td>-0.078</td>
<td>-0.053</td>
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<tr>
<td>3xB / K11</td>
<td>-0.078</td>
<td>-0.078</td>
<td>-0.053</td>
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<tr>
<td>3xB / K12</td>
<td>-0.073</td>
<td>-0.079</td>
<td>-0.050</td>
</tr>
<tr>
<td>3xB / K13</td>
<td>-0.083</td>
<td>-0.077</td>
<td>-0.053</td>
</tr>
</tbody>
</table>
Example of results: Swept envelope examples

References results – without kink protection system

Gain factor K2

Steering system applied for two bogies

Car body 1

Car body 2

Car body 3
Example of results: Swept envelope examples

References results – without kink protection system

Gain factor K4

Steering system applied for three bogies

Car body 1

Car body 2

Car body 3
Example of results: Swept envelope examples

References results – without kink protection system

Gain factor $K_5$ - Steering system applied for three bogies

Car body 1  Car body 2  Car body 3
Example of results: Swept envelope examples

References results – without kink protection system

Gain factor $K_8$

Steering system applied for three bogies

Car body 1

Car body 2

Car body 3
Example of results: Swept envelope examples

References results – without kink protection system

Gain factor K9

Steering system applied for three bogies

Car body 1

Car body 2

Car body 3
Example of results: Safety against derailment (Y/Q ratio)

Steering system applied for three bogies
Example of results: Safety against derailment (Y/Q ratio)

Steering system applied for three bogies
Example of results: Safety against derailment (Y/Q ratio)

Steering system applied for three bogies
Conclusions and future work

Conclusions:

- Kink protection system reduces swept envelope of tram passing through curve.
- Y/Q ratio (safety against derailment) not exceeding limit values.
- Carbody and bogie structure should be resistant for additional loads resulting from kink protection system.

Future work:

- Verification of kink protection system for different kind of tram kinematics.
- Co-simulation with numerical model of hydraulic kink protection system.
Thank You for Your Attention