Study on the Relationship between Lateral Offset of the Center of Gravity of Goods C_{70} Gondola and the Derailment Coefficient

Bao Tian per
School of Traffic and Transportation
Beijing Jiaotong University
Beijing, China
e-mail: baotian@bjtu.edu.cn

Chen Chao
School of Traffic and Transportation
Beijing Jiaotong University
Beijing, China
e-mail: chenchao@bjtu.edu.cn

Han Mei
School of Traffic and Transportation
Beijing Jiaotong University
Beijing, China
e-mail: mhan@bjtu.edu.cn

Chen Shiyong
School of Traffic and Transportation
Beijing Jiaotong University
Beijing, China
e-mail: 13125695@bjtu.edu.cn

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: Loaded cargo must be positioned on the position with equal either weight in both side [4]

II. THE VEHICLE DERAILMENT AND DERAILMENT 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). Derailment 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.

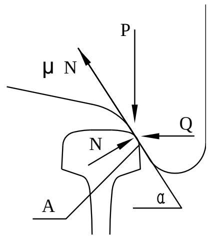

Figure 1. Schematic derailment trends

Shown in Fig .1, when the wheel is in a critical state of derailment, the wheel slide down, the frictional force is the upward direction, according to the force equilibrium point A can be obtained,

$$P\sin\alpha = \mu N + Q\cos\alpha \qquad (1)$$

$$N = P\cos\alpha + Q\sin\alpha \qquad (2)$$

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

$$\frac{Q}{P} = \frac{\mu \tan\alpha}{1+\mu \tan\alpha} \qquad (3)$$

Where: Q - lateral force between wheel and rail; P - vertical force between wheel and rail; α - rim angle; μ - 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]:

$$\frac{Q}{P} \le \begin{cases} 1.2 & \text{The first limit} \\ 1.0 & \text{The second limit} \end{cases} \qquad (4)$$

III. THE ESTABLISHMENT OF C_{70} 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

C_{70} 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:

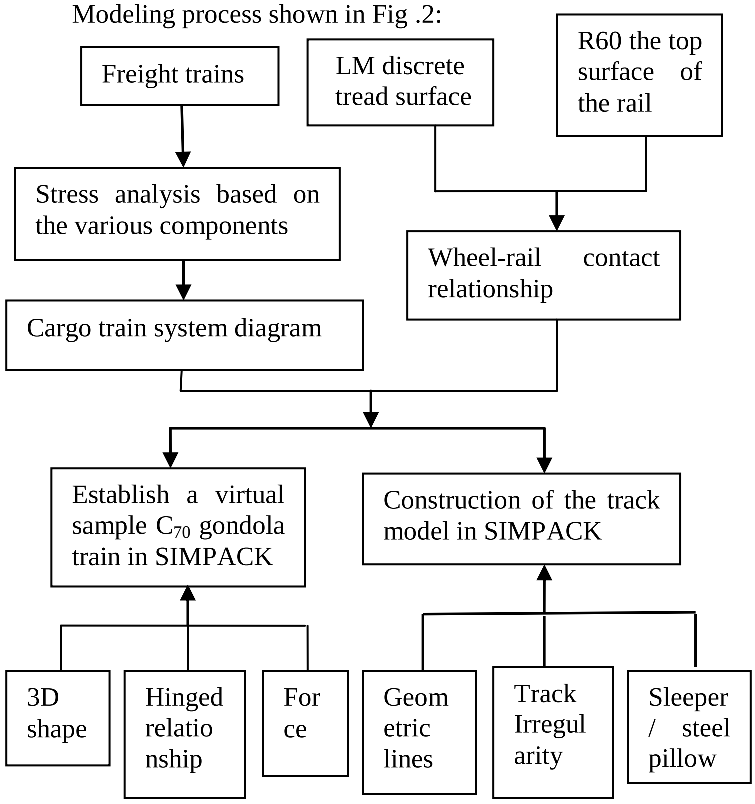

Figure 2. SIMPACK platform modeling process

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

Figure 3. Virtual prototyping software model view in SIMAPCK

IV. DESIGN SIMULATION CONDITIONS

A. Experimental conditions

Choose the grade Ⅰ, Ⅲ grade categories lines as C_{70} 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):

$$V_{\max} = \sqrt{\frac{(h+h_0)R}{11.8}} \qquad (5)$$

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 experimental results.

TABLE Ⅰ. GRADE Ⅰ LINE-LEVEL SIMULATION PROGRAM

①	②	③	④	⑤	⑥	⑦
70	450	120	80	10,30,50,70	2400	80
	600	100	80	10,30,50,60,80		
	1200	80	90	10,30,50,70, 90, 1200		
	Straight	—	—	30,50,70, 90,1200		

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

TABLE Ⅱ. GRADE Ⅲ LINE SIMULATION PROGRAM

①	②	③	④	⑤	⑥	⑦
70	350	160	120	10,30, 50,70	2400	80
	600	80	80	10,30, 50,70		
	straight	—	—	10,30, 50,70		

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 such as cost and cycle issues. According to set a good simulation conditions, take the simulation experiments in SIMPACK and obtain simulation results of C_{70} gondola train at different levels of circuit simulation results working conditions.

TABLE Ⅲ. SIMULATION RESULTS

①	②	③	④	⑤	⑥	⑦	⑧
R 350 Grade Ⅲ line	10	-80	1.1564	R 450 Grade Ⅰ line	10	-80	0.9852
	10	+80	1.1405		10	+80	0.9661
	30	-80	1.1717		30	-80	0.7486
	30	+80	1.1623		30	+80	0.7091
	50	-80	0.7516		50	-80	0.5049
	50	+80	0.6987		50	+80	0.4451
	70	-80	0.9302		70	-80	0.7449
	70	+80	0.8749		70	+80	0.7421
R 600 Grade Ⅲ line	10	-80	1.0378	R 600 Grade Ⅰ line	10	-80	0.8369
	10	+80	1.0038		10	+80	0.6459
	30	-80	0.7799		30	-80	0.6719
	30	+80	0.7779		30	+80	0.5366
	50	-80	0.5428		50	-80	0.5175
	50	+80	0.5423		50	+80	0.4933
	60	-80	0.5127		60	-80	0.4655
	60	+80	0.5253		60	+80	0.4232
	70	-80	0.6548		80	-80	0.6168
	70	+80	0.6185		80	+80	0.6335
Grade Ⅲ line	10	80	0.2319	R 1200 Grade Ⅰ line			
	30	80	0.3208		10	-80	0.6786
	50	80	0.3089		10	+80	0.5204
	70	80	0.3435		30	-80	0.3903
Grade Ⅲ line	30	80	0.2719		30	+80	0.3139
	50	80	0.3913		50	-80	0.3107
	70	80	0.2922		50	+80	0.2656
	90	80	0.3211		70	-80	0.2753
	120	80	0.3431		70	+80	0.2095
R1200 Grade Ⅲ	120	-80	0.4411		90	-80	0.3046
	120	+80	0.4099		90	+80	0.2181

Where: ① Transition curve（m） ② Speed (km/h) ③ Lateral offset (mm)④Derailment Coefficient⑤ Transition curve(m)⑥ Speed (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 Ⅳ. MOST UNFAVORABLE CONDITIONS SIMULATION PROGRAM:

①	②	③	④	⑤	⑥	⑦	⑧
70	350	160	III	120	30	2400	10， 20，30, 40, 50, 60, 70, 80, 90, 100, 120, 130, 140, 150, 160, 170, 180

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

TABLE Ⅴ. SIMULATION RESULTS MOST UNFAVORABLE CONDITIONS

Working conditions		Derailment coefficient	Working conditions		Derailment coefficient
	Lateral offset			Lateral offset	
R350 Grade III line, speed of 30 km/h	−10	1. 1273	R350 Grade III line, speed of 30 km/h	−90	1. 1771
	−20	1. 1342		−100	1. 1823
	−30	1. 1408		−110	1. 1894
	−40	1. 1478		−120	1. 1972
	−50	1. 1513		−130	1. 2013
	−60	1. 1597		−140	1. 2101
	−70	1. 1666		−150	1. 2149
	−80	1. 1717		−160	1. 2186

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.

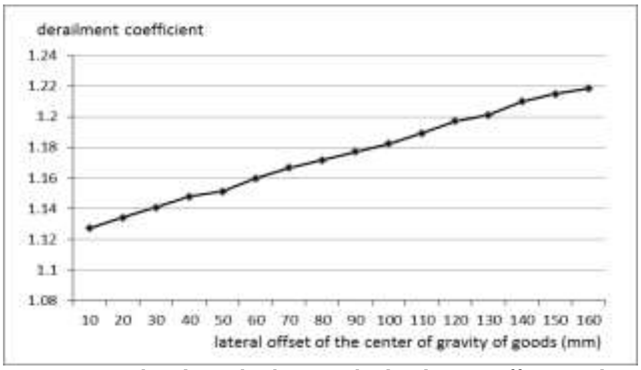

Figure 4. The relationship between the derailment coefficient and lateral offset of the center of gravity of goods in most unfavorable conditions

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.

B. Straight line condition analysis

TABLE VI. DERAILMENT COEFFICIENT OF LINEAR SIMULATION CONDITIONS

Working conditions		Derailment coefficient	Working conditions		Derailment coefficient
	Lateral offset			Lateral offset	
Straight line, Grade Ⅰ line, speed of 90km/h	10	0.3368	Straight line, Grade Ⅰ line, speed of 90km/h	90	0.4922
	20	0.3496		100	0.5422
	30	0.3623		110	0.6446
	40	0.3713		120	0.7478
	50	0.3815		130	0.8085
	60	0.3985		140	0.8517
	70	0.4178		150	1.0068
	80	0.4546		160	1.3989

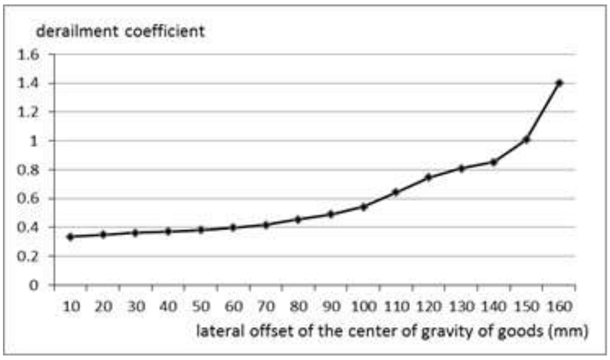

Figure 5. The relationship between the derailment coefficient and lateral offset of the center of gravity of goods in straight line conditions

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 C_{70} 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

[1] People's Republic of China railways. Goods transportation rules and fill. Beijing: China railway Publishing House, 1955.

[2] Han Mei, Wang Yanling, Pang Liang, Chen. “Based on derailment coefficient of safety criteria height of gravity for car restrictions”. China railway science 28.4 (2007): 106-110. DOI:10.3321/j.issn:1001-4632.2007.04.020.

[3] People's Republic of China railways. Railway freight loading reinforcement rules. Beijing: China railway Publishing House, 2006。

[4] Former Master Car Builder's Association. General Rules for Loading All Commodities.The Associationg of American Railroads 425 Third Street ,SW.,Washington,D.C.20024.1960

[5] Peng Yongzhao, Lang Maoxiang, Jiangtao Liu. Review on railway long heavy freight loading reinforcement in China. Logistics Tchnologies 28.11 (2009): 31-34. DOI:10.3969/j.issn.1005-152X.2009.11.010.

[6] 85, GB5599. Specification for railway vehicle dynamics performance evaluation and test and evaluation [s]. Diss. 1985.

[7] Shen Gang. "Based on the analysis of running stability of four-axle electric locomotives of SIMPACK." Urban Rail Transit Research 15.1 (2012): 80-83. DOI:10.3969/j.issn.1007-869X.2012.01.018.

[8] Chen. Height of railway General reasonable limitation of gravity for car. Diss., Beijing Jiaotong University, 2011.

[9] Campos, Javier, and Pedro Cantos. "Rail transport regulation." Policy Research (1999).

[10] Bojović, Nebojša J. "A general system theory approach to rail freight car fleet sizing." European Journal of Operational Research 136.1 (2002): 136-172.