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Analysis of Application Effect of Upper Locking Double Layer Nonlinear Fasteners in Nanjing Metro

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Abstract: In this paper, the vertical and transverse frequency response characteristics of steel rails under two track structure III fastener and upper locking double-layer nonlinear fasteners (GJ-32 fasteners) are compared by online detection and hamming method on the line of normal operation of subway tunnel from Shuanglong avenue to Nanjing South Station of Nanjing Metro Line 1. The results show that: (1) The GJ-32 fasteners has a better inhibitory effect on rail vibration between 200-400 Hz compared with the III fastener; (2) The GJ-32 fasteners has better damping performance and damping characteristics; (3) The development of corrugated rail of III fastener is serious, and the growth of corrugated rail is effectively inhibited by the upper locking double-layer nonlinear fasteners.

Key words: Upper locking double layer nonlinear fasteners, rail corrugation, roughness, III fastener, vibration reduction.

1. Introduction

The frequency response of the track structure reflects the inherent characteristics and combination forms of each component system of the track system. By analyzing the system frequency response function, the vibration frequency distribution of each component of the track can be obtained. The frequency response characteristics of steel rails are inherent features of track structures, and their significant frequencies do not change due to changes in the vehicle system. When subjected to external forces within the corresponding frequency range, the steel rails will produce severe vibrations. In order to reduce the environmental vibration caused by wheel rail excitation in rail transit, measures such as reducing the stiffness of the fastening pad and adopting a new type of rail structure with low stiffness are mainly adopted to block the propagation of vibration energy to the rail foundation on the transmission path. The commonly used medium damping fasteners in existing subways include GJ-32 fasteners and III fastener [1].

Due to severe rail corrugation, the existing III type shock absorber section was polished on December 19, 2014. On January 15-16, 2015, some fasteners were replaced in the K7+429~K7+917 section of the down line from Nanjing South Station to Shuanglong Avenue. This section is an underground line with a curve radius of R = 350 m. The original Type III fastener in the K7+600~K7+675 section will be replaced with an upper locking double-layer nonlinear shock absorber clip (GJ-32 fastener). This interval was continuously tracked and tested for 6 months without rail grinding to observe the changes in rail corrugation within this interval [2].

2. Type of Fastener

GJ-32 fasteners are mainly composed of rail elastic pads, upper iron pads, middle elastic pads, lower iron pads, and insulation self-locking sleeves. They have excellent dynamic vibration reduction performance and belong to medium vibration reduction fasteners. The fastening system has a compact structure, light weight, adjustable pre clamping force, easy installation and maintenance, and a static stiffness of 12-18 kN/mm.

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The main characteristics of the upper locking double-layer nonlinear fastener are as follows:

(1) Nonlinear elastic pad: adopting the unique technology of "non-linear high torsion anti vibration pad" design; The fasteners have high lateral and torsional stiffness, excellent overload protection function, and good safety.

(2) Non adhesive bolt free detachable structure: capable of transmitting longitudinal and transverse forces as well as flipping moments without the need for bolts, easy to assemble and disassemble.

(3) Effective improvement of corrugation: The natural frequency of the iron pad on the fastener and the connection stiffness of the fastener system have been optimized, effectively suppressing the development of rail corrugation, while reducing rail vibration and noise, and improving ride comfort.

The Type III shock absorber adopts a cast iron elliptical bottom plate connected to the track bed, and the upper and lower iron plates are vulcanized with rubber rings as a whole. The vulcanized rubber shear deformation is used to provide lower vertical support stiffness, with a static stiffness of 8-12 kN/mm.

3. Rail Corrugation Test

This test uses a high-precision corrugation analysis trolley (CAT), as shown in Fig. 2, to test the surface roughness of the steel rail [3].

The roughness level Lr of the rail surface is expressed in the form of a 1/3 octave wavelength spectrum to indicate the degree of rail corrugation. The calculation method for the surface roughness level Lr of steel rails is as follows [4]:

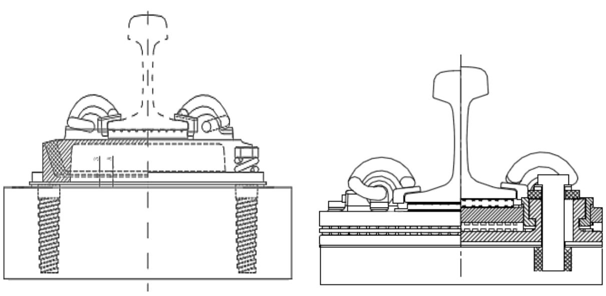

Fig. 1 Type III fastener and GJ-32 fastener.

Fig. 2 High-precision CAT wave grinding car test.

$$L_r = 20\log(\frac{r_{rms}}{r_0})$$

In the formula: r_0 is the reference value for the surface roughness level of the steel rail, $r_0 = 1$ μm;

The effective value of the amplitude of surface wave grinding for steel rails.

4. Track Vibration Test

Online dynamic testing selects the peak operating period of subway trains under normal operating conditions, and records the dynamic deformation and vibration of 30 trains under the same operating conditions on each test line during the peak operating period. The comparison of various working condition tests should select test results under similar routes, equivalent vehicle models, and similar vehicle speeds as much as possible.

4.1 Track Vibration Measurement

The vibration measurement section of the track is located at the same section at 1/2 of the fastener span, and the measurement sensor position is shown in Fig. 3. The main testing points include: (1) vertical vibration of the left and right rail bases and lateral vibration of the rail waist; (2) Vertical and lateral vibrations in the center of the track bed.

4.2 Tunnel Wall Vibration Measurement

The vertical and lateral vibrations of the tunnel wall corresponding to the cross-section are measured, mainly using fixed blocks fixed on the tunnel wall to place accelerometers. The position of the accelerometers is shown in Fig. 4.

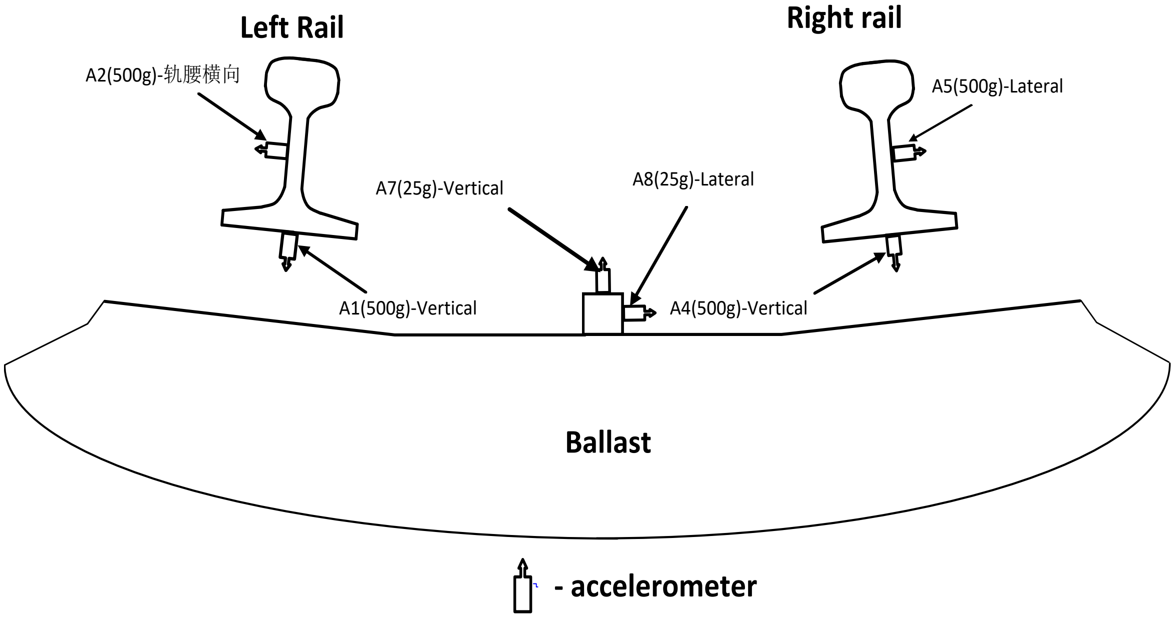

Fig. 3 Accelerometer position on rail and track bed at span/2.

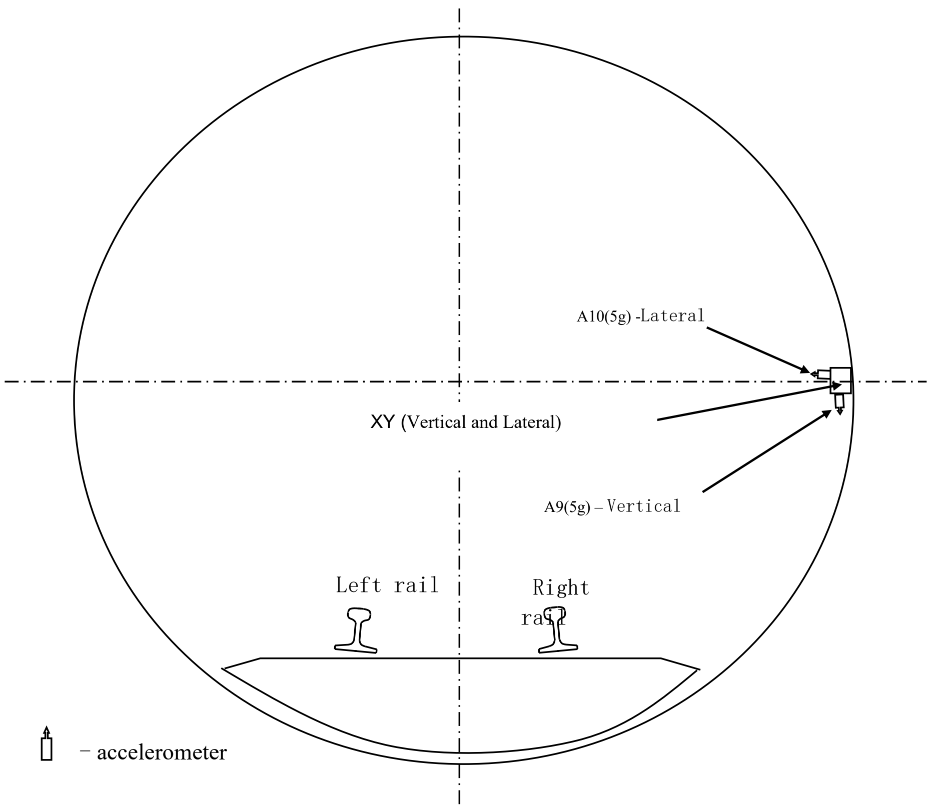

Fig. 4 Tunnel wall vibration acceleration position.

5. Analysis of Actual Application Effects

5.1 Analysis of Spectral Characteristics of Rail Vibration

The trains running on Nanjing Metro Line 1 are A-type trains with 6 carriages, each carriage is 24.4 meters long, 3 meters wide, and 3.8 meters high. The average speed of trains on the down line from Shuanglong Avenue to Nanjing South Station is 65 km/h. The 1/3 octave frequency spectrum of the rail vibration speed level in the two types of fastener sections is shown in Fig. 5, with a vibration frequency band of 25-2500 Hz. From the high/low rail vibration spectrum in Fig. 5, it can be seen that the rail vibration in the III type damper section is the highest. In terms of the peak resonance of the steel rail, there was no significant resonance observed between the DTVI2 and GJ-32 fasteners, while the Type III shock absorber steel rail had a significant resonance peak at 250 Hz. Among them, GJ-32 fasteners have a significant reduction in rail vibration compared to III fastener between 200-400 Hz.

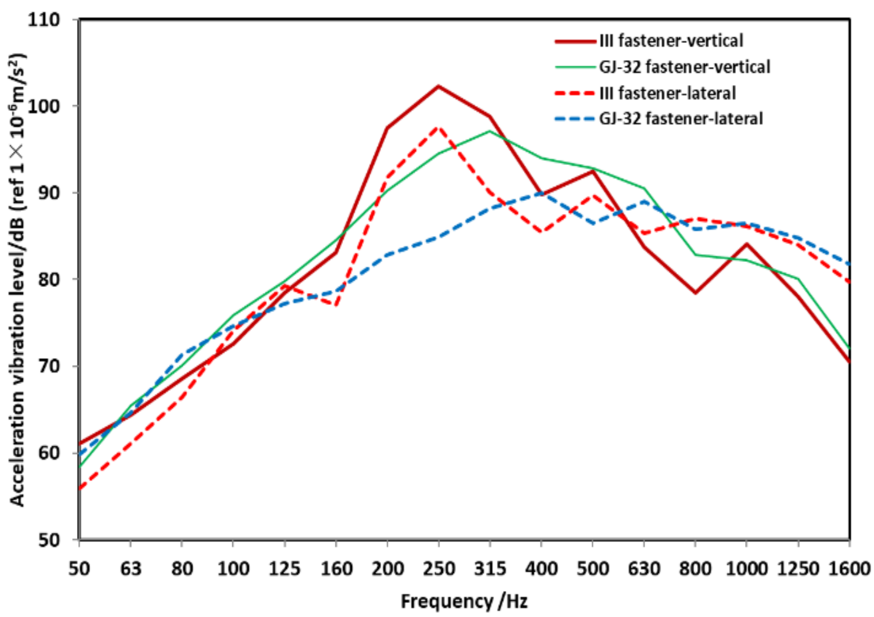

Fig. 5 Rail vibration 1/3 octave.

5.2 Analysis of Tunnel Wall Vibration Effects

The response of three types of fasteners on the tunnel wall was tested during normal operation of a 6-car A-type train running on Nanjing Metro Line 1, with a curve radius of 350 meters and an average speed of 65 km/h. The 1/3 octave frequency spectrum of the vibration acceleration level of the tunnel wall is shown in Fig. 6, and the calculation is carried out using the vibration acceleration Z-weighting method [5]. The total acceleration level of tunnel wall vibration is shown in Table 1. In Fig. 6, it can be seen that the DTVI2 fastener and the III type shock absorber both produce resonance peaks on the tunnel wall at 63 Hz, while the GJ-32 fastener produces resonance peaks on the tunnel wall at 40 Hz and 31.5 Hz, respectively, similar to the vibration pattern of the track bed. The vibration peak values of the three types of fasteners are relatively close, and the total vibration level of the tunnel wall between the III type shock absorber and GJ-32 fastener interval is not significantly different.

Table 1 Total acceleration level of tunnel wall vibration/dB.

Name	DTVI2 fastener	III fastener	GJ-32 fastener
Tunnel wall vibration	70.9	60.4	60.1

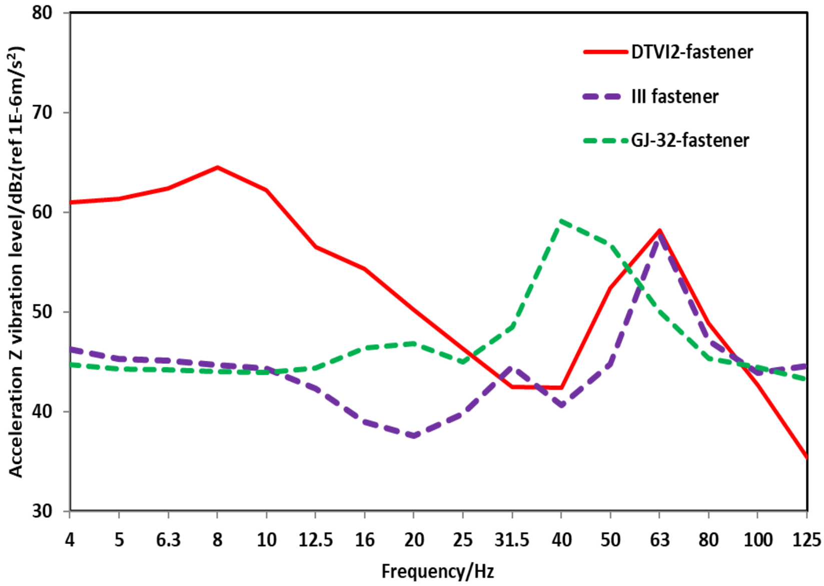

Fig. 6 Tunnel wall vibration 1/3 octave.

5.3 Analysis of Damping Performance of Fasteners

Dynamic damping of the track system is another important modal parameter of the track, which reflects the absorption and propagation characteristics of vibration energy by the track structure. For different track structures, the higher frequency vibration energy retained on the rail will exacerbate the development of rail corrugation to varying degrees. This article mainly uses the half power method to calculate. From Table 2, it can be seen that the damping of GJ-32 fasteners is 3.83%, and the damping of III fastener is 2.84%. The lower the damping characteristics of the steel rail, the more intense the dynamic interaction between the wheel and rail will be due to the increasing degree of rail corrugation, which may result in noise, loosening, and fracture of the elastic bars [6].

5.4 Analysis of the Suppression Effect of Rail Corrugation

The Type III track vibration dampers and GJ-32 fasteners of the Nanjing Metro from Shuanglong Avenue to Nanjing South Station were used to track and test the corrugation of the steel rails in the same section for six consecutive months at the same time. Table 3 shows the relationship between the corrugation wavelength and frequency of the fastened steel rails.

As shown in Fig. 7, the total roughness of the steel rail changes, and the corrugation of the III type shock absorber steel rail increases slowly with time. The low rail of the III type shock absorber has a growth rate of 0.6 dB/month at a wavelength of 80 mm and 2.2 dB/month at a wavelength of 40mm; The high rail of Type III shock absorber has a growth rate of 2.5 dB/month at a wavelength of 63 mm and 1.9 dB/month at a wavelength of 31.5 mm. The wave wear of the steel rail on the GJ-32 fastener decreases slowly with time, and the decrease rate of the GJ-32 fastener on the low rail at a wavelength of 80mm is 2.1 dB/month, and the growth rate at 40 mm is 0.9 dB/month; The reduction rate of GJ-32 clip high rail at a wavelength of 63 mm is 0.2 dB/month, and the growth rate at 31.5 mm is 1.3 dB/month.

Table 2 Damping characteristics of two types of vibration-damping fasteners

Main parameters	GJ-32 fastener	III fastener
Response frequency	116.2 Hz	88.3 Hz
Damping ratio	3.83%	2.84%
Loss factor	0.077	0.057

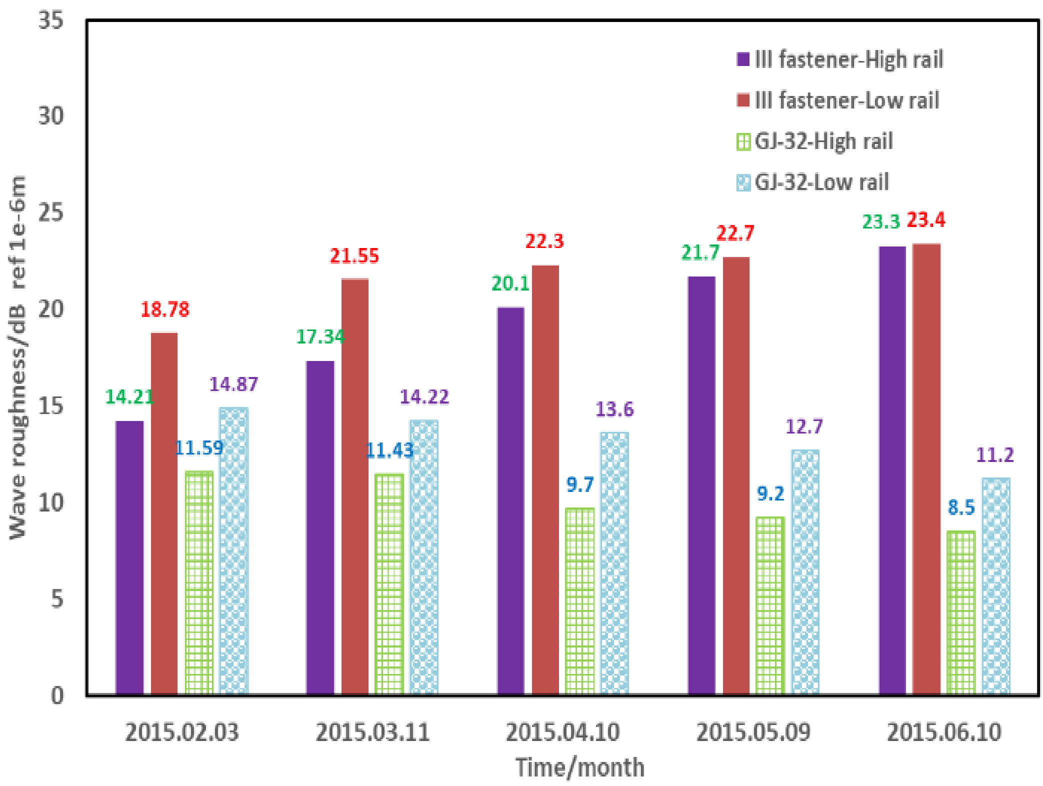

Fig. 7 Total rail roughness variation.

Table 3 Rail wavelength and frequency of fastener (speech at 65 km/h).

Name		III fastener	GJ-32 fastener
02.03	Wavelength	80, 63	80, 63
	Frequency	225, 286	225, 286
03.11	Wavelength	80, 63, 40	80, 63
	Frequency	225, 286, 451	225, 286
04.10	Wavelength	80, 63, 40	80, 63
	Frequency	225, 286, 451	225, 286
05.09	Wavelength	80, 63, 40	80, 63
	Frequency	225, 286, 451	225, 286
06.10	Wavelength	80, 63, 40	80
	Frequency	225, 286, 451	225
07.06	Wavelength	80, 63, 40	80
	Frequency	225, 286, 451	225

6. Conclusion

Through on-site testing of III fastener and GJ-32 fasteners from Shuanglong Avenue to Nanjing South Station on Nanjing Metro Line 1, the following conclusions were drawn:

(1) The rail vibration of Type III shock absorber is higher than that of GJ-32 fasteners. In terms of peak resonance of steel rails, the GJ-32 fastener section steel rails mainly exhibit peak frequencies at 315 Hz, while the Type III shock absorber steel rails have significant peak frequencies at 250 Hz、500 Hz, and 1000 Hz, respectively.

(2) According to the calculation and analysis of the damping characteristics of steel rails, the damping ratio of GJ-32 fasteners is greater than that of III fastener. The lower the damping characteristics of the rail, the greater the vibration energy of the rail due to the

dynamic interaction between the wheel and rail, and the long-term effect will reduce the service life of the fasteners.

(3) The vertical vibration of the tunnel wall with GJ-32 fasteners has a better damping effect compared to DTVI2 fasteners, with a damping effect of 10.8 dB.

(4) Based on continuous 6-month tracking tests of rail corrugation within the same interval, it was found that the corrugation of Type III shock absorber rails increases slowly with time, with an average high/low growth rate of 1.5 dB/month; With the increase of time, the corrugation of GJ-32 fasteners gradually decreases, with an average decrease rate of 0.7 dB/month for high/low rails.

(5) At a speed of 65km/h, GJ-32 fasteners can effectively suppress short wavelengths of steel rails (31.5mm, 80mm), while also effectively controlling the vibration level of steel rails in the range of 200-400 Hz, which is also the most prone to rail corrugation.

The results show that severe rail corrugation has developed in the III type shock absorber section, while GJ-32 fasteners effectively suppress the growth of rail corrugation.

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