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Simulation on Vehicle Vibration Offset of NX70 Flatcar

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Abstract: The current rolling stock gauge for standard gauge railway is a static gauge to check the vehicle frame. The contradiction of large construction gauge and small rolling stock gauge has always existed. It is important to set down the clearance requirements in respect of physical size for the safe passage of rail vehicles. Reasonably determining the maximum vibration offset can improve the efficiency of clearance. As an example, analyze the complex vibration of NX70 flat car by simulation test on the running track. Comprehensive considering the track model, loading plan, line conditions and running speed, then SIMPACK is used to present the vehicle system dynamics simulation model. After researching simulation result, respectively determine the maximum vehicle vibration offset for railroads of Class I, Class II and Class III on the height of the center of gravity 2000 mm and 2400 mm. According to the clearance between the structure gauge and the position of maximum vibration offset, analyze the safety of vehicle operation since the center of gravity is higher than before. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: NX70, Vibration offset, SIMPACK, Track spectrum, Rolling stock gauge.

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1. Introduction

Safety is an important measurement of railways operation. Chinese government has promulgated the regulations such as rolling stock gauge, basic structure gauge, tunnel structure gauge, bridge structure gauge etc. The most basic is rolling stock gauge and structure gauge for standard gauge railways, which are in continual mutual restriction and dependence. There must be a certain restrictive clearance obtained by increasing a suitable gap to the vehicle gauge, in order to ensure the safety of the space required for locomotive and vehicles.

Measuring the vibration offsets is very important to check rolling stock gauge. Ju Dianming, Han Mei, Guo Weihong (1996) presents a mathematical model to calculate the offset generated by rolling vibration of vehicle loaded with out-of-gauge goods [1]. Ju Dianming (1997) analyzes the factors influenced the lateral vibration offset and present a mathematical model [2]. Han Mei (2006) establishes a simulation model to calculate vehicle lateral vibration offset, analyzes the related factors, then determines the computed condition and calculates the offset [3].

The railroad freight car's dynamic characteristic leads to most of the freight damage. Ren Zunsong (2009) describes the relationship between the main structure of a vehicle and suspension parameters by establishing system dynamics modeling to evaluate vehicle performance [4]. Yan Junmao, Fu Maohai (2009) discusses the structure and principle of the bogie, and then provides the calculation method of lateral, vertical and longitudinal stiffness for spring and rubber components [5].

Vehicle in the actual run-time conditions is extremely complex. It is helpful to create a multi-rigid-body vehicle dynamics model based on SIMPACK to calculate the vehicle vibration offset. It

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can solve the realistic problem of railway freight transport based on the results of simulation.

2. Vehicle Dynamics Model

2.1. Vehicle Vibration System

Vehicle is six degrees of freedom system with carbody, bogies and the spring suspension. Each vehicle body has a set of mutually perpendicular axes (x, y, z), called principal axes. x is horizontal axis being oriented in the vehicle forward direction. y is horizontal axis goes from left to right, and z is vertical axis goes from top to bottom. It is free to move forward/backward, up/down, left/right which are translation in three perpendicular axes, combined with rotation about three perpendicular axes, often termed pitch, yaw, and roll [4]. Vibration of vehicle system is shown in Fig. 1.

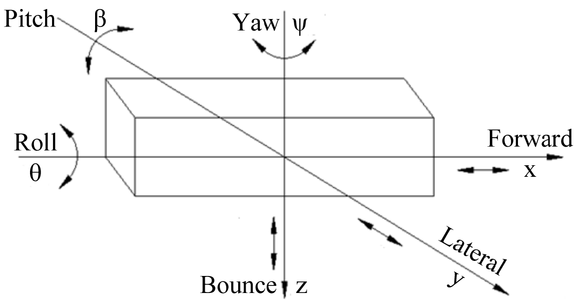


Fig. 1. Vibration of vehicle system.

Vibration in a vehicle can be attributed to the various elements: vehicle frame, suspension system, loading conditions, line condition and travelling speed. A kinematic coupling for vibration of vehicle exactly constrains 6 degrees of freedom. The forward/backward vibration of a driving vehicle is called the longitudinal vibration; the combination of bounce and pitch vibration is called the vertical vibration; the combination of yaw, left/right and roll vibration is called the lateral vibration. In general, the vertical vibration and lateral vibration is weak coupling, so the vertical and lateral vibration of the vehicle can be examined respectively.

2.2. NX70 Flatcar Dynamics Model

The steering machine of ordinary wagon, such as gondola car, flat car and boxcar are mostly three piece bogies, which includes wheelsets, the load supporting foot, side frame, bolster, car body, and two suspensions. NX70 flat car is the main type in 70t class car. It consists with Chinese type K6 bogie. When building the vehicle dynamic model, K6 bogie can be treated as sub structure. At the same time, the force of side bearing and the center plate reacts between car body and bolster. The dummy body is introduced in main model [6-13]. Topology of the truck model is shown in Fig. 2.

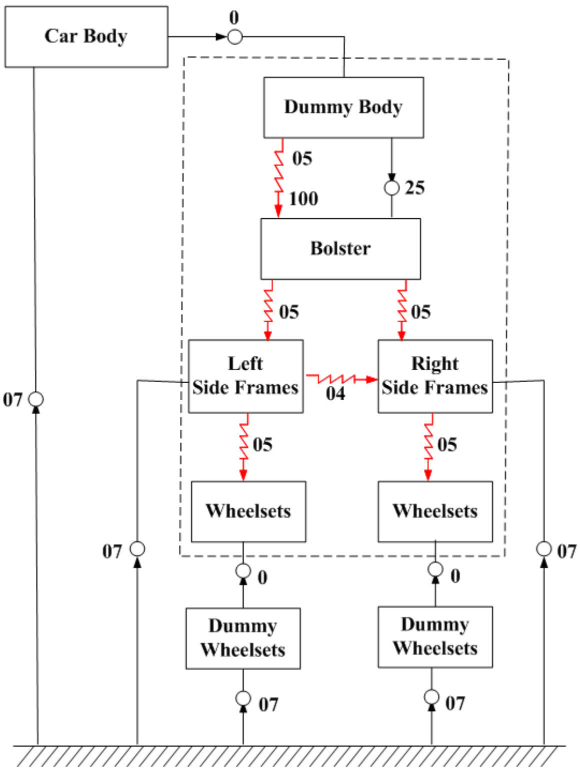


Fig. 2. Topology of NX70 flatcar.

Based on the topology of NX70 flatcar, simulation model can be established in the order of wheelsets→bogie→vehicle.

3. Simulation Conditions

3.1. Track Model

The track geometric irregularity is the main factor which causes the vehicle vibration [4]. It has four kinds, namely the vertical track irregularity, lateral irregularity, roll irregularity and Gauge irregularity. In China, railroads are classified as Class I, II and III. But China do not have mature mainline railway track spectrum. Compared in terms of power spectrum density (PSD), amplitude of time domain samples and dynamic performance, it is usually used American railway track spectrum to describe Chinese line conditions when do vehicle dynamics simulation analysis.

Comparison on Chinese Main Railway Lines and American Railway Lines, the maximum allowed speed is 128 km/h in Class 5 railroads in the United States, 96 km/h in Class 4 railroads, 64 km/h in Class 3 railroads. The “Rules on Track Maintenance” prescribes that different railroads Class need different track irregularity excitation in China. Among them, the best running conditions is Class I railroads, vehicle maximum speed increased to 120 km/h. The worst running conditions is Class III railroads, with the smaller curve radius, the maximum operating speed is generally not more than 70 km/h. The highest running speed of Class II railroads is not more than 80 km/h [14, 15]. Therefore, track spectrum of Class 5 railroads in the United States is selected as the external excitations for Class I railroads in China, track spectrum of Class 4 railroads for Class II railroads, and track spectrum of Class 3 railroads for Class III railroads.

3.2. Loading Plan

Goods loading in NX70 flat car are considered as a homogeneous cargo. Cargo length was calculated by the vehicle's length, width is calculated according to the maximum width of the rolling stock gauge, height is calculated according to the loading weight and the center of gravity of the goods. Loading weight is considering three weight levels, namely loading mark, loading mark-10t and loading mark-20t.

“Railway cargo loading and reinforcing rules” prescribes that if the height of the centre of gravity is more than 2000 mm from the rail surface, it should implement speed limit. If the center of gravity must be deviated, lateral deviation of the centre of gravity can not exceed 100 mm. Weight difference of two bogies is not greater than 10t [16].

Considering the current situation and the development of railroads, the height of the center of gravity 2000 mm and 2400 mm is selected, the loading plan is shown in Table 1.

Table 1. Loading plan of NX70 flatcar.

Number	Loading weight (t)	Weight difference of two bogies (t)	Lateral deviation of the centre of gravity (mm)
1	70t	0	0
2	70t	0	100
3	60t	0	0
4	60t	0	100
5	60t	10	0
6	60t	10	100
7	50t	0	0
8	50t	0	100
9	50t	10	0
10	50t	10	100
11	Empty car		

3.3. Line Conditions and Traveling Speed

Vehicle vibration is widely assumed to be closely related to the line conditions and traveling speed.

The track is the foundation of the railroads. All vehicles must routinely negotiate curves and straight line. A compound S-shaped curve is adopted. Turning radius was a longstanding problem with wagons. At the ends of a curve, the amount of cant cannot change from zero to its maximum immediately. It must change gradually in a track transition curve. The length of the transition depends on the maximum allowable speed, the higher the speed, the greater length is required. The necessary superelevation of outer rail in a curve is normally set up to balance the effect of centrifugal force, thus allowing vehicles to maneuver through the curve at higher speeds.

The expected speed of the wagon is not identical. The track bearing high-speed passenger trains translates to a maximum allowable unbalanced superelevation and the low-speed freight track translates to surplus superelevation. In general, a curve radius of the track is determined by considering the small radius curve and a large radius curve track with maximum surplus superelevation. According to “Code for design of railway line” and actual situation, the curve radius and superelevation of outer rail are chosen for railroads Class I, II and III respectively [17, 18]. The main parameters of the line conditions and traveling speed used in the simulation are listed in Table 2.

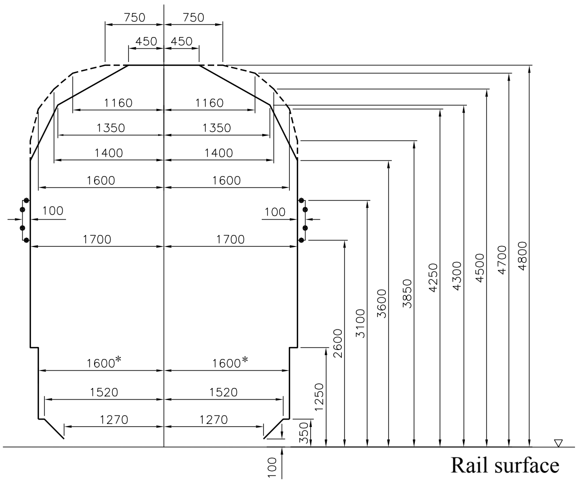
Table 2. Line conditions and traveling speed.

Rail Classes	Curve radius (m)	Superelevation of outer rail (mm)	Track transition curve (m)	Traveling speed (km/h)
Class I	R450	80	110	20, 40, 60, 80
	R1200	90	100	20, 40, 60, 80, 100, 120
	Straight line	–	–	20, 40, 60, 80, 100, 120
Class II	R400	90	100	20, 40, 60, 80
	R700	80	90	20, 40, 60, 80
	Straight line	–	–	20, 40, 60, 80
Class III	R350	120	100	20, 40, 60, 70
	R600	80	80	20, 40, 60, 70
	Straight line	–	–	20, 40, 60, 70

3.4. Measuring Points

The measuring point’s selection is mainly based on the rolling stock gauge and the loading calculation of vehicle vibration offset [19]. The Rolling stock gauge is shown in Fig. 3.

According to the structure gauge for standard gauge railways (GB146.2-83), the minimum height of the overhead contact system of electric railways is 5700 mm. The safety height between contact network and the top of goods is 400 mm. The Chinese standard platform heights for freight are 1100 mm. Therefore, the maximum load height is 5300 mm and the minimum height is 1100 mm when calculating the vehicle vibration offset [20, 21]. The measuring points are shown in Table 3.



——— Profile of rolling stock gauge (Unit: mm)

Fig. 3. Rolling stock gauge for standard gauge railways.

Table 3. Measuring points of vehicle vibration offset.

Measuring points	**Height from the rail surface (mm)**	**Half width of carbody (mm)**
1	1100	1600
2	1250	1700
3	1800	1700
4	2400	1700
5	3000	1700
6	3600	1700
7	4300	1350
8	4800	450
9	5000	450
10	5300	450

4. Simulation Results

4.1. Height of the Center of Gravity 2000 mm

According to the vehicle dynamic model, simulation is carried out with 11 kinds of loading plan, 40 line conditions and traveling speed. Simulation results can be obtained by analyzing the 440 different schemes. The maximum vibration offset are listed in Table 4 and Table 5, the position of maximum vibration offset is shown in Table 6 and Table 7 respectively.

Table 4. Maximum lateral vibration offset of the center of gravity 2000 mm (Unit: mm).

Height from the rail surface	**Class I**		
	R450	**R1200**	**Straight line**
5300	123.56	115.64	96.39
5000	118.67	111.13	93.13
4800	115.42	108.11	90.96
4300	107.29	100.58	85.54
3600	95.92	90.90	77.95
3000	86.19	83.24	71.58
2400	76.50	75.58	65.33
1800	66.82	67.92	59.08
1250	59.85	60.89	53.35
1100	58.26	58.98	51.79
Height from the rail surface	**Class II**		
	R400	**R700**	**Straight line**
5300	139.21	108.58	114.05
5000	134.26	104.81	108.33
4800	131.00	102.30	104.51
4300	122.85	96.05	94.98
3600	111.45	87.42	81.63
3000	101.67	80.02	71.71
2400	93.35	72.73	65.90
1800	86.81	68.43	60.10
1250	80.81	64.54	54.78
1100	79.61	63.48	53.35
Height from the rail surface	**Class III**		
	R350	**R600**	**Straight line**
5300	149.28	148.09	131.56
5000	144.97	143.76	124.29
4800	137.43	136.48	119.62
4300	122.57	120.86	109.94
3600	109.68	107.42	96.39
3000	102.34	89.33	84.78
2400	95.00	81.51	73.18
1800	87.67	74.54	61.62
1250	80.94	68.21	51.03
1100	79.10	66.49	48.14

Table 5. Maximum vertical vibration offset of the center of gravity 2000 mm (Unit: mm).

Half width of carbody	**Class I**		
	R450	**R1200**	**Straight line**
450	42.84	41.77	40.32
1350	46.56	44.99	40.05
1600	49.07	48.22	40.64
1700	50.35	49.51	40.87
Half width of carbody	**Class II**		
	R400	**R700**	**Straight line**
450	46.67	43.47	42.10
1350	52.82	51.87	50.23
1600	54.59	54.19	53.55
1700	55.78	55.67	54.88
Half width of carbody	**Class III**		
	R350	**R600**	**Straight line**
450	46.40	44.45	41.51
1350	50.94	48.74	43.27
1600	55.63	53.33	48.45
1700	57.51	55.57	50.52

Table 6. Maximum lateral vibration offset of measuring points of the center of gravity 2000 mm (Unit: mm).

Height from the rail surface	Half width of carbody	Class I, II		Class III	
		Maximum vibration offset	**Position of Maximum vibration offset**	**Maximum vibration offset**	**Position of Maximum vibration offset**
4800	450	131.00	581	137.43	588
4300	1350	122.85	1473	122.57	1477
3600	1700	111.45	1812	109.68	1810
3000	1700	101.67	1802	102.34	1803
2400	1700	93.35	1794	95.00	1795
1800	1700	86.81	1787	87.67	1788
1250	1700	80.81	1781	80.94	1781
1100	1600	79.61	1680	79.10	1680

Table 7. Maximum vertical vibration offset of measuring points of the center of gravity 2000 mm (Unit: mm).

Height from the rail surface	Half width of carbody	Class I, II		Class III	
		Maximum vibration offset	**Position of Maximum vibration offset**	**Maximum vibration offset**	**Position of Maximum vibration offset**
1100	1600	54.59	1155	55.63	1156
1250	1700	55.78	1306	57.51	1308
3600	1700	55.78	3656	57.51	3658
4300	1350	52.82	4353	50.94	4351
4800	450	46.67	4847	46.40	4847

Several conclusions can be drawn from results.

Firstly, it is obvious that there was a significant vibration offset of the end of vehicle than the middle of vehicle. This is due to the pitch vibration and yaw vibration. The position of maximum lateral vibration offset is 1812 mm in Class I and II railroads, 1810 mm in Class III at the half width 1700 mm.

Secondly, the maximum vibration offset basically appears in the most dangerous condition. There are three kinds of loading plan: 70 t with lateral offset of the centre of gravity 100 mm, 60 t with lateral offset 100 mm and weight difference of two bogies 10 t, 50 t with lateral offset 100 mm and weight difference 10 t.

Thirdly, line conditions directly affect the vibration offset. The best operating condition is Class I railroads, and the worst is Class III railroads. In Class I railroads, the maximum vitration offset is occurred in the 450 m radius curve with 80 km/h. In Class II railroads, occurred in the 400 m radius curve with 80 km/h. In Class III railroads, occurred in the 350 m radius curve with 40 km/h.

4.2. Height of the Center of Gravity 2400 mm

Based on the most dangerous condition, simulation is carried out with 3 kinds of loading plan, 40 line conditions and traveling speed. Simulation results of the 120 different schemes are listed in Table 8, Table 9, Table 10 and Table 11, respectively.

Table 8. Maximum lateral vibration offset of the center of gravity 2400 mm (Unit: mm).

Height from the rail surface	Class I		
	R450	**R1200**	**Straight line**
5300	133.77	123.17	112.62
5000	128.40	118.98	108.59
4800	124.82	116.18	105.90
4300	115.87	109.20	99.18
3600	103.35	99.53	89.77
3000	92.61	91.25	81.71
2400	81.87	82.96	73.64
1800	71.16	74.68	65.58
1250	62.95	67.08	58.19
1100	61.99	65.01	56.17
Height from the rail surface	**Class II**		
	R400	**R700**	**Straight line**
5300	151.06	125.24	115.37
5000	145.38	118.69	110.19
4800	141.60	114.32	106.74
4300	132.25	103.40	98.11
3600	122.46	91.20	86.10
3000	114.07	84.70	76.04
2400	105.75	78.98	69.64
1800	97.56	73.26	63.24
1250	90.05	68.01	57.38
1100	88.00	66.58	55.78
Height from the rail surface	**Class III**		
	R350	**R600**	**Straight line**
5300	150.59	150.17	143.16
5000	144.02	143.05	134.82
4800	139.97	139.28	129.27
4300	129.93	129.77	115.38
3600	116.85	115.50	96.63
3000	105.63	103.27	82.50
2400	95.92	91.03	68.59
1800	91.02	78.80	55.19
1250	87.15	69.71	48.74
1100	86.09	67.95	46.98

Table 9. Maximum vertical vibration offset of the center of gravity 2400 mm (Unit: mm).

Half width of carbody	Class I		
	R450	**R1200**	**Straight line**
450	44.15	40.78	36.10
1350	53.07	43.67	36.14
1600	55.58	44.47	36.32
1700	56.58	44.79	36.41
Half width of carbody	**Class II**		
	R400	**R700**	**Straight line**
450	59.31	56.14	52.39
1350	65.21	57.82	57.12
1600	66.90	59.53	57.50
1700	67.58	60.21	57.65
Half width of carbody	**Class III**		
	R350	**R600**	**Straight line**
450	46.33	46.01	45.32
1350	64.21	55.79	60.78
1600	71.04	68.45	66.27
1700	77.77	73.77	68.47

Table 10. Maximum lateral vibration offset of measuring points of the center of gravity 2400 mm (Unit: mm).

Height from the rail surface	Half width of carbody	Class I, II		Class III	
		Maximum vibration offset	Position of Maximum vibration offset	Maximum vibration offset	Position of Maximum vibration offset
4800	450	141.60	592	139.97	590
4300	1350	132.25	1483	129.93	1480
3600	1700	122.46	1823	116.85	1817
3000	1700	114.07	1815	105.63	1806
2400	1700	105.75	1806	95.92	1796
1800	1700	97.56	1798	91.02	1792
1250	1700	90.05	1791	87.15	1788
1100	1600	88.00	1688	86.09	1687

Table 11. Maximum vertical vibration offset of measuring points of the center of gravity 2400 mm (Unit: mm).

Height from the rail surface	Half width of carbody	Class I, II		Class III	
		Maximum vibration offset	Position of Maximum vibration offset	Maximum vibration offset	Position of Maximum vibration offset
1100	1600	66.90	1167	71.04	1172
1250	1700	67.58	1318	77.77	1328
3600	1700	67.58	3668	77.77	3678
4300	1350	65.21	4366	64.21	4365
4800	450	59.31	4860	46.33	4847

It is clear that the change trend of vibration offset is the same to the height of the center of gravity 2000 mm, but the value is greater. The position of maximum lateral vibration offset is 1823 mm in Class I and II railroads, 1817 mm in Class III at the half width 1700 mm. It has a safety gap to the construction gauge. So it is possible to improve the centre of gravity from 2000 mm to 2400 mm for car loaded.

5. Conclusions

Track, loading, line conditions and traveling speed are critical factors that have great impact on the vehicle vibration offset and operation safety of railways. In general the lower the center of gravity and the more stable the vehicle. It is possible to calculate the position of maximum vibration offset based on vehicle dynamics system to determine the clearance from the construction gauge.

Acknowledgements

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