Simulation on dynamic envelope gauge of NX70 flat car

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Abstract. In railway transportation, the clearance provided between the vehicle and structure gauge is an important safe space. The general rules and methods for inspecting of rolling stock gauge are based on a static gauge in China. Dynamic envelope gauge calculation considers the rolling stock displacement much more than before. The paper combines dynamics simulation with the Standard for Metro Gauge to calculate the dynamic envelope gauge. The lateral static vibration offset caused by the error of manufacturing, installation and maintenance is calculated. The lateral dynamic vibration and the vertical dynamic vibration offset caused by the suspension and wheel/rail gap is obtained by dynamic simulation. According to the current structure gauge, the clearance between the dynamic envelope gauge and the structure gauge can be calculated and the safety of railways operation can be analyzed. As an example, NX70 dynamic simulation model is established. The clearance between the vehicle and structure gauge is enough to curve and straight line when the center height of gravity increased to 2400mm for NX70.

Keywords: Dynamic Envelope, Vibration offset, SIMPACK, Rolling stock gauge.

1 Introduction

Railway freight transportation is a very important mode as the environmental and economic benefits. In order to ensure the safety of freight transportation, dynamic envelope gauge can be used to increase a suitable gap to the structure gauge for standard gauge railways.

Luo Xiangping (1997) proposed the method of calculation for one kind of fully dynamic envelope curve of subway car limiting gauge [1]. Han Mei (2006) established a simulation model to calculate vehicle lateral vibration offset [2]. Teng Wanxiu (2009) made a comparison between different methods in terms of the parameters of a metro carriage by using different calculation approaches [3]. Zhang Xiaoming (2012) discussed the dynamic simulation for subway car dynamic envelope line based on the calculation method of “Standard for Metro Gauge” [4]. Luo Ren (2014) compared the differences and similarities of applying CJJ 96-2003 Standard, the UIC 505 Code and dynamics method to calculate method, then the method of combining dynamics simulation with the CJJ 96-2003 standard

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to calculate the dynamic gauge is discussed[5]. Ma Rongcheng (2015) proposed a new method entitled as vehicle-track spatially coupled model, in which effected by the parametric excitations of track and other related factors during the vehicle operation are taken into consideration. The proposed method is employed to practical engineering applications. The simulation results indicate that the calculation speed is faster and the results are more precise by using the proposed method [6].

2 Theoretical calculation of the dynamic envelope gauge

Combining with the results of Zhang Xiaoming (2012) and Luo Ren (2014), it is possible to combine dynamics simulation with the CJJ 96-2003 standard to calculate the dynamic envelope gauge. The calculation method for Metro Gauge (CJJ 96-2003) considers the factors of the dynamic envelope as random and non-random factors. The sum of square and the square root are used to the random factors, directly sum method is used to the non-random factors. But some of the parameter values are not easy to be confirmed, the values are close to the extreme value, the calculation result is conservative [7].

Dynamic simulation can obtain the maximum lateral vibration offset Y_1 and the maximum vertical vibration offset Z by considering speed, wind force, track conditions, wheel rail state etc. Using CJJ 96-2003 standard can calculate the deviation C to obtain the lateral static offset Y_2 of manufacturing, installing and maintaining. The lateral offset ΔY can be calculated,

$$\Delta Y = Y_1 + C \tag{1}$$

$$Y_2 = \sum e_i + \sqrt{\sum d_i^2} \tag{2}$$

Where, Y_1 is maximum lateral vibration offset; Y_2 is lateral static offset; C is the deviation obtained from lateral static offset; e_i is offset come from non-random factors; d_i is offset come from random factors.

2.1 Lateral static offset

Lateral static offset come from elastic deformation of car body, side frame and wheelsets, the spring positioning error, manufacturing error, but it is unable to obtain the accurate data. Therefore, the following factors are selected for calculating lateral static offset.

2.1.1 Non-random factors

Non-random factors are: e_1- the clearance between the rail and wheel flange; e_2- the manufacture error, clearance and wear of center pin; e_3- the bearing axial clearance. These factors can be calculated as follows.

(1) The clearance exists between the rail and wheel flange

“The railway technology management procedures” prescribes that the minimum distance between wheel flanges is 1350 mm, the minimum wheel flange thickness is 23 mm in China [8], see Figure 1.

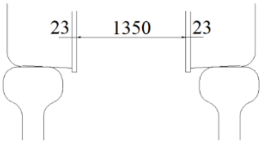

Fig. 1. Clearance between the rail and wheel flange.

The minimum distance between outside of wheel flanges is 1350+23*2=1396 mm. The standard gauge of straight line is 1435 mm. The gauge widening is 0 mm when the curve radius R⩾300m. The allowable deviation of track gauge are shown in Table 1.

Table 1. The allowable deviation of track gauge.

Speed (km/h)	v⩽120	120＜v⩽160	160＜v⩽200
Allowable deviation (mm)	＋6, －2	＋4, －2	±2

The maximum allowable positive deviation of track gauge is 6 mm. The maximum gauge of straight line and R≥300m curve is 1435+6＝1441mm.

2.1.2 Random factors

Random factors are: d_1 - manufacturing error of bogie side frame, 2 mm; d_2 - manufacturing error of wheelsets, 1 mm. The offset of random factors $\sqrt{\sum d_i^2}$ is: $\sqrt{\sum d_i^2} = \sqrt{d_1^2 + d_2^2} = \sqrt{1^2 + 2^2} = 2.24\text{mm}$. Therefore, Lateral static offset Y_2 in straight line is: $Y_2 = \sum e_{is} + \sqrt{\sum d_i^2} = 31.75 + 2.24 = 34\text{mm}$

In curve line are: $R \geqslant 350$ m, $Y_2 = \sum e_{ic} + \sqrt{\sum d_i^2} = 31.75 + 2.24 = 34\text{mm}$; 350 m$> R \geqslant$ 300 m, $Y_2 = \sum e_{ic} + \sqrt{\sum d_i^2} = 34.25 + 2.24 = 36.5\text{mm}$; $R <$ 300 m, $Y_2 = \sum e_{ic} + \sqrt{\sum d_i^2} = 39.25 + 2.24 = 41.5\text{mm}$.

2.2 Deviation come from the lateral static offset

The minimum radius of curvature in the simulation model is R≥350m, therefore the maximum lateral static offset in the simulation is $Y_2 = 34mm$.

The length of NX70 is $L = 15.4m$, the distance of the center of bogies is $l = 10.92m$.

The center of the two bogies shifted to different side in straight line, the maximum deviation reached at the end of the vehicle [9]:

$$C_s = \frac{L}{l} Y_2 = \frac{15.4}{10.92} * 34 = 47.95mm$$

When the vehicle is operating on a curve under the most dangerous position, the maximum lateral offset is divided into two parts, inside of the curve and outside of the curve. The center of the two bogies shifted to inside of the curve simultaneously, the maximum deviation reached in the middle of the vehicle. Maximum deviation for the middle of vehicle can be calculated as follows [10].

$$C_i = \frac{l^2}{8R} * 1000 + Y_2 \tag{3}$$

The center of the two bogies shifted to different sides, the maximum deviation reached at the end of the vehicle. Maximum deviation for the end of vehicle can be calculated as follows.

$$C_o = \frac{L^2 - l^2}{8R} * 1000 + \frac{L}{l} Y_2 \tag{4}$$

The maximum center plate deviation from the central line of track is shown in Table 2.

Table 2. The maximum center plates deviation from the central line of track.

Rail Class		C_s (mm)	C_i (mm)	C_o (mm)
Class I	R450	-	67.12	80.70
	R1200	-	46.42	60.23
	Straight line	47.95	-	-
Class II	R400	-	71.26	84.80
	R700	-	55.29	69.00
	Straight line	47.95	-	-
Class III	R350	-	76.59	90.06
	R600	-	58.84	72.51
	Straight line	47.95	-	-

3 Vehicle dynamic model

3.1 NX70 Flatcar Dynamic model

NX70 flatcar is the main type in China which equipped with K6 bogie [11]. According to the vibration, car body, side frame, wheelset and cross bar have 6 degrees of freedom. Bolster has 2 degrees of freedom relative to car body. A vehicle model can be set up in SIMPACK [12-20]. After the simulation model established, nominal forces can be calculated automatically to guarantee the static equilibrium of the system for a given state.

3.2 Model verification test

The loading of NX70 is 57.858t. The weight difference of two bogies is 10t. The center height of gravity is 2405mm. A virtual model which has the same loading conditions is built in SIMPACK. The track geometric irregularity is the main factor which causes the vehicle vibration [10]. Compared the power spectrum density, amplitude of time domain samples and dynamic performance, American railway track spectrum is usually used to describe Chinese track conditions when doing vehicle dynamic simulation. The indexes of running stability of operation and simulation test for NX70 are presented in Table 3.

Table 3. Comparing the operation test and simulation test.

Curve radius (m)	Operation test		Simulation test	
	Derailment coefficient	Wheel unloading rate	Derailment coefficient	Wheel unloading rate
R350	0.633	0.448	0.652	0.513
R600	0.442	0.465	0.487	0.486
R1432.6	0.325	0.522	0.342	0.547
Straight line	0.267	0.485	0.301	0.504

Compared with the results of operation test, the dynamic simulation has been approved to be effectively.

4 Simulation conditions

The weight of NX70 is 23.8t, the loading capacity is 70t. The loading plan, track conditions and speeds are shown in Table 4. Track excitations is selected as, Class 5 railroad in US for Class I railroad in China, Class 4 railroad for Class II, and Class 3 railroad for Class III. Four loading levels are considered, 70t, 60t, 50t and 0t. Lateral deviation of the goods gravity center are 0mm and 100mm. Loading difference of two bogies are 0t and 10t. The height of combined gravity center is 2400mm. There are 11 loading plan, 40 track conditions and speeds. The measuring points are shown in Tabl (1)e 5.

Table 4. Track conditions and speeds.

Rail Class	Curve radius(m)	Superelevation (mm)	Transition curve (m)	Speeds(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

Table 5. Measuring points of vehicle vibration offsets.

Measuring points	1	2	3	4	5	6	7	8	9	10
Height from the rail surface (mm)	5300	5000	4800	4300	3600	3000	2400	1800	1250	1100
Half width of the car body (mm)	450	450	450	1350	1700	1700	1700	1700	1700	1600
Half width of structure gauge (mm)	1520	1700	1820	2058	2264	2440	2440	2440	2440	2376

5 Results discussion

5.1 Maximum lateral vibration offsets

After simulation, the maximum lateral vibration offsets are listed in Table 6-7.

Table 6. Maximum lateral vibration offsets at the end of vehicle (Unit: mm).

Height from rail surface		5300	5000	4800	4300	3600	3000	2400	1800	1250	1100
Class I	R450	133.77	128.4	124.82	115.87	103.35	92.61	81.87	71.16	62.95	61.99
	R1200	123.17	118.98	116.18	109.20	99.53	91.25	82.96	74.68	67.08	65.01
	Straight line	112.62	108.59	105.90	99.18	89.77	81.71	73.64	65.58	58.19	56.17
Class II	R400	150.59	144.02	141.60	132.25	122.46	114.07	105.75	97.56	90.05	88.00
	R700	125.24	118.69	114.32	103.40	91.20	84.70	78.98	73.26	68.01	66.58
	Straight line	115.37	110.19	106.74	98.11	86.10	76.04	69.64	63.24	57.38	55.78
Class III	R350	151.06	145.38	139.97	129.93	116.85	105.63	95.92	91.02	87.15	86.09
	R600	150.17	143.05	139.28	129.77	115.5	103.27	91.03	78.80	69.71	67.95
	Straight line	143.16	134.82	129.27	115.38	96.63	82.50	68.59	55.19	48.74	46.98

Table 7. Maximum vertical vibration offsets (Unit: mm).

Half width of	At the middle of vehicle	At the end of vehicle

Car body		450	1350	1600	1700	450	1350	1600	1700
Class I	R450	24.55	32.35	34.52	35.39	44.15	53.07	55.58	56.58
	R1200	24.11	30.24	32.06	32.79	41.77	44.99	48.22	49.51
	Straight line	20.41	24.21	25.47	25.98	40.32	40.05	40.64	40.87
Class II	R400	32.30	41.21	44.47	45.78	59.31	65.21	66.9	67.58
	R700	29.51	35.46	38.41	39.61	56.14	57.82	59.53	60.21
	Straight line	25.42	35.41	38.09	39.14	52.39	57.12	57.5	57.65
Class III	R350	34.88	56.19	63.01	65.74	46.33	64.21	71.04	77.77
	R600	33.22	50.14	55.25	57.44	46.01	63.79	68.45	73.77
	Straight line	28.63	43.56	50.93	53.9	45.32	60.78	66.27	68.47

5.2 Half width needed for the vehicle

The half width needed in the straight line is:

$$B_s = B + \Delta y = B + Y_1 + C_s \tag{5}$$

The half width needed inside the curve is:

$$B_i = B + \Delta y = B + Y_1 + C_i \tag{6}$$

The half width needed outside the curve is:

$$B_o = B + \Delta y = B + Y_1 + C_o \tag{7}$$

5.3 The clearance between the vehicle and the structure gauge

According to the fundamental structure gauge for standard gauge railways, the value of widening in the curve is calculated with the car body length of 26m, the distance between bogie center is 18m and the actual radius. The value of the widening in the curve can be calculated as follows [8].

Inside the curve:

$$W_i = \frac{40500}{R} + \frac{H}{1500} h \text{ (mm)} \tag{8}$$

Outside the curve:

$$W_o = \frac{44000}{R} \text{ (mm)} \tag{9}$$

where, H is the height from the rail surface, mm; h is the superelevation of outer rail, mm.

According to the rolling stock gauge, considering the half width needed and vertical dynamic vibration offset of the measuring points, the dynamic envelope gauge can be calculated and shown in Figure 2.

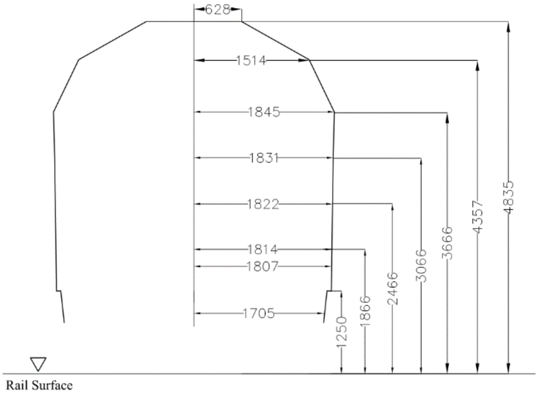

Fig. 2. The dynamic envelope gauge of NX70.

6 Conclusion

It is possible to solve the realistic problem of railway freight transport based on vehicle dynamic system. The simulation results are benefit to determine the clearance from the construction gauge, which show that the clearance between the vehicle and the structure gauge is safe.

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