Study on Running Safety with Gauge Widening*

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Abstract
Gauge widening has been set in order that rolling stock runs safely and smoothly on curved tracks. Recently gauge widening has been reduced due to the change of vehicle structures and track maintenance. The reduction of gauge widening may lead the decrease of steering ability of wheelsets and running safety of vehicles. The purpose of this study is to grasp curving performance and running safety when gauge widening was varied. Stand tests were carried out by a bogie test stand, and the authors concluded that the curving performance can be increased according to gauge widening, but the effect is limited in perfect rolling region, and not so effective for normal setting range.

Key words: Gauge Widening, Curving Performance, Running Safety, Stand Test

1. Introduction
Originally gauge widening has been set up for the purposes that multi-axle vehicles, such as three-axle bogies, run safely and smoothly on tracks in curved sections. Rolling stock structures, however, have been changed in recent years, and the main type of bogies has become two-axle bogie with shorter wheel-base. On the other hand, reduction of gauge widening could maintain higher accuracy and bring lower maintenance cost. From these points of view, gauge widening has been reduced in many railways recently. But, if gauge widening is reduced, it is possible that curving ability of wheelset will be reduced and consequently running safety of vehicles will be lowered. Therefore it is very important to grasp quantitatively the effect caused by reduction of gauge widening, and the authors started the study on the influence of running performance when gauge widening had been set up variably.

2. Bogie Rolling Test Stand

2.1 Outline of rolling stock test stand
In this study rolling stock tests were carried out by the bogie rolling test facility as shown in Fig.1. The test facility belongs to "National Traffic Safety and Environment Laboratory". It has four rolling-rig units to simulate rails. Each rolling-rig unit has a pair of wheels for standard gauge (1435mm gauge) track and narrow gauge (1067mm gauge) track.
Running conditions of bogie can be simulated by driving the rolling rigs. The gauge widening can be widened up to 35mm by shifting the units to simulate gauge widening. A great feature of the facility is that it can examine the bogie under curving sections. A half car body with one bogie can be simulated by using the facility. Fig.2 shows the side view and the plane view of the rolling stock test stand. The test stand has the following three features in order to simulate the curving condition.

1. Rail-wheel beds can be rotated around the vertical axis, and a corresponding angle (rail-wheel yaw angle) can be given according to the simulated curving condition.
2. Due to the function of sub-motor and differential gear box, the rotating speed difference between outside and inside rail wheels can be given corresponding to the length difference between outside and inside rails in the curve.
3. Lateral force can be applied to the car body frame to simulate approximately the influence of centrifugal force and the deficiency of track cant elevation.

The cross section of the rail wheel is machined corresponding to the standards profile design of top of the rail. The basic cross section of the rail wheel is a 50kgN rail with 1/40 of tie-plate inclination. Those configurations can be changed easily just by changing the tire of the rail wheel, which is installed on the rim of the ring. The parameters of curving condition, such as rotating speed difference and attack angle of rail wheel, are measured by rotary encoders equipped on test facility, and parameters concerning bogie characteristics, such as contact forces and attack angles between wheel and rail, are measured by similar methods as running tests from onboard or wayside. Table.1 shows the specification of rolling stock test stand. Various parameter of car/rail system, such as wheel tread profile, wheelset suspension stiffness, bogie arrangement, rail corrugation characteristics and so on, are examined on the test stand. A lot of effective examination results about curving performance have been obtained by using the test stand [1][2][3][4].

Fig.1 The appearance of rolling stock test stand
2.2 Test Conditions

The test truck used in this examination was "SS130" bogie, which was a bolster-less truck. The bogie was designed for subway car as shown in Fig.3. It has measuring wheelsets of wheel/rail contact forces. The bogie has the wheel of arc-shaped wheel tread for subway lines with severe curves [5] as shown in Fig.4 and wheelbase of 1900mm. Longitudinal
The stiffness of primary suspension was 7.5MN/m. Rail wheel used in the test was 50kgN rail. Rail gauge was 1435mm.

The load on the bogie was 74kN. The train speed was 20km/h. The solid lubricant was not given on rail wheels. Gauge widening was set up at intervals of 5mm, from 0mm to 35mm. As both left and right rail wheels could shift in the direction of cross-tie, the center of the rail gauge was invariable under certain conditions. The test pattern of running test was as follows: after running on track in straight line, the bogie ran in curve sections, and at the end it ran on straight line. Track in curve sections was simulated by changing difference of speed between left and right rail wheels and angles between those rail wheels. The curving performances of railway bogie used to be evaluated by the lateral force of the front wheelset to the rail, rail corrugation formation tendency, wheel flange and rail shoulder wear, noise emmission and so on. In this study the lateral force of the first wheelset on outside was evaluated. The steady lateral force was measured at balancing speed in curves. Table.2 shows gauge widening and radius of curvature about test condition.
Table 2 Test Condition

<table>
<thead>
<tr>
<th>Gauge Widening</th>
<th>Radius of Curvature</th>
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</thead>
<tbody>
<tr>
<td>0mm</td>
<td>600m~260m</td>
</tr>
<tr>
<td>5mm</td>
<td>600m~200m</td>
</tr>
<tr>
<td>10mm</td>
<td>500m~180m</td>
</tr>
<tr>
<td>15mm</td>
<td>500m~120m</td>
</tr>
<tr>
<td>20mm</td>
<td>400m~180m</td>
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<tr>
<td>25mm</td>
<td>500m~120m</td>
</tr>
<tr>
<td>30mm</td>
<td>500m~120m</td>
</tr>
<tr>
<td>35mm</td>
<td>500m~100m</td>
</tr>
</tbody>
</table>

3. Characteristics of Contact Point between Wheel and Rail

3.1 Rolling radius difference

Characteristics of contact point between the wheel tread shown in Fig.4 and 50kgN rail was calculated when gauge widening was changed. Fig.5 shows relationship between rolling radius difference and lateral displacement of wheelset. The larger lateral displacements of wheelset were given, the larger rolling radius difference were made. The chang points of each lines show the points where the flange of the wheel came in contact with gauge corner of rail; so-called “flange-contact” condition. Then the value of rolling radius differences were calculated at every gauge widening. Fig.6 shows relationship between gauge widening and rolling radius difference. As the more the gauge widening was expanded, the more rolling radius difference was increased. This figure shows that the rolling radius difference becomes larger especially when the gauge widening is expanded more than 20mm. In this case, wheel/rail contact point may exist within the wheel tread inclination of 1/5. The difference of rolling radius difference is not so large when gauge widening is set up between 0mm and 20mm.

3.2 Radius of curvature in perfect rolling

Fig.7 shows relation between gauge widening and radius of curvature in perfect rolling. Radius of curvature in perfect rolling means the radius of curvature in case that wheelset can roll without longitudinal slip. When gauge widening is set at every 5mm between 0mm and 20mm, rolling radius difference is not changed so largely. On the other hand, when gauge widening is more than 20mm, larger gauge widening makes perfect rolling in smaller radius of curvature.

Fig.5 Relation of rolling radius difference and lateral displacement of wheelset
4. Test Results

4.1 Traces of contact points on rail wheel

Fig.8 shows traces on inside front rail wheel made by the test bogie. It indicates that when gauge widening is not given the contact point on inside front rail wheel is almost around the center of the top of the rail wheel. On the other hand, the more gauge widening is expanded, the more contact points are moved toward the gauge corner.
4.2 Lateral force of outside wheel of first wheelset

Fig.9 shows relation between lateral force of outside wheel of the first wheelset and radius of curvature obtained by test results. In the figure dotted lines indicate perfect rolling stage of wheelset. This figure shows that the lateral force of the outside wheel is reduced while gauge widening is expanded. However, in case of radius of curvature was less than 200m, the reduction of lateral force by gauge widening expansion is small. And lateral force decreases conspicuously in the case of large gauge widening such as 30mm and 35mm. It is thought this tendency is produced by the following reasons.

1) When radius of curvature was smaller than that of perfect rolling shown in Fig.7, the first wheelset would be unable to steer fully, and the attack angle of the wheelset became larger, then lateral creep force toward outside direction of curvature was generated.

2) On the rear wheelset the longitudinal creep forces were generated at wheel/rail contact points due to insufficient movement toward outside track, and these creep forces made the moment toward opposite direction of steering of the bogie. Then the reaction forces of these creep forces were generated at wheel-flange/rail-gauge-corner contact point of the first wheelset. As the results the lateral force of outside wheel of the first wheelset became larger.

3) On the contrary, when radius of curvature was larger than that of perfect rolling, the first wheelset would be able to steer fully, and undesirable phenomena described above were not produced, then the attack angle and the lateral contact force of the first wheelset were smaller.

4) When large gauge widening such as 30mm or 35mm was set up, perfect rolling could be realized in smaller curving radius, so the lateral contact force became smaller even in steep curves.

5) The effects of gauge widening expansion was limited within perfect rolling region, so it is important to realize the expansion of perfect rolling range by the design of wheel/rail contact geometry, such as wheel tread profile, rail head profile, etc.
5. Conclusion

Running safety was studied with gauge widening about combination of arc-shaped wheel tread for subway lines and 50kgN rail. The conclusions are as follows,

(1) The curving performance could be increase according to gauge widening, but this effect was limited in perfect rolling region. The improvement could be effective in case of very large widening such as 30mm, 35mm, but not so effective for normal setting region especially in very sharp curves.

(2) Radius of curvature for perfect rolling was calculated based on rolling radius difference of wheelset. When radius of curvature was larger than that of perfect rolling, lateral force of outside wheel of the first wheelset could be reduced according to gauge widening expansion. When radius of curvature was smaller than that of perfect rolling, the lateral force was little affected by gauge widening on the contrary.

(3) Radius of curvature in perfect rolling was changed as gauge widening was varied. If radius of curvature of perfect rolling became smaller, the lateral force of outside wheel of the first wheelset could be decreased even on sharper curve, and the region of radius where curving performance were improved would be expanded.

(4) Radius of curvature in perfect rolling would be different for different wheel-tread/rail-head profile. Relationship between radius of curvature in perfect rolling and gauge widening would be changed according to wheel/rail profile. So the influence on running safety by gauge widening change would be different for wheel/rail shape. Therefore the different combinations of the profiles of wheel tread and rail head may realize different effects of gauge widening expansion.

References


