Abstract—The transverse offset center of gravity of goods is one of basic railway technical standards. The current Railway Freight Loading Reinforcement Rules in our country states: The transverse offset center of gravity of goods should be less than 100mm. This rule quoting The Soviet Union’s 1950s rules is lack of basis. It just meets the derailment coefficient in theory. Based on the analysis of vehicle running, the study identified derailment coefficient and the transverse offset center of gravity of goods. Create the virtual prototype model in simulation software, and design appropriate operating condition based on derailment factors of influence factors. Built C_{70} wagon model in SIMPACK simulation platform. Determine the freight loading conditions, tracks conditions and running speed. According to the simulation of experimental data, analysis the relationship between derailment coefficient and the transverse offset center of gravity of goods. To explore the existing railway freight loading reinforcement on cargo weight the rules allowing lateral offset provisions of modify ability. The transverse offset center of gravity of goods.

Keywords- Cargo weight; Horizontal offset; Derailment coefficient; Freight train; Relationship;

I. THE TRANSVERSE OFFSET CENTER OF GRAVITY OF GOODS

The transverse offset center of gravity of goods is the main content of the paper. China’s railway freight for a transverse offset of the center of gravity of the provisions first appeared in 1955 in the People’s Republic of China promulgated by the Ministry of Railways’ freight transport rules and fill. Its big wide shipment of the provisional rules of Article 20 states: cargo loaded on the train when the center of gravity shall be situated in the middle of the floor; when the occasion demands, to deviate from the horizontal direction is limited to not more than 100 mm \[1\]. The limit is the reference the former Soviet Union standard \[2\]. Article 14 of the existing “rail freight loading reinforcement rules” stated: Cargo projection should focus on the car floor located at the intersection of the centerline of the longitudinal and transverse. When needing displacement, the lateral displacement should not exceed 100mm. When more than 100, take counterweight measures \[3\]. US cargo transport standards< General Rules for Loading All Commodities > stated: Load cargo must be positioned on the position with equal either weight in both side \[4\].

II. THE VEHICLE DERAILEMENT AND DERAILEMENT COEFFICIENT

The vehicle derailment means that vehicle wheel fall the track surface (Including re-rail after derailment) or the top of the wheel rim above the track surface (Except that because the job requires). Derailement generally include two categories: climb derailment and jump derailment. Climb derailment is that vehicle running in a straight line, wheel tread surface and the rail top surface contact with each other, when the vehicle passes through the curve wheel withstand lateral forces came from the body. With increasing lateral force, and wheel-rail vertical force is insufficient to maintain the stable operation of the vehicle, the wheels continue to slide in the rotation state, it exceed the critical condition occurs derailed. Jump derailment is that vehicle running at high speed, the larger the lateral line irregularity, especially along the direction of the irregularity of the circular curve produced a big change, so that the wheel produced a large lateral impact velocity, if the impact velocity exceeds a certain value, it is possible to jump on the wheel caused the derailment rail.

Vehicles running on the line, the wheel is influenced by a variety of static and dynamic loads and these loads can be attributed to the force acting on the vertical and lateral force on the wheel \[5\]. In 1896, Nadal deduced Current general derailment coefficient formula by using
static equilibrium relations between wheel and rail derailment trend deduced.

\[ P \sin \alpha = \mu N + Q \cos \alpha \quad (1) \]
\[ N = P \cos \alpha + Q \sin \alpha \quad (2) \]

By (1) and (2) derailment coefficient formula can be obtained

\[ \frac{Q}{P} = \frac{\mu \tan \alpha}{1 + \mu \tan \alpha} \quad (3) \]

Where: \( Q \) - lateral force between wheel and rail;
\( P \) - vertical force between wheel and rail; \( \alpha \) - rim angle; \( \mu \) - the coefficient of friction between wheel and rail.
Derailment coefficient (promise not to derail) can be obtained by calculating 1.5.

Our GB5599-85 "Railway Vehicle Dynamics Performance Evaluation and test evaluation norms" required derailment coefficient safety standards \[6\]:

\[ \frac{Q}{P} \leq \begin{cases} 1.2 & \text{The first limit} \\ 1.0 & \text{The second limit} \end{cases} \quad (4) \]

III. THE ESTABLISHMENT OF C70 GONDOLA CAR MODEL

In order to accurately draw the relationship between the transverse offset center of gravity of goods and derailment coefficient, test program need to design a different curve radius, the outer rail high, the speed and the transverse offset center of gravity of goods. Real vehicle test process will produce repeated and reinforced cargo handling operations, the entire testing process need complex operation, much money and long time. This paper plans to use SIMPACK simulation experiments.

A. The introduction of SIMPACK

SIMPACK is a mechanical system kinematics and dynamics simulation software. By relative coordinates with complete recursive algorithm, you can quickly build dynamic model of the mechanical system, including joints, constraints, various external forces or interactions, and automatically form dynamic equations, and then get the moving property of system by using a variety of solved ways \[7\].

Restrictions on the maximum speed on the line conditions, in accordance with the requirements of line-

B. The process of modeling

C70 gondola structure built in SIMPACK divided into the body, bolster, side frame, wheel pairs, where the body including the empty hull and cargo and structure interaction by setting the corresponding force. Bogie vehicle established under the crossbar for K6 bogie. Finally, through the 3D shape, articulated relations and handling of the force, a virtual kind of car model is established \[8\].

Modeling process shown in Fig. 2:

1. Stress analysis based on the various components
2. Cargo train system diagram
3. Establish a virtual sample C70 gondola train in SIMPACK
4. Construction of the track model in SIMPACK

Through the establishment of the model, get a virtual view of the kind of car models in SIMAPCK software.

Figure 2. SIMPACK platform modeling process

Figure 3. Virtual prototyping software model view in SIMAPCK

IV. DESIGN SIMULATION CONDITIONS

A. Experimental conditions

Choose the grade \(\text{Ⅰ, Ⅲ}\) grade categories lines as C70 gondola operating conditions.

level: Ⅲ level on the line, freight trains do not exceed the maximum operating speed of 70km/h; grade Ⅰ line no
more than 120km/h. According to the test speed "vehicle
dynamics test identification" requirements, and
considering the low speed through a small radius curves
unfavorable conditions, on the curve, the maximum
operating speed is calculated by the following equation
(5):

\[ V_{\text{max}} = \sqrt{\frac{(h + h_0)R}{11.8}} \]  

Type 5, Vmax- maximum speed allowed by the
curve, km/h; R- curve radius, m; h- ultra outer rail, mm;
h_0- not allow the maximum balance of high, take 75mm.

B. The simulation program
This article will design full car load weight as 70t,
the height of the center of gravity of goods as 2400mm. In
the design process of the simulation program, different
line conditions are designed to identify the most
unfavorable conditions in accordance with the
erminal conditions.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Grade & Simulation Program & Line & Level \\
\hline
450 & 120 & 80 & 10,30,50,70 \\
600 & 100 & 80 & 10,30,50,60,80 \\
70 & 1200 & 80 & 90 \\
& & & 2400 \\
& & 90 & 1200 \\
\hline
\end{tabular}
\end{table}

Where: ①Weight (t) ②Radius (m) ③Transition curve
(m) ④Outer ultrahigh (mm) ⑤Running speed (km/h) ⑥
Height of gravity center (mm) ⑦Lateral offset (mm)

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Grade & Simulation Program & Line & Level \\
\hline
450 & 120 & 80 & 10,30,50,70 \\
600 & 100 & 80 & 10,30,50,60,80 \\
70 & 1200 & 80 & 90 \\
& & & 2400 \\
& & 90 & 1200 \\
\hline
\end{tabular}
\end{table}

Where: ①Weight (t) ②Radius (m) ③Transition curve
(m) ④Outer ultrahigh (mm) ⑤Running speed (km/h) ⑥
Height of gravity center (mm) ⑦Lateral offset (mm)

V. SIMULATION RESULTS

SIMPACK simulation can effectively solve practical
experiments in SIMPACK and obtain simulation results of
C_70 gondola train at different levels of circuit simulation
results working conditions.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
Grade & Simulation Program & Line & Level & ① & ② & ③ & ④ \\
\hline
450 & 120 & 80 & 10,30,50,70 & 10 & -80 & 1.1564 \\
600 & 100 & 80 & 10,30,50,60,80 & 10 & +80 & 1.1405 \\
70 & 1200 & 80 & 90 & 30 & -80 & 0.7999 \\
& & & 2400 & 80 & 30 & +80 & 0.7779 \\
& & 90 & 1200 & 60 & -80 & 0.5127 \\
& & & & 80 & +80 & 0.5253 \\
& & & & 60 & -80 & 0.6548 \\
& & & & 80 & +80 & 0.6185 \\
\hline
\end{tabular}
\end{table}

Where: ①Transition curve (m) ②Speed (km/h) ③
Lateral offset (mm) ④Derailment Coefficient ⑤Transition
curve(m) ⑥Speed (km/h) ⑦Lateral offset ⑧ Derailment
Coefficient (mm)

VI. THE SUMMARY OF THE RELATIONSHIP BETWEEN
THE DERAILMENT COEFFICIENT AND LATERAL OFFSET
OF THE CENTER OF GRAVITY OF GOODS

A. The analysis and simulation results of the most
unfavorable conditions
The simulation results can be obtained through the
above, C_70 gondola car in the experiment simulated
conditions in the most adverse conditions derailment
coefficient is: curve radius R350, Ⅲ grade lines within
partial 80mm, speed of 30km / h.
This paper in the most adverse conditions, research the relationship between the derailment coefficient and lateral offset of the center of gravity of goods.

The most unfavorable conditions simulation program:

<table>
<thead>
<tr>
<th>TABLE IV. MOST UNFAVORABLE CONDITIONS SIMULATION PROGRAM:</th>
</tr>
</thead>
<tbody>
<tr>
<td>①</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>350</td>
</tr>
<tr>
<td>12</td>
</tr>
</tbody>
</table>

Where: ① Weight (t) ② Radius (m) ③ Transition curve (m) ④ Line level ⑤ Outer ultrahigh (mm) ⑥ Running speed (km/h) ⑦ Height of gravity center (mm) ⑧ Lateral offset (mm)

TABLE V. SIMULATION RESULTS MOST UNFAVORABLE CONDITIONS

<table>
<thead>
<tr>
<th>Working conditions</th>
<th>Lateral offset</th>
<th>Derailment coefficient</th>
<th>Working conditions</th>
<th>Lateral offset</th>
<th>Derailment coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>R350, Grade III line, speed of 30 km/h</td>
<td>-10</td>
<td>1.1273</td>
<td>R350, Grade III line, speed of 30 km/h</td>
<td>-90</td>
<td>1.1771</td>
</tr>
<tr>
<td>-20</td>
<td>1.1342</td>
<td>-100</td>
<td>1.1823</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-30</td>
<td>1.1408</td>
<td>-110</td>
<td>1.1894</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-40</td>
<td>1.1478</td>
<td>-120</td>
<td>1.1972</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-50</td>
<td>1.1513</td>
<td>-130</td>
<td>1.2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-60</td>
<td>1.1597</td>
<td>-140</td>
<td>1.2101</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-70</td>
<td>1.1666</td>
<td>-150</td>
<td>1.2149</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-80</td>
<td>1.1717</td>
<td>-160</td>
<td>1.2186</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The table above is the most unfavorable conditions simulation program simulation results, with the center of gravity of goods increases the lateral offset increasing. This is because as the center of gravity of the vehicle longitudinal center offset distance goods is increasing, vehicles produce partial load, the inside of the load increased, the curve when the vehicle by steering bogie adversely affected to render the derailment coefficient increases, influence $C_{70}$ safe operation of heavy vehicles.

B. Straight line condition analysis

<p>| TABLE VI. DERAILMENT COEFFICIENT OF LINEAR SIMULATION CONDITIONS |
| --- | --- | --- |</p>
<table>
<thead>
<tr>
<th>Working conditions</th>
<th>Lateral offset</th>
<th>Derailment coefficient</th>
<th>Working conditions</th>
<th>Lateral offset</th>
<th>Derailment coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight line, Grade I line, speed of 90km/h</td>
<td>10</td>
<td>0.3368</td>
<td>Straight line, Grade I line, speed of 90km/h</td>
<td>90</td>
<td>0.4922</td>
</tr>
<tr>
<td>20</td>
<td>0.3496</td>
<td>100</td>
<td>0.5422</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.3623</td>
<td>110</td>
<td>0.6446</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>0.3713</td>
<td>120</td>
<td>0.7478</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.3815</td>
<td>130</td>
<td>0.8085</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.3985</td>
<td>140</td>
<td>0.8517</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>0.4178</td>
<td>150</td>
<td>1.0068</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>0.4546</td>
<td>160</td>
<td>1.3989</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. The relationship between the derailment coefficient and lateral offset of the center of gravity of goods in most unfavorable conditions

Shown for the trends that lateral offset of the center of gravity of the cargo influence the derailment coefficient Fig. 4, the center of gravity of the cargo unit of the lateral offset of 10mm in the process of growing, derailment coefficient has maintained a growth trend, but its value growth is not obvious.

Figure 5. The relationship between the derailment coefficient and lateral offset of the center of gravity of goods in straight line conditions
Fig. 5 shows a straight line condition grade Ⅰ 90km / h, because the current line of trains on all domestic actual operating speed of heavy vehicles of up to 80km / h, empty up to 70km / h, so take a slightly higher in the actual operating speed of 90km / h as the experimental speed. And select for full load 70t.

When lateral offset is 10mm, the derailment coefficient is 1.1273. When lateral offset is 160mm, the derailment coefficient is 1.2186. Derailment coefficient increases of only 0.0913, increase the proportion of only 7.98%. Our country sets the allow coefficient of 1.0 and the risk coefficient of 1.2. In the most unfavorable condition, the impact of the center of gravity of goods is very limited and the regulation is not obvious.

To reduce the substantial impact small radius curves in working conditions and find out the relationship between the derailment coefficient and lateral offset of the center of gravity of goods, design the straight line conditions. Thereby reducing the serious impact of the large angle of attack derailment coefficient.

VII. THE SUMMARY

In this paper, the main research contents are as follows:

1. Look up the fruit of the transverse offset center of gravity of goods and master the latest achievements.

2. Study the influencing factors of the derailment coefficient and analysis the influence of these factors.

3. Built C70 wagon model in SIMPACK simulation platform. Determine the freight loading conditions, tracks conditions and running speed.

4. Determine the most unfavorable condition by the analysis of simulation results. Carry out the simulation calculation to determine the different transverse offset centers of gravity of goods. Analysis experimental results, summarize the relationship between the transverse offset center of gravity of goods and the derailment coefficient.

Through these studies, we can draw with the center of gravity of the lateral offset rising freight derailment coefficient showing a rising trend. Domestic cargo lateral offset of the center of gravity of the current is limited to 100mm, the experimental data can be seen, the limit has further room for improvement.

ACKNOWLEDGEMENTS

This work was financially supported by the Fundamental Research Funds for the Central Universities (2014JBM061)

REFERENCES


