Dynamic Performance of Metro Train Passing Through Turnout Branch in Depot

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Abstract: Turnout is the weak link of track, which is the key factor affecting the safety of train. The most important feature is variation of the cross section shape along the length direction, which leads to transverse irregularity and vertical irregularity. A type A vehicle-turnout coupled dynamics model was established by using the multi-body dynamics software UM, and based on the 7# right turnout, the type A metro vehicle model and variable cross section rail turnout model were established to analyze the dynamics performances of train pass through turnout branch, which were then evaluated according to the present vehicle operation safety evaluation standard. The results show that when Chinese type A subway vehicle passes through the 7# turnout branch at the speed of or below 50 km/h all safety indexes meet the relevant safety standards, which ensures the safe operation of the train; but the lateral displacement of the vehicle wheel is relatively larger, thus there is a tendency of train shaking. The higher the vehicle speed is, the greater the wheel/rail lateral force is.

Keywords: Suggest approximately 4-8 keywords for indexing purposes (spaced by semicolon)

1 Introduction

Turnout is a key component in track structure, which bears and delivers the loads caused by the running subway trains and guides the wheels running along the track. Because of the complexity of its structure and mechanical properties, turnout is a weak point in the track and also a key device ensuring the safety of trains traveling and controlling the speed of trains passing through stations. In urban rail transit, the passing speed of turnout onto main track or siding is a key factor restricting the carrying capacity, and the performance of the turnout influences the intensity, stability and carrying capacity directly, as well as the comfortability of passengers and the safety of the travelling. Due to the special features of urban railway transit such as low speed, low axle load, simplex wheelbase, small fixed wheelbase, large density of trains, short intervals of trains and long operation time, it is demanded that the turnout should have good elasticity and vibration attenuation ability, and the fasteners should be simple and convenient to regulate.

Lu et al. (Jiang, Lu, 2001) of China Academy of Railway Sciences established calculating method for longitudinal force and displacement of seamless turnout considering interaction of two rails with non-linear friction. This method takes into consideration the interaction of stock rail and guiding rail, focusing on the properties of seamless turnout bearing loads and delivering temperature stress, which accords with the practical cases. Wang et al. (Wang, 1997) developed a theory and method of dynamic calculation regarding many factors by using FEM, and analyzed different influence factors, which offers reference for department of turnout design, paving and maintenance. Wang (Wang, 2005) developed a FEM model of seamless turnout, and analyzed different factors influencing the longitudinal force and displacement, figuring out that the rail temperature changes rate, size of the turnout, welding forms, ballast bed friction, fasteners friction and the limiter are the main factors. Yu and Liu (Yu, Liu, 2006) proposed through safety check that single crossover with midway of 3.4m
and the allowable speed of $30\text{km·h}^{-1}$ should be applied in the subway to ensure the travelling safety and passenger comfortability. Tian and He (Tian, He. 2007) introduced the line type selection, planar form and other main structures of type 9 turnout with movable frog in Guangzhou Metro line 4, and proved the correctness of the structure through turnout dynamic simulative calculation. Li (Li. 2007) selected type 9 straight switch scissors crossing model to investigate the seamless turnout with straight switch. Zhang (Zhang. 2008) took the type 5 turnout in Guangzhou Metro line 4 as an example, which is the smallest type in China, and introduced the design and maintenance of turnout.

A vehicle-turnout coupled dynamics model is established in this paper, based on the vehicle-turnout dynamics theory, to investigate the dynamics properties of the 7# turnout used in the urban railway transit depots, under the condition of seamlessness (Yao, 2015, zhai, 2015, jia.2014). The performance of the turnout influences the intensity, stability and carrying capacity of the track, hence it is necessary to investigate its mechanical characteristics, as to improve the trains passing speed, the carrying capacity of the turn-back line and even the depot. It is also important and impedance for the urban railway transit safety.

2 The Establishment of the Model

2.1 Dynamical Model of Metro Train

The type A metro train is composed of the body and bogies. The bogie is the core component of the vehicle system, which consists of frames, wheels, axle boxes, primary and secondary suspension devices, playing the role of guiding, braking and load bearing. According to the multibody dynamics theory, a type A metro train model is established in the UM software, as shown in Figure 1. The main parameters of vehicle system are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>Length between vehicle centers</td>
<td>15.7</td>
<td>m</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>2.5</td>
<td>m</td>
</tr>
<tr>
<td>Nominal rolling circle’s lateral span</td>
<td>1.493</td>
<td>m</td>
</tr>
<tr>
<td>Nominal rolling circle diameter</td>
<td>0.84</td>
<td>m</td>
</tr>
<tr>
<td>Body mass</td>
<td>50877</td>
<td>kg</td>
</tr>
<tr>
<td>Frame mass</td>
<td>2721.5</td>
<td>kg</td>
</tr>
<tr>
<td>Wheel mass</td>
<td>1900</td>
<td>Kg</td>
</tr>
<tr>
<td>Tread type</td>
<td>LMA</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: The vehicle-turnout coupled model established in UM

1.2 The Turnout Model

Due to the complexity of the turnout structure, the analysis of the wheel/rail interaction in the turnout period remains a difficult problem, and there is not much investigation in foreign countries, among which the typical ones are listed in literatures. To investigate the dynamic performances of trains passing through turnout in UM, a turnout vibration model should be established at first. Here a turnout system analysis model is established based on the 50 kg·m-1 rails used widely in China and 7# lateral speed-up turnout(with concrete ties and a movable frog), as shown in Figure 2. In this model, different paths of the turnout is simulated by 7 Euler beams, as shown in Figure 2a, No.1 and No.2 represent the straight stock rail and curve stock rail, respectively; No.3 and No.4...
represent the straight and curve point rail respectively; No.5 and No. 6 represent the long and short guard rail respectively; No.7 represents the lateral guard rail. The boundary conditions of these beams are set according to the rail bounds in practical case: stock rails are treated as beams supported of both ends; 2 point rails(from beginning to the end of wing rail) and guard rails are treated as beams with both ends free; short and long guard rails are treated as beams with one end free and the other supported; turnout ties are vertically treated as beams on elastic foundation with both ends free and laterally treated as rigid mass blocks, as shown in Figure 2. This model takes into full consideration the spatial intersecting characteristics of the turnout and combines it with the vehicle into a vehicle-turnout coupled system featured with spatial intersecting beams.

During a train passing through the turnout, the contours of point rails close to stock rails are keeps changing. In this analysis the contours are given by measurements, as shown in Figure 3.

![Figure 2: Dynamics model of turnout structure](image)

2 Dynamics Index of Vehicle System

The dynamics index of vehicle system includes wheel/rail vertical force, wheel/rail lateral force and wheelsets lateral displacement, derailment coefficient and wheel load reduction rate.

2.1 Derailment Coefficient

The general index of derailment is Q/P, the quotient of wheel/rail lateral force Q and wheel/rail vertical force P, also known as Nadal formula for it is proposed by Nadal, a French scientist.

Nadal supposed the wheels on the derailment side are in the position of two-point contact and the flange contact point lies to the fore of tread contact point, thus it can be inferred that the wheel materials at the flange contact point tend to move downward relative to track materials, and the flange has reached the slip phase relative to rails. Based on this suppose, the mechanical characteristics of contact points under critical derailment condition can be derived, as shown in Figure 4.

![Figure 3: Profile variation of point rails of the switch section](image)
Mechanical characteristics of contact point under critical derailment condition

As is shown in Figure 4, under the action of lateral force \( Q \) and vertical force \( P \), the normal force on flange contact point of rail is \( N \), the tangential friction force \( N' \); the join force \( F \) is numerically equate to the join force of \( P \) and \( Q \), but in opposite direction. Let the flange angle be \( \alpha \), then the tangential and normal equilibrium equation of the contact point can be derived as:

\[
\begin{align*}
P \sin \alpha - Q \cos \alpha &= \mu N \\
N &= P \cos \alpha + Q \sin \alpha
\end{align*}
\]  

(1)

Solve the equation, and the limit value of \( Q/P \) given by Nadal formula is:

\[
\frac{Q}{P} = \frac{\tan \alpha - \mu}{1 + \mu \tan \alpha}
\]  

(2)

According to literature (GB5599-85,1985), for passenger vehicles with maximum speed below 120km/h, \( Q/P \leq 0.8 \).

2.2 Wheel Load Reduction Rate

Wheel load reduction rate is an index other than derailment coefficient used for evaluating the safety of train travelling in China. It is used to evaluate derailment caused by a serious reduction of load on a single side of wheel in case of wheel/rail lateral force close to or equivalent to zero. The formula is given as:

\[
\frac{\Delta P}{P} = \frac{P_2 - \frac{1}{2}(P_1 + P)}{P_1 + P} = \frac{P_2 - P_1}{P_1 + P}
\]  

(3)

where \( P_1 \) is the weight of wheel on the load reduction side; \( P_2 \) is the weight of wheel on the load increment side; \( P \) is the average weight of wheels on load reduction and increment side.

According to literature (GB5599-85,1985), for passenger vehicles with maximum speed below 120km/h, the regulation of wheel load reduction rate is given as:

\[
\left\{ \begin{array}{l}
\frac{\Delta P}{P} \leq 0.65 \text{(quasistatic)} \\
\left( \frac{\Delta P}{P} \right)_{\text{dyn}} \leq 0.8 \text{(dynamic)}
\end{array} \right.
\]  

(4)

3 Analysis of Calculation Results

3.1 Dynamic Response of Train Passing Through Turnout Branches

Based on the models above, the dynamic responses of type A metro train passing through the 7# turnout in the urban railway transit depot under the condition of seamlessness are analyzed. Figure 5~13 show the wheel/rail vertical force, wheel/rail lateral force and wheelsets lateral displacement, derailment coefficient and wheel load reduction rate of four wheelsets, versus time data.
It can be seen in Figure 5 and Figure 6 that when train passes the turnout, the wheel/rail vertical force increases 10kN, and the maximum lateral force is 30kN, and lateral force of wheelset 1 and 3 is higher than that of wheelset 2 and 4; the derailment coefficients of four wheelsets are all below 1.0; the wheel load reduction rate of four wheelsets are all below 0.6. All safety indexes of train passing turnout meet the requirement of limit values. From Figure 13 it can be seen that the lateral displacement of wheelsets reaches 7mm when the train passes turnout. Thus it can
be inferred that when train passes turnout, the wheel/rail vertical force, wheel/rail lateral force, derailment coefficient and wheel load reduction rate will all increase, but all the safety indexes meet the requirement of limit values; the lateral displacement of wheelsets is relatively larger, thus the vehicle tends to shake.

3.2 Influence of Vehicle Speed on Wheel/Rail Lateral Force

![Figure 14: Lateral forces under different vehicle speed](image)

It can be seen in Figure 14 that the higher the vehicle traveling speed, the greater the wheel/rail lateral force.

4 Conclusions

A metro vehicle-turnout coupled dynamic model is developed by the multibody dynamics software UM, and through simulation some conclusions can be derived that:

When train passes turnout, the wheel/rail vertical force, wheel/rail lateral force, derailment coefficient and wheel load reduction rate will all increase, but all the safety indexes meet the requirement of limit values; the maximum lateral displacement of wheelsets is 7mm, thus there is a tendency of train shaking; the higher the vehicle traveling speed, the greater the wheel/rail lateral force.

References


