Research on Reasonable Line Type of Suspended Monorail Turnout

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Abstract. Turnouts are key line equipment for suspended monorail transit. In order to determine the reasonable line type of the symmetrical suspension monorail turnout, a dynamic model of the multi-degree-of-freedom (MDOF) suspended monorail transit system is established according to the multi-body dynamics theory, and the influence of the radius of the circular curve and the length of straight between two curves on the dynamic performance of the vehicle passing the turnout is analyzed. The research findings show that: The turnout should be the turnout #5 with the frog angle is 11°18′36″, and the line shape of the circular curve and the straight line should be used. The radius of the circular curve can affect the dynamic performance of the vehicles passing the turnout greatly, and should not be less than 50 m. The length of straight between two curves has little influence on the dynamic performance, but it should be greater than 6.6 m.

1. Introduction

Turnout is an important part of suspended monorail transit system, which is crucial to the safety and comfort of sky train operation. At present, there are some researches on suspended monorail traffic in the world. Reference [1] introduced the development of monorail, characteristics of suspended and straddle monorail system, vehicle parameters and application of monorail in the world. Reference [2] introduced the development of suspended monorail vehicles, presented the status quo of different kinds of suspended monorail vehicles considering the running gears, described the technical characteristics of suspended monorail vehicles, and made a contrast analysis on the advantages / disadvantages between a straddled-type monorail and a suspended monorail. The research on the wheel-rail dynamics of sky train transit always concerns common sectional lines, Reference [3] analyzed the research status of the suspended monorail bogie, according to the actual situation in China, and main technical parameters of the vehicle were determined by reference to the bogie technology of the suspended monorail vehicle in Chiba, Japan and Dortmund, Germany. Reference [4] took into consideration the elements of walking wheel, guide wheel, suspended mechanism and vehicle body, and used Matlab/Simulink software to do simulation analysis. Through force analysis, the dynamic equation was written out, and then the corresponding data were obtained by simulation of the equation. Reference [5] validated the correctness of the model structure of the suspended monorail vehicle from the dynamic aspect, and checks the vehicle stability when passing the curve of small curvature radius with the Sperling index. Reference [6] established a 41-DOF suspended monorail
train model based on the SIMPACK platform, made a simulation analysis on the vehicle-bridge coupling dynamics of the suspended monorail transit system and evaluated the effect of factors such as running speed, track irregularity and train formation on the dynamic response of vehicles and bridges. Reference [7] analyzed the effect of guide wheel pre-pressure on the critical speed and curve negotiation ability of vehicles through SIMPACK. Reference [8] completed the analysis of the internal noise of suspended monorail vehicle under different operating conditions by using the finite element software Virtual.Lab Acoustic. Reference [9] presented dynamic modeling and simulation calculation through SIMPACK and made a simulation analysis on the key parameters (damper between vehicles, guide wheel pre-pressure, steady wheel) for design of suspended monorail trains and key conditions of vehicles (cross wind, air spring) during running. Reference [10] established a vehicle simulation model through the analysis software ADAMS and analyzed the dynamic change of radial force of guide wheels and the effect of which on the curve negotiation performance of vehicles. However for the key equipment - turnouts for sky train vehicle transfer, considering the effect of track irregularity on the dynamic performance of vehicles passing turnouts, no any research on the dynamic performance of vehicles passing turnouts with regard to different kinds of SSTT bogie and Prose associated bogie vehicles has been presented in the world. However, no any research on the reasonable line type of the turnout of symmetric monorail system has been presented in the world.

2. Monorail traffic and turnout

Monorail traffic is characterized by only one track, rather than the two balancing tracks of traditional railways. The track of monorail system is a beam, and the biggest feature is that the single track beam supports the vehicle and guides the vehicle. As shown in Fig. 1, according to the relative position between vehicle and track beam, monorail traffic can be divided into two types: suspended and straddle type; the suspended monorail system is also known as "sky train", the vehicle is suspended under the suspended track beam supported by the vertical column. Through the walking device on the upper part of the vehicle, the vehicle runs along the walking plane of the lower opening box track beam, and the steering wheel is rolling along the guide surface of the track beam to realize the driving direction. The suspended monorail traffic can be divided into symmetrical and asymmetrical type according to the bogie and track beam, as shown in Figure 2.

![Fig. 1 monorail system](image-url)
Fig. 2 Structure of suspended monorail

The main types of turnouts in suspended monorail system are integral translational turnout and integral swing type turnout. As shown in Figure 3, the integral swing type turnout is more widely used in suspended monorail system and mainly composed of running surface, adjusting rail, movable rail, movable guide surface, compensation rail and switch; the movable rail in the turnout beam can rotate around the axis to achieve the transformation of line. The swinging turnout is characterized by fast speed and small space, and the structure is rather complex, and it is mostly used in symmetrical suspension monorail system.

3. The introduction and determination of turnout line type

The common plane lines of railway turnouts are mainly circular curve, transition curve and crooked curve. The design and manufacture of circular curve is relatively simple, and the laying and maintenance is convenient. There are more plane line forms of the transition curve, such as second-degree or cubical parabola, spiral line and sinusoidal curve, the design and manufacture are more complicated and the laying and maintenance is more difficult, it is suitable for the large number turnout, and makes centrifugal acceleration and centrifugal acceleration increments change gradually to improve the comfort of passengers. Crooked curve is composed of curves of different curvature, including double circle curve, double transition curve, and so on. Considering the structure of suspended monorail turnout is more complicated than ordinary railway turnout, it is more difficult to manufacture, and the speed of vehicle passing through turnout in the diverging route is low, so the circular curve type is adopted.
As shown in Figure 4, when the circular curve matches the straight switch rail, the tangent point of the guide curve can be selected at the proper position of the heel of switch rail, generally used in the small number code turnout with lower lateral speed. When the circular curve matches the curve rail, the guide curve and the radius of the curve rail can be equal or unequal. The curve of the switch rail and the working edge of the stock rail can be tangent, phase cut or separated, it is usually used in the turnout with higher lateral speed. In order to facilitate the manufacturing, construction, and meet the dynamic performance of the vehicle passing through the turnout, the stock line type of the suspended monorail turnout adopts the circular curve to match the straight switch rail.

4. Establishment of dynamic model
The suspended sky train vehicle model consists of three parts mainly: bogie, oscillating device and vehicle body. The bogie is connected with the vehicle body through the oscillating device. In this paper, the Shanghai sky train transformation (SSTT ) bogie is selected as the example.

The simplified model is shown in Fig. 5 (a) and (b). It can be seen that there exist DOFs between the oscillating rod and bogie in the yaw direction and between the oscillating rod and vehicle body in the side oscillating direction. Table 1 shows some vehicle parameters. Fig. 6 shows the running wheel and guide wheel numbers of the SSTT bogie; Fig. 7 shows the acceleration measuring points of the vehicle body.

| Table 1 Some key vehicle parameters |
|-------------------------------|
| Vehicle L./mm | Vehicle W./mm | Vehicle H./mm | Vehicle mass /t | Ctr. distance of bogie /mm | Running wheel base/mm | Running wheel gauge/mm | Guide wheel base (upper) /mm | Guide wheel base (lower) /mm | Guide wheel gauge /mm |
|----------------|----------------|---------------|-----------------|--------------------------|---------------------|------------------------|-----------------------------|-----------------------------|------------------------|
| 10292          | 2300           | 3539          | 13              | 6600                     | 1730                | 340                    | 2410                        | 2754                        | 500                    |
5. Influence of radius of circular curve on walking performance of vehicle

In the calculation, the 50 m straight line are set before and after the turnout, and make the vehicle pass through the turnout in the diverging route at the speed of 20 km/h; the influence of the radius of the circular curve on the dynamic performance of the vehicle is analyzed.

5.1. Setup of calculating parameters

As a new type of urban rail transit, the operating speed of suspended monorail vehicle is much lower than the speed of high-speed railway. The design speed of vehicle passing through suspended monorail turnout in the diverging route is lower, which is 15 km/h, so choose turnout #5, which is beneficial to the flexibility of the line design, the saving of land resources and the cost of construction.

The smaller the radius of the circular curve is, the smaller the length of the turnout, on the contrary, the total length of the turnout will increase when the angle of the frog is same. But when the radius of the curve decreases, the centrifugal force and lateral acceleration of vehicle body will increase. Figure 8 is the preliminary design of the No. 5 turnout line type. In order to further analyze the effect of
radius of the circular curve on walking performance of vehicle, circular curves of 40 m, 50 m and 60 m are set up in accordance with table 2. Finally, the proper radius of the circular curve is determined.

Fig. 8 Preliminary design of suspended monorail turnout line type

Table 2 Conditions setting

| Cond. | Radius/m | Length of beeline segment (Ahead)/m | Length of beeline segment (Hinder)/m | Length of circular curve/m | Length of turnout beam/m |
|-------|----------|------------------------------------|-------------------------------------|---------------------------|-------------------------|
| Cond. 1 | 40       | 53.200                             | 50.000                              | 7.896                     | 18.810                  |
| Cond. 2 | 50       | 53.200                             | 50.000                              | 9.870                     | 19.960                  |
| Cond. 3 | 60       | 53.200                             | 50.000                              | 11.844                    | 20.790                  |

5.2. Dynamic performance of vehicle passing through turnout

Fig. 9 shows the variation of lateral acceleration and maximum lateral acceleration of each measuring point under different radius of curve. From Figure 9 (a), (b), and 9 (c), it can be seen that the vehicle will produce lateral acceleration under the action of centrifugal force when the vehicle enters the turnout curve. Figure 9 (d) shows that the maximum lateral acceleration of the vehicle body will be significantly reduced with the increase of the radius of the curve, and the lateral acceleration at both ends of the car body is obviously greater than that in the middle of the car body. The maximum lateral acceleration of vehicle body under various conditions is not more than 1 m/s².
The structure of suspended monorail bogie is special, it is necessary to analyze the guidance force of guide wheel to avoid big guidance force which can affect dynamic performance of vehicle passing through turnout seriously. There are 8 guide wheels in the SSTT bogie, as shown in Figure 10 (a), under the different radius of the curve, guidance forces of the No. 1 guide wheel are different; As shown in Figure 10 (b), the guidance force of No.5 and 6 guide wheels which located at the lower part of the bogie and near the inside of the curve are between 7~12 kN which are bigger than others; the guidance force of No.3 and 4 guide wheels which located at the upper part of the bogie and near the outside of the curve are between 5~7 kN and others are smaller.

6. Influence of length of tangent between two curves on walking performance of vehicle

When the vehicle enters second reverse curve from first curve, the unbalanced acceleration changes greatly and affects the passengers' comfort. Therefore, a straight line is set between the two reverse curves to ensure the smoothness and comfort of the vehicle operation. In order to compare the influence of the length of different tangent between curves on vehicle dynamic performance. The radius of the circular curve is 50 m, make the vehicle pass through the turnout in the diverging route at the speed of 20 km/h, the lateral acceleration of vehicle body and guidance force of guide wheel are obtained when the length of the line is 6m, 7m and 8m respectively.
The lateral acceleration of vehicle body of the measuring points A and C is shown in Figure 11 (a) and (b). Figure 12 (a) and (b) are the guidance force of guide wheels 5 and 6. The simulation results show that when the vehicle runs on the first curve, the length of tangent between curves does not affect the lateral acceleration and the guidance force. When the vehicle travels to the reverse curve, the direction of the lateral acceleration reverses, the length of tangent between curves affects the lateral acceleration of vehicle body and the guidance force of guide wheel. Due to the low speed of suspended monorail vehicle, the length of tangent between curves does not affect the operation of vehicles much.

Considering that the full wheelbase of the suspended monorail train is 6.6 m, if the line is less than this length, due to the track irregularities and the error of manufacturing assembly, the vehicle can not pass the curve possibly. Therefore, it is recommended that the length of tangent between curves should be greater than 6.6 m.

7. Conclusions
In this paper, a suspended monorail traffic system dynamic model is established through the software UM, the speed of vehicle passing through the turnout in the diverging route is 20 km/h, the influence of the radius of the circular curve and the length of the tangent between curves on the dynamic performance of the vehicle passing through suspended monorail turnout is analyzed. The detailed conclusion is shown below:

(1) With the increase of the radius of the curve, the value of the lateral acceleration of the vehicle body will be significantly reduced, and the lateral acceleration at both ends of the vehicle body is obviously larger than the lateral acceleration in the middle of the body.

(2) With the increase of the radius of the curve, the guidance force decreases, and the angle of the
vehicle passes through the turnout, and the difference of the guiding force between the different guide wheels is remarkable.

(3) The length of tangent between curves has little effect on the dynamic performance of vehicle, and does not affect the safety and comfort of vehicle operation.

(4) The number of the suspended monorail turnout is determined to be No. 5, the basic line is a circular curve and a straight line, the radius of the circular curve is not less than 50m, and the length of tangent between curves is more than 6.6 m.

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