Matching performance of CHN60N rail with various wheel profiles for Chinese high-speed railway

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Abstract. The matching of wheel profile with rail profile is the key issue in design of high-speed railway, it directly affects the vehicle dynamics performance during travelling and the wear behavior of wheel/rail. The matching performance of wheel profiles LMA, S1002CN and XP55 widely used in Chinese high-speed railway with CHN60N rail was analyzed in the study in terms of wheel/rail contact geometry, wheel/rail rolling contact and vehicle-track coupling dynamics. The results indicate that: By comparing the matching performance of the three wheel profiles with CHN60 rail, S1002CN profile matches best with the CHN60N rail. XP55 profile is not applicable to CHN60N rail.

1. Introduction

Correct wheel-rail profile matching can improve the dynamic performance, riding stability and curving performance of traveling vehicle, reduce wheel/rail wear, prolong fatigue life of wheel and rail, and ensure riding safety[1-8]. There are mainly three types of electric multiple unit (EMU) available in Chinese high-speed railway, which may differ in wheel tread (as show in figure 1). For instance, CRH1 and CRH2 EMU adopts LMA tread, CRH3 EMU adopts S1002CN tread, while CRH5 EMU prefers XP55 tread.

![Figure 1. Typical wheel treads for Chinese high-speed railway.](image1)

![Figure 2. CHN60N rail used in Chinese high-speed railway.](image2)

In this study, the matching relationship of CHN60N rail (as show in figure 2) with the various wheel treads available in Chinese high-speed railway was analyzed comprehensively in terms of
wheel/rail contact geometry, wheel/rail rolling contact state and vehicle-track coupling dynamic performance.

2. Wheel/Rail Contact Geometry
The distribution of wheel/rail contact points on rail top surface at different lateral displacements for three wheel profiles is plotted in figure 3. The figure can reflect wheel/rail wear trend to some extent. As can be seen from figure 3 that, LMA/CHN60N contact points are densely distributed and concentrate within about 0.4mm from rail centerline; at lateral displacement of -9~1.8mm, LMA/CHN60N contact points move to the interior of the rail with distribution width of 6.08mm. XP55 is a conical profile (profile conicity=5.5%), so XP55/CHN60N contact points are denser than LMA/CHN60N contact points, concentrating within 6~7mm from rail centerline; this may produce certain unbalanced loading and lead to uneven wear of rail. S1002CN/CHN60N contact points are distributed much even than the above two types and have the largest distribution width, which is contributive to the uniformity of wear on rail top surface.

Equivalent conicity reflects the running smoothness in straight line and the curving performance of wheel-set. Figure 4 presents the variation of equivalent conicity with wheel-set lateral displacement when CHN60 rail matches with different wheel profiles. For LMA profile, at lateral displacement of below 2mm, the equivalent conicity remains the same, and this profile produces good lateral stability and low wheel/rail dynamic effect; while at lateral displacement of above 2mm, the equivalent conicity increases steadily. For S1002CN profile, at lateral displacement of below 2.2mm, the equivalent conicity fluctuates significantly but increases on the whole; at lateral displacement of 2.2mm~5.4mm, the equivalent conicity drops remarkably from 0.14 to 0.10; and at lateral displacement of greater than 5.4mm, the equivalent conicity becomes stable at about 0.10. For XP55 profile, the equivalent conicity has small fluctuation at lateral displacement of below 1.2mm, but changes greatly at lateral displacement of 4.6mm and 5.8mm, from 0.045 to 0.067 and from 0.061 to 0.071 respectively, which may cause abrupt change in lateral force of wheel-set, affecting the lateral stability of vehicle.

3. Wheel/Rail Rolling Contact
The size of contact area directly influences the distribution of contact stress on wheel/rail contact area. figure 5 provide the size of contact area when different wheel profiles are in contact with CHN60N rail at different lateral displacements. As can be seen from figure 5 that, when the wheel-set is aligned with the track centerline, the contact area is 86.72mm² for LMA profile, 113.6mm² for S1002CN profile and 80.56mm² for XP55 profile, respectively. When the wheel-set moves slightly to the left (within 2.5mm), S1002CN profile has much greater contact area than the other two types. As the
wheel-set moves to the left further till the left flange clings to the rail, the left wheel/rail contact area increases gradually, but the right wheel/rail contact area remains basically the same for LMA profile; the left and right wheel/rail contact area decreases gradually for S1002CN profile, with the minimum contact area of 64.8 mm² for left wheel and rail and 84.32 mm² for right wheel and rail, respectively; the left wheel/rail contact area increases first and then decreases, while the right wheel/rail contact area remain unchanged for XP55 profile.

If the wheel/rail normal contact force remains the same, the normal contact stress of wheel and rail depends mainly on the characteristics of wheel/rail profiles. The distribution of the maximum normal stress in the contact patch between three wheel profile types and CHN60N rail at different lateral displacement is plotted in figure 6. The distribution of wheel/rail contact area is contrary to the distribution of the maximum normal contact stress of wheel and rail.

![Figure 5. Area of wheel/rail rolling contact.](image1)

![Figure 6. Maximum normal stress of wheel/rail rolling contact.](image2)

4. Assessment of Dynamic Performance

4.1. Curving Performance

Figure 7 demonstrates the variation of lateral displacement of front guide wheel-set (the first wheel-set) with the traveling distance during curving movement. As can be seen in the figure that, S1002CN profile has the smallest lateral displacement of guide wheel-set and the best curve negotiation ability; LMA profile and XP55 profile produce much greater lateral displacement of guide wheel-set than S1002CN profile, and have poor curve negotiation ability. This lies in that LMA profile and XP55 profile have smaller equivalent conicity, and the wheel-set lateral displacement is practically irreversible.

Figure 8 shows the variation of wear index of outer wheel of guide wheel-set with the traveling distance during curving motion. When the wheel-set approaches the transition curve, the maximum wear index of outer wheel of guide wheel-set is 7.42 N·m for S1002CN profile, 13.66 N·m for XP55 profile, as well as 21.05 N·m for LMA profile since the flange closely clings to the rail. Therefore, the wheel/rail wear will be worsened when the wheel of LMA profile travels in the transition curve. When the wheel-set rolls on to the circular curve, the wear index of outer wheel of guide wheel-set for S1002CN profile and XP55 profile is almost the same, about 2.50 N·m, while the wear index of LMA profile may have a peak of 7.50 N·m in the circular curve.
4.2. Lateral Riding Stability
A vehicle-track coupling dynamic model was used in the study. Applying the fourth, fifth and sixth grade track irregularity PSD of US railways to the straight track, and letting the vehicle travel at 250km/h produces the lateral and vertical vibration acceleration of carbody. The vibration response of vehicle of different wheel profiles was evaluated with Sperling index. The evaluation results are as shown in Table 1.

| Profile Type | Grade 6 PSD of US Railway | Grade 5 PSD of US Railway | Grade 4 PSD of US Railway |
|--------------|---------------------------|---------------------------|---------------------------|
|              | Lateral | Vertical | Lateral | Vertical | Lateral | Vertical |
| LMA          | 1.65    | 0.92     | 2.01    | 1.15     | 2.20    | 1.38     |
| S1002CN      | 1.68    | 0.92     | 2.07    | 1.15     | 2.28    | 1.38     |
| XP55         | 1.82    | 0.92     | 2.21    | 1.15     | 2.47    | 1.38     |

Table 1 indicates that, wheel profile type mainly affects the lateral running smoothness of carbody, not the vertical running smoothness of carbody. Under the effect of irregularities, the vehicle of LMA profile has the best lateral running smoothness of carbody, followed by S1002CN profile that is slightly inferior to LMA profile, and the XP55 profile which has the worst lateral running smoothness of carbody.

5. Conclusions
(1) For the matching of LMA profile with CHN 60N rail: The wheel/rail contact area is large and uniform, the maximum normal contact stress is small, however, the excessive distribution of wheel/rail contact points on rail top surface may cause uneven wear. This matching case can provide the best running smoothness of carbody under random excitation, but poor curve negotiation ability due to smaller equivalent conicity.

(2) For the matching of S1002CN profile with CHN 60N rail: At small lateral displacement of wheel-set, the wheel/rail contact area is large; the maximum normal contact stress is the smallest; the wheel/rail contact points are distributed uniformly on rail top surface. This matching case can provide good running smoothness of carbody under random excitation and best curve negotiation ability.

(3) For the matching of XP55 profile with CHN 60N rail: The wheel/rail contact area is small; the maximum normal contact stress is the greatest; the wheel/rail contact points are concentrated within 6~7mm from the center of rail top surface, which may lead to severe uneven wear of rail. This matching case can provide the least running smoothness of carbody under random excitation and poor curve negotiation ability.
To sum up, the matching case of S1002CN profile with CHN60N rail is the best. XP55 profile is
not applicable to CHN60N rail.

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