IJR International Journal of Railway
Vol. 1, No. 2 / June 2008, pp. 31-36

The Korean Society for Railway

A Study of Wheel Tread Spalling Problem of DF_{21} Locomotive

Ma Weihua† and Luo Shihui*

Abstract

DF_{21} diesel locomotive was designed to satisfy the requirement of Kunming Meter track and the 2Co self-guided radial bogie was used to suit the complex curve track. There are totally 12 locomotives was served on the track. The first two locomotives were devotion running on the track since April 2003, the wheel tread splling was occurred on the middle wheel set of the two locomotives after running nearly 150 thousands km on the track of the two locomotives at August 2004. The dynamic analysis was carried out to find the reason. The wheel set longitudinal vibration resonance phenomenon was existed on the locomotive dynamic performance, and this was caused by the too big longitudinal stiffness of the journal box bar on the middle wheel set. Wheel set longitudinal vibration resonance maybe an important reason of lead to wheel tread spalling. The corresponding mend methods were put forward from the point of view of wheel set longitudinal vibration resonance. All the wheel tread of the 12 locomotives on the middle wheel set were in good condition and not occurred the wheel tread spalling after the mend till December 2007 after 350 thousands km were finished. The mechanism of the wheel tread splling and corresponding mend method was discussed in detail in this paper.

Keywords : *Meter track, Diesel locomotive, Wheel tread spalling, Dynamic, Wheel set*

1. Introduction

Kunming meter track with the gauge of 1000 mm was the single “Meter track” in China railway track, and it has a long history about 100 years. The length of Kunming meter track was 827 km in which nearly 58.4% was curve track. There was 40% curve track which the radius was less than 110 m in all curve tracks, and the smallest curve radius was 87 m, the biggest limit slope was 30‰, and the 43 kg/m rail was adopted in the meter track.

The traction locomotive of Kunming meter track was changed from steamer locomotive to Dongfanghong 21 diesel locomotive (DFH_{21}) at 1979. Two derailment accidents in average of the locomotive were happened once a year. The new designed Dongfeng 21 locomotive (DF_{21}) was adopted on the track to improve the locomotive traction power and the running safety at 2003. The main parameters of the two locomotives were shown in Table 1.

The self-guided radial bogie named SR-1 was adopted in DF_{21} locomotive. The first two locomotives was serviced on the track at April 2003, but the wheel tread spalling was occurred on the middle wheel set of both the two locomotives at August 2004 after the 150 thousands km was running on the meter track. The wheel tread spalling was shown in Fig. 1. The wheel fatigue was first occurred on the rolling circle position of the wheel and behaved as denseness grind crack. The big shelling or spalling on the rolling circle position of the wheel was induced with the increase of the running distance.

Table 1. Locomotive parameter of meter track

Type	DFH_{21}	DF_{21}
Factory	Sifang factory	Sifang factory
Amount	102	12
Keep amount	81	12
Axle type	B_0-B_0	C_0-C_0
Gauge	1000 mm	1000 mm
Wheel load	15 t	14 t
Design speed	50 km/h	60 km/h
Constant speed	12.5 km/h	15.3 km/h
Diesel	12V180ZJA	CAT3512B
Power	772 kW	1470 kW
Length	12676 mm	16000 mm
Brake	Hydraulic	Resistance

†Correspond author: Traction Power State Key Laboratory Southwest Jiaotong University Sichuan Province Chengdu City P.R. China 610031
E-mail: maweihua2008@gmail.com; TEL: 13084477943
*Traction Power State Key Laboratory Southwest Jiaotong University Sichuan Province Chengdu City P.R. China 610031

Fig. 1 The initial stage of wheel tread fatigue (left) and wheel spalling (right)

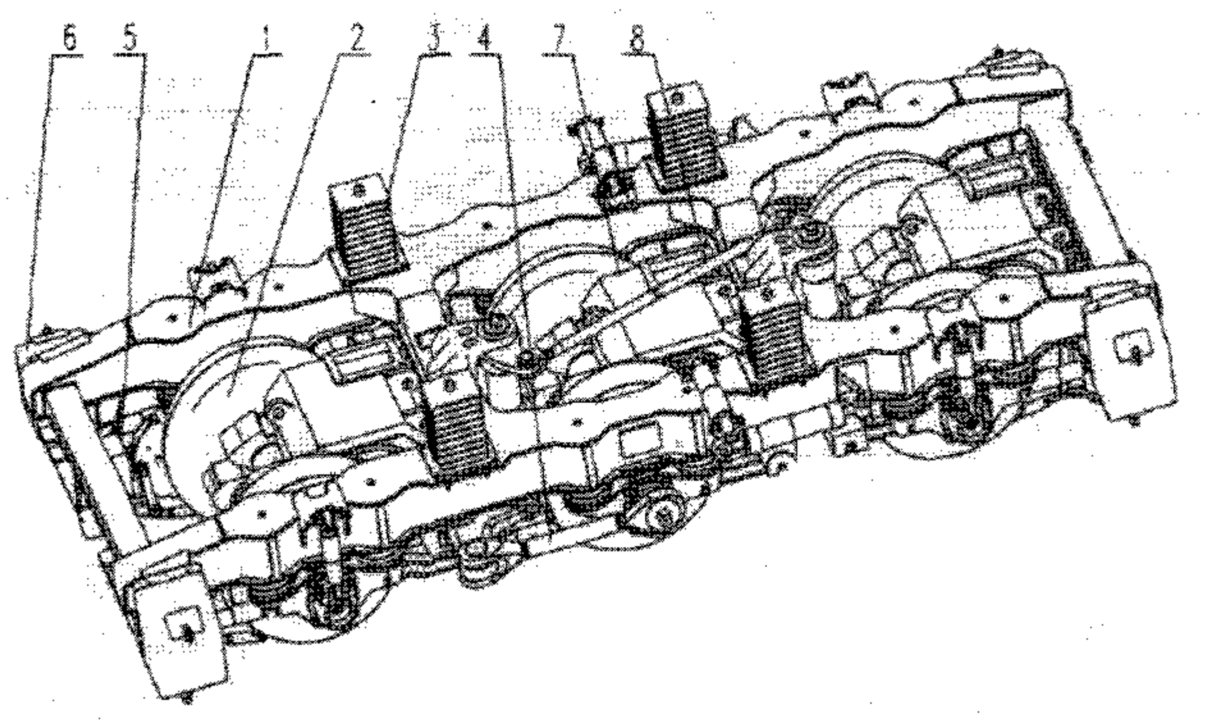
To the wheel damage problem, China railway science and research institute carried out the wheel tread spalling mechanism research of the civil wheel based on the metallography analysis. The railway vehicle wheel spalling damage can divided into 4 basis type such as contact fatigue spalling, brake spalling, local scratch spalling and local contact fatigue spalling according to the statistic of wheel tread invalidation in China [1]. The similar view was put forward by the abroad research, it says that the wheel tread variable has many facets during the railway vehicle running on the track and the form mechanism and the influence research was not enough yet [2]. The essence problem of rolling contact wheel damage was the contact stress problem, the wheel contact stress on the wheel surface and adjacent zone were calculated during the wheel damage research. Although it can explain the wheel tread spalling problem with high load wheel by the stress distributing acquired through above research, the uniformity dispose character of the spalling on the wheel and the wheel tread spalling which was happened on the light load wheel can not explained by the stress distributing.

The wheel tread spalling problem of DF_{21} locomotive was the first spalling case on the locomotive with radial bogies. The load which leads the wheel contact fatigue was comes from the dynamic interaction of wheel/rail contact, in other words, railway vehicle dynamic performance was one of the most important reasons of wheel/rail contact fatigue. Then the bigger stress which was caused by the dynamic load was response by the wheel fatigue damage. It was ignored in the past research of wheel spalling. The wheel tread spalling mechanism was researched and the mend method was put forward from the point of view of wheel set longitudinal vibration dynamic character.

2. Bogie Information and Wheel Tread Splling

2.1 Bogie Design

The SR-1 type bogie was self-guided radial bogie, the key parameters of the radial guided devices was adjusted to suitable the requirement of the curve track of the meter track and the structure characteristic of the locomotive. The basic structure of the bogie including bogie weld frame, the journal box setting which was made up of single journal box bar and coil spring, the supporting setting in the secondary suspension system, motor suspension setting, radial adjustment machine and hand brake system, etc.. The SR-1 type bogie was shown in Fig. 2.



1) bogie frame 2) journal box 3) supporting setting 4) traction setting 5) basic brake setting 6) accessories 7) motor suspension 8) radial adjustment machine

Fig. 2 SR-1 type bogie

The SR-1 type bogie has many characteristic compared with the tradition C_0 diesel locomotive bogie:

1) The journal box suspension system was consisted of single journal box bar, double coil spring and end axle vertical damper;

2) The top of the steel spring was elevation for the reason of the single journal box bar was in the wheel axle plane. The coil spring was put inside the side beam of the bogie so as not to elevation the position of the bogie frame. So the bottom plane of the bogie frame were no longer the level up close form and the corresponding position of the side beam was widen;

3) Adding the radial adjustment machine;

4) The lateral orientation stiffness was increased through a special components to keep the radial bogie has enough running stability and the yaw movement of the ending wheel set was constraint in some degree;

5) The ending wheel set longitudinal damper was setup to damp the vibration and not influence the semi-static radial adjustment.

2.2 Bogie service on the track

There were three main problems of the locomotive when the first two locomotives have finished one year running on the track and running 120 thousands km:

1) The free lateral play of the middle wheel set was not enough. It leads the bogie has big wheel set lateral force, then the crack was caused on the local of the bogie frame;

2) The welding technology was difficulty between the spring canister on the side beam of the bogie frame and the main body of side beam of the bogie frame. The amount of the welding line was too many on the key suffer position, and leads the local intension was low;

3) There was oil leak at the gear case.

These problems were solved on the following 10 locomotives after the corresponding mending method was adopted.

DF_{21} locomotive compared with DFH_{21} locomotive that the traction power nearly increased double times, the locomotive length was increased 3324 mm, the wheelbase was increased 1100 mm and the wheel load was a little light. It was never occurred the derailment accident of all the 12 locomotives since they were serviced on the meter track. This was a very big improve compared with the DFH_{21} locomotive which occur two derailment accident every year in average. This also tested that the DF_{21} locomotive can be competent for the curve rail of the meter track.

But wheel tread spalling was occurred on the locomotive at the middle wheel set when the first two locomotives has running about 150 thousands km on the meter track. The severity wheel tread spalling as shown in the Fig. 1.

2.3 Summarize of wheel tread spalling

The wheel tread spalling of DF_{21} locomotive on the middle wheel set was contact fatigue spalling for the reason of that there was no tread brake on the middle wheel set and the uniformity distributing of the spalling on the wheel rolling circle. Wheel contact fatigue spalling was the normal type among the wheel spalling but it was the most uncertain type, the mechanism and the disciplinary about it has far beyond formed according to reference [1] and [2].

DF_{21} locomotive has a quite high adhesion coefficient. The biggest restrict slope was 30‰, the high difference of the two end of the meter track was nearly 1808m, the average slope of the track was about 4‰, the jump-start traction force was 268.9 kN, the traction power was 1500 t for the restrict of adhesion coefficient of 0.32 at jump-start conditions. All the data shows that the adhesion of the locomotive during the normal running was quite high.

The wheel tread spalling was only happened on the middle wheel set of the C_0 track, it was a very strange phenomenon. Generally speaking, the wheel/rail contact force on middle wheel set was smaller than that on the end wheel set for the reason of middle wheel set nearly not has the guide function in C_0 bogie; at the same time, there was brake device on the end wheel set and there was not on the middle wheel set. From above information, the wheel spalling has more chance occurred on the end wheel set than on the middle wheel set in normal thought, but the fact was just on the contrary.

The wheel tread spalling on the radial bogie can be explained according to the research results of reference [3], it said that the longitudinal vibration resonance can be avoided if there was some longitudinal damp on the wheel set longitudinal direction, the wheel set longitudinal vibration resonance may turn to small amplitude longitudinal vibration and there was also big decrease on the wheel/rail dynamic load. As there was end wheel set longitudinal damper, so the wheel tread spalling can not happened on the end wheel set, this also tested the right of the wheel set longitudinal vibration theory. According to the viewpoint, wheel/rail contact fatigue was caused by the wheel abnormal longitudinal vibration resonance, the wheel tread spalling maybe amend or eliminated if the wheel set longitudinal vibration was decreased. This also put forward a method to solve wheel tread spalling problem of the DF_{21} locomotive. As the railway vehicle dynamic performance was vary with suspension parameters, the wheel tread contact fatigue problem also maybe solved by the adjustment of the suspension parameters.

3. Wheel Set Longitudinal Vibration Resonance

The vertical or lateral vibration character of the vehicle was partly considered in the wheel/rail contact fatigue research, but the variable of wheel/rail tangential force which was caused by the wheel longitudinal vibration character in elastic orientation wheel set was not considered in the contact fatigue research. The coupling of the wheel/rail stick slip vibration and the wheel set longitudinal vibration maybe leaded by the wheel/rail tangential force vary. Then the wheel set longitudinal vibration resonance was caused and let the variable of wheel/rail dynamic tangential force far beyond the semi-static value. It could not explain the wheel tread spalling which was occurred on the light wheel load railway vehicle if the wheel/rail tangential force was ignored during the contact stress calculation. The wheel set longitudinal vibration resonance was first put forward in the world in reference [4] and [5]. The locomotive longitudinal dynamic and the wheel/rail rolling contact problem was considered in a same system, combine the locomotive dynamic performance under certain track irregularity with the wheel/rail contact load, it was a new thought of solving the wheel tread spalling.

3.1 Universality of wheel set longitudinal vibration

The wheel set which has elastic orientation in the longitudinal direction was a spring mass system, so it has all the character of the spring mass. The wheel set longitudinal vibration may be happened if the wheel set was affected by the longitudinal force or the displacement impulse during the train running on the track. The wheel set longitudinal vibration resonance mechanism and the reason has not form a reasonable model although the elastic orientation wheel set longitudinal vibration was researched in reference [3-5].

Wheel set longitudinal vibration was a familiar phenomenon during the railway vehicle running on the track even on the physics sense. The research of double journal box bar orientation which was carried at 1965 has point out that the creep force variable maybe caused by the coupling of longitudinal and vertical orientation, and this would lead the wheel set speed-up or speed-down, but it doesn't consider the influence with the wheel/rail contact fatigue [6].

3.2 Wheel set longitudinal vibration condition

Vibration resonance was the big vibration which happened when the frequency of the outer impulse were close or equal the frequency of the system fixed vibration. For the elastic orientation wheel set of the railway vehicle, the longitudinal vibration resonance was the wheel set violent vibration in the longitudinal direction when the frequency of the outer impulse was close to the wheel set fixed vibration frequency. This longitudinal vibration was represented by wheel local rolling vibration. The main reason which caused the self-excited vibration was and only be the wheel/rail rolling contact in the whole railway vehicle system. The wheel set longitudinal vibration was caused by the wheel/rail rolling contact just like the railway vehicle lateral hunting movement was caused by the wheel/rail rolling contact.

The frequency of the wheel set longitudinal vibration resonance of the elastic orientation wheel set can formulas approximately:

$$f_L = \frac{1}{2\pi}\sqrt{\frac{2*k_x}{m}}$$

In which, m was the un-spring mass; k_x was the longitudinal stiffness of the journal box orientation. This frequency was the fix character frequency and not changed with the railway vehicle speed. The wheel set longitudinal vibration resonance may be formed by the influence of track irregularity, vehicle vertical and lateral vibration, wheel/rail contact normal force, the variable of contact spot, etc.. The wheel set longitudinal vibration was shown in Fig. 3. The simple forecast formula of the wheel set longitudinal vibration speed was put forward in reference [3].

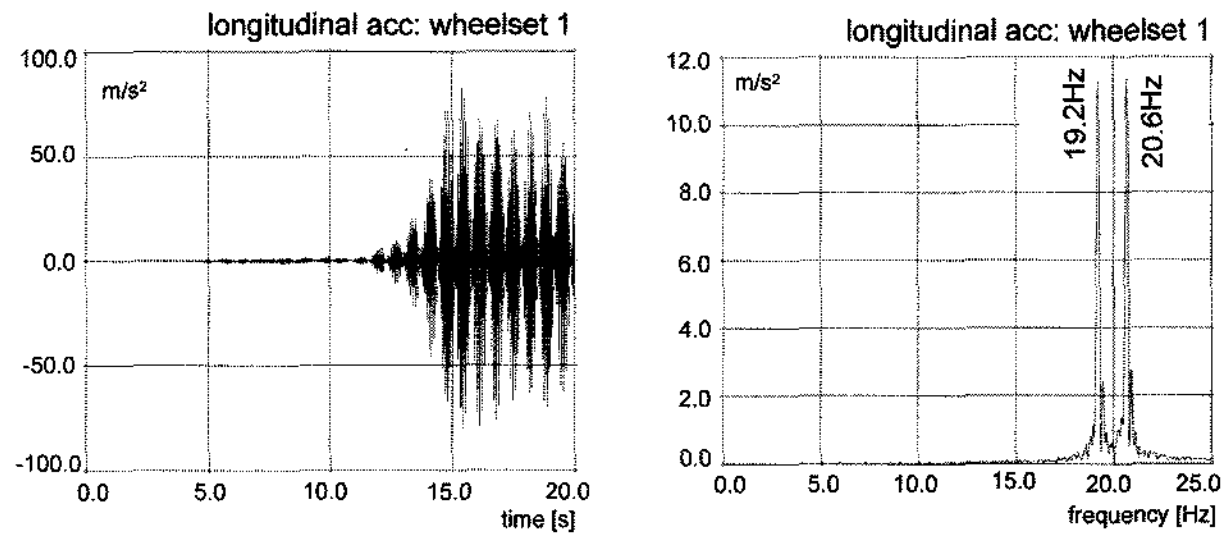


Fig. 3 Wheel set longitudinal vibration

But it was far beyond mature.

From Fig. 3 can see that the big variable wheel/rail longitudinal tangential force was formed if the wheel set longitudinal vibration resonance was occurred. The grind crack was easy occurred on the wheel tread rolling contact circle as shown in figure 1 by the function of the tangential force, then the wheel tread spalling was happened at last. The wheel tread spalling can be decreased or eliminated if the wheel set longitudinal vibration was decreased as the wheel/rail contact tangential force was turn small.

Wheel set longitudinal vibration also be decreased if there was some damp on the wheel set longitudinal suspension, and the vibration resonance could not happened. But there was no primary longitudinal damper on the railway vehicle. The viewpoint has tested by the following two examples.

Case 1: the wheel tread spalling not occurred on the end wheel set of the SR-1 type radial bogie as there was longitudinal damper at the end wheel set. In the same bogie, the wheel tread spalling occurred on the middle wheel set and there was no primary longitudinal damper on the middle wheel set. In the same time, the brake setting was on the end wheel set.

Case 2: The probability of wheel tread spalling of integer wheel was much higher than the wheel with wheel rim according to the railway service department and the factory. There was a friction plane between the wheel rim and the wheel center; it has the function of damp although it was very tighten. It may do favor to damp the wheel set longitudinal vibration resonance.

3.3 Wheel set longitudinal vibration influence

Wheel set longitudinal vibration will be influenced by all the factors which can influence the railway vehicle dynamic performances. Such as train speed, wheel/rail adhesion coefficient, wheel load etc.. The biggest influence factor was the unspring mass and the journal box longitudinal stiffness according to the formula of the frequency of wheel set longitudinal vibration resonance. The influence of the journal box stiffness was shown in Fig. 4.

The results of Fig. 4 shown that the soft journal box

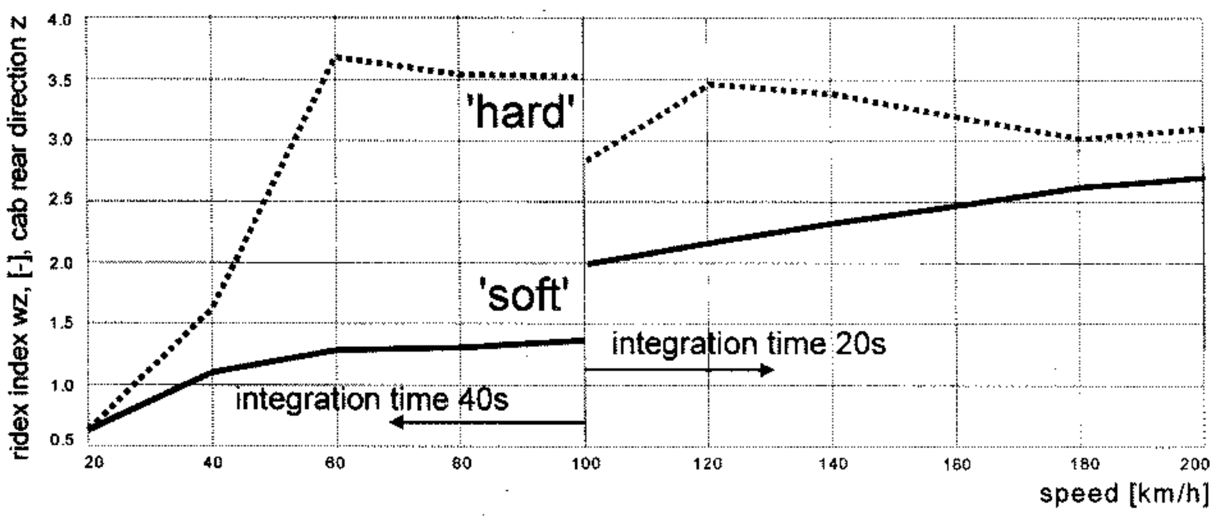
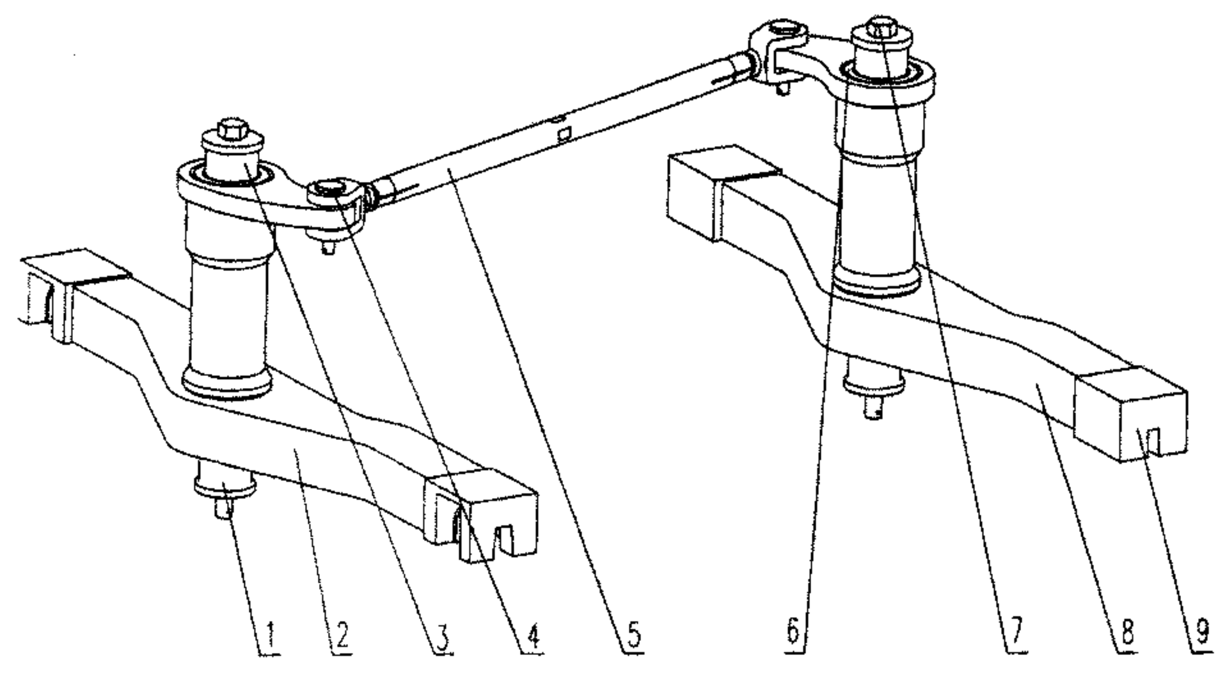


Fig. 4 The influence of journal box stiffness to wheel set longitudinal vibration (ride index)



1/3) taper press cover 2/8) guide setting 4) pin axle 5) coupling link bar 6) taper rubber 7) screw 9) journal box bar base

Fig. 5 The radial adjustment setting and the journal box bar

stiffness will do favor to decrease the wheel set longitudinal vibration (the vertical ride index of the railway vehicle was improved if the wheel set longitudinal vibration was decreased for the coupling of longitudinal vibration and vertical vibration in some degree). But the journal box longitudinal stiffness also has big relation with the locomotive stability, traction and brake system, so the journal box stiffness should be much softer under the condition of satisfy the requirement of stability, traction and brake.

4. Amend Methods and the Effect

4.1 Journal box stiffness analysis

The orientation stiffness of each journal box of the traditional C_0 diesel bogie was nearly the same. There was a big difference of the orientation stiffness of the journal box on the end wheel set and on the middle wheel set for the adopted of the radial adjustment settings. It was different with the traditional C_0 bogie.

To the end wheel set, one end of the journal box bar was connected with the journal box and the other end was connected with the pull bar base as shown in Fig. 5. The rubber sphere joint with big stiffness was used in both end of the journal box bar. The traction force was transferred from journal box bar to the guide setting, and transferred to the bogie frame by the guide setting. The connection point between the guide setting and the bogie frame was the middle guide pole, and there was taper rubber between the guide pole and the bogie frame, so the journal box bar stiffness was consisted of three stiffness in reality: the stiffness of the journal box bar and the rubber sphere joint, the bending stiffness of the guide beam structure and the stiffness of the taper rubber. The series of the three stiffness leads the real longitudinal orientation stiffness was far much smaller than the stiffness of the journal box bar and the rubber sphere joint.

To the middle wheel set, the structure of the journal box bar was the same with the journal box bar on the end wheel set. The difference of the two was the journal box bar length. Middle wheel set has no relation with the radial adjustment, so the traction force was transferred to the bogie frame by the journal box bar. This means that the orientation stiffness of the middle wheel set was the stiffness of the journal box bar and the rubber sphere joint. The stiffness of the rubber sphere joint was much big to assure the effect work of the radial adjustment settings, and this leads the orientation stiffness of the middle wheel set was too big.

4.2 Amend method

According to the new viewpoint of that the wheel set longitudinal vibration has a big relation with the wheel tread fatigue spalling, and combined the analysis of the orientation stiffness of each journal box of the SR-1 type bogie, then decided to change the stiffness of the rubber sphere joint of the middle wheel set journal box bar, this also means that the different rubber sphere joint was used in the middle wheel set and end wheel set.

As the longitudinal/lateral orientation stiffness of the middle wheel set for the C_0 bogie nearly has no influence to the lateral stability of locomotive, so decrease the stiffness of the rubber sphere joint on the middle wheel set could not lead the lateral stability accident. But the problem of the traction and brake must be pay attention to: 1) The stick slip vibration of the middle wheel set maybe occurred at the jump-start condition if the primary longitudinal stiffness was too low, and the traction force will also be influenced; 2) Avoid the middle wheel set has a big longitudinal displacement during the jump-start and close to the brake plate if the stiffness was too small.

The value of the stiffness of the rubber sphere joint was changed to 1/3 of the former value according to the demonstrate analysis. The rubber sphere joint of the journal box bar on the middle wheel set of the first two locomotives was changed at October 2004, and the rubber sphere joint with small stiffness was directly used on the middle wheel set of the following ten locomotives at November 2004.

4.3 Amend effect

Till December 2007, all the twelve locomotives has finished 350 thousands km on the meter track and the wheel tread of the middle wheel set were keep in good condition. There was no grind impress was observed on the wheel tread and the wheel tread spalling was not happened certainly, even the facula which generally existing on the wheel tread and has the character of light and shade was not observed on the wheel tread of the middle wheel set. Compared with the wheel tread spalling of the middle wheel set of the first two locomotives which was shown in figure 1 can known that the amend method was a big improvement, it also can say that the amend method was very effective.

5. Conclusions

Wheel tread spalling of DF_{21} locomotive was researched according to the specific viewpoint of science, put forward corresponding amend method and improve the wheel tread spalling at last:

1) Wheel tread spalling of DF_{21} locomotive was caused by wheel set longitudinal vibration resonance;

2) The wheel tread spalling was solved from the point of view of railway dynamic; the stiffness of the rubber sphere joint of the journal box bar was decreased.

3) The effective of the amend method was tested by three years running experience.

The solve of the wheel tread spalling of the DF_{21} locomotive was a big improve of the meter track locomotive, it also do a big contribution to the wheel tread fatigue research, point out a new research thought of the wheel fatigue. Too many research work and practice examples were needed to perfect the wheel set longitudinal vibration resonance theory.

This paper was aided by National Natural Science Fund of China with the No. 50775191.

Reference

1. Zhang Bin, and Fu Xiuqin, The present conditions and the analysis of wheel tread peeling on locomotives and rolling stock [J]. Rolling Stock, 2005, 43(5): 1-5.
2. Roland Mueller, Veraenderung von Rad- laufflaechen im Betriebseinsatz und deren Auswirkungen auf das Fahrzeugverhalten[J]. ZEV+DET Glas. Ann. 1998. 11 (122).
3. Luo Shihui, Jin Dingchang, and Chen Qing, Study on longitudinal vibration of wheel sets and related problems of rail vehicles [J]. Journal of the China Railway Society, 2005, 27(3): 26-34.
4. Ma Weihua, Luo Shihui, and Song Rongrong, Influence of track irregularity to wheelset longitudinal vibration and the correlation performance. Journal of Southwest Jiaotong University. 2006. 3, (14): 238-252.
5. Luo Shihui, Study on wheelset longitudinal dynamic behaviour and wheel spalling problem. International advanced academic forum on vehicle dynamics, Beijing, Sep. 23, 2005.
6. Gierth E. and Seibert K. W., Die elektrische C_0C_0 Schnellzug lokomotive Baureihe E03 der Deutsche Bundesbahn. eb Heft 10 1965, (36): 230-251.