Evaluation of Performance of Bogie to Control Decrement in Wheel Load in Operating Speed Range

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When vehicles run through curved sections presenting significant twisting irregularities, the wheel load on the front axle on the outer rail may decrease. Concomitant large lateral force in such cases make it easy for the wheel to climb the rail, increasing the risk of derailment. A new type of bogie has therefore been developed to prevent flange climb derailment by controlling the decrease in wheel load. Confirmation was obtained of the satisfactory basic performance of the bogie through a series of experiments. Confirmation was also obtained of the satisfactory performance of the bogie in the operational running speed range through experiments carried out on the RTRI test line.

Keywords: new type of bogie, running safety, decrease of wheel load, test line, operating speed

1. Introduction

When vehicles run through curved sections presenting significant twisting irregularities, such as a transition curve exiting a sharp curve, the wheel load on the front axle on the outer rail may decrease due to twisting of the contact plane between the bogie and the track. This occurs due to elongation of the front axle spring on the outer rail when the degree of the twist in the contact plane under the wheel on the outer rail is greater than that in other wheel positions. If there is any additional irregularity in the vehicle or the track at this time, the wheel load diminishes further. Addition of a large lateral force acting on the bogie at this time, makes it very easy for the wheel to climb the rail, increasing the risk of derailment. In order to prevent this type of flange-climb derailment, it is therefore necessary to reduce lateral forces and control the decrease in wheel load.

RTRI has been studying bogie structures to prevent derailment by finding ways to control the decrease in the wheel load. A bogie with a wheel load control mechanism was thus developed based on the results of this study. Figure 1 shows the outside view of the bogie. The performance of the developed bogie has so far been verified in terms of running stability by conducting bench tests on the RTRI rolling stock test plant [1], and confirmation of the running safety of the bogie was obtained through running tests carried out on the RTRI test line [2]. Confirmation of the bogie performance when running in the operational speed range, which could not be obtained on the RTRI test line because high speed tests are not possible, was achieved through running tests carried out on the MTC (Mihara Test Center) test line over a period of three months with a cumulative test run mileage of about 5300 km [3].

2. Outline of the developed bogie designed to control decrease in wheel load

2.1 Basic structure

In order to control the decrease in wheel load that occurs in track sections with significant twisting, such as transition curves exiting a sharp curve, it is necessary to improve the bogie’s capacity to follow the twisted track.

The bogie that was developed to control decrease in wheel load does so by having a special bogie frame equipped a rotation mechanism. A normal bogie frame consists of two side beams and one cross beam joined rigidly together with a rotating mechanism as shown in Fig. 2. This means that the bogie can follow the twist in the track as the side beams rotate thereby controlling the decrease in wheel load.

The rotation mechanism incorporates sliding bearings, which constitute the core technology of the developed bogie. The sliding bearings are cylindrical and are press-fitted to the side beams. The rotating shaft fixed to the cross beam is inserted into the side beam through the sliding bearings, then the side beam can rotate around the rotating shaft. Also the rotation angle of the side beams is limited to two degrees by a rotation angle control pin mechanically, so that the side beams do not interfere with the vehicle body and bogie parts. In addition, the side beams and the cross beam are fitted reasonably tightly together, to ensure good running stability. The contact surface is equipped with plate-shaped sliding bearings, as shown in Fig. 3.

The structure of the developed bogie is the same as that of a normal bogie except for the bogie frame and the new traction device. Most of the bogie parts are therefore
compatible with normal bogie parts. The bogie specifications are shown in Table 1. The target speed was 130 km/h, which is the maximum speed for ordinary meter-gauged lines in Japan, and the bogie was equipped with yaw dampers to ensure good running stability at the target speed. In order to avoid the cross beam from interfering with the vehicle body and bogie parts during rotation, it was equipped with a new traction device. The new bogie is an estimated 7% heavier than a normal bogie, because of the rotation mechanism and traction device.

Prior to validating the newly developed bogie in tests at operational speed, basic performance tests were carried out to ensure running safety at low speed and running stability.

The running stability performance of the developed bogie was evaluated in a hunting test on the RTRI rolling stock test plant. As result of the examination, the critical speed for the normal bogie configuration (i.e. 2 functioning yaw dampers) was above 300 km/h, while the critical speed without yaw dampers (i.e. all yaw dampers have failed)

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Table 1 Specifications of the developed bogie

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target speed on the meter-gauged lines (1067 mm)</td>
<td>130 km/h</td>
</tr>
<tr>
<td>Gauge</td>
<td>1067 mm</td>
</tr>
<tr>
<td>Rigid wheel base</td>
<td>2100 mm</td>
</tr>
<tr>
<td>Bogie weight</td>
<td>5932 kg</td>
</tr>
<tr>
<td>Maximum rotation angle</td>
<td>± 2 deg</td>
</tr>
<tr>
<td>Number of yaw dampers</td>
<td>2</td>
</tr>
<tr>
<td>Car-body suspension type</td>
<td>Bolster-less type</td>
</tr>
<tr>
<td>Axle box suspension type</td>
<td>Axle beam type</td>
</tr>
</tbody>
</table>

2.2 Basic performance

Prior to the validating the newly developed bogie in tests at operational speed, basic performance tests were carried out to ensure running safety at low speed and running stability.

The running stability performance of the developed bogie was evaluated in a hunting test on the RTRI rolling stock test plant. As result of the examination, the critical speed for the normal bogie configuration (i.e. 2 functioning yaw dampers) was above 300 km/h, while the critical speed without yaw dampers (i.e. all yaw dampers have failed)
was 220 km/h, about 100 km/h higher than the target maximum speed. No clear difference was observed in the critical speed between the developed bogie and the normal bogie as shown in Fig. 4. These results confirmed that running stability of the developed bogie was sufficient.

Running safety of the developed bogie at low speed (up to 30 km/h) was evaluated through running tests on the RTRI test line. The bogie was run on a transition curve exiting a sharp curve (radius 160 m; cant 90 mm; gauge widening 10 mm; cant reduction rate 400 times). As a result of the examination, the reduction ratio of the wheel load of the developed bogie was always lower (decrease by about 30% on the average) than on the normal bogie at all the running speeds as shown in Fig. 5. These results confirmed that the running safety of the bogie in the low speed range was sufficient.

3. Confirmation test of the performance in the operating speed range

3.1 Test condition

The maximum running speed on the RTRI test line for the transition curve exiting a curve is about 40 km/h for safety, because the total length of the test line is about 1km. In addition, the test line has no curves with a radius more than or equal to 160 m. For this reason, tests with the new bogie involving curves with a radius equal to or above 160 m could not be conducted on this line. Tests on the new bogie in the higher operational speed range, including the function to control decrease in wheel load (i.e. function aimed at improving running safety) were conducted on the MTC test line.

The running tests to confirm the performance of the developed bogie in the operational speed range were conducted on the MTC test line loop as shown in Fig. 6. One lap on the test line is about 3.2 km, and there are six curves with radii of 120 ~ 700 m and a straight section of about 1km in length. In these tests, all sections of the test line were used to confirm the performance of the developed bogie. The decrease in wheel load ratio was measured in the transition curve exiting curve R3 (radius 160 m; cant 107 mm; gauge widening 15 mm; cant reduction ratio 560 times) chosen because it was easy to set the test speed conditions there (hereinafter target test section).

A meter-gauge (1067 mm) test vehicle equipped with the new bogie was used for the test. The test vehicle was towed as shown in Fig. 7. The performance of a normal bogie was also examined for comparison with the new bogie.

In the target test section where decrease of the wheel load ratio was measured, the test running speeds were set at 10, 20, 30, 40, 50, and 55 km/h. In other sections, the running speed was set to remain slightly below the maximum speed of 80 km/h.

The main measurement items were as follows:
1) Wheel load and lateral force on the front axle of the bogie;
2) Displacement of the car body, the side beams and cross beam;
3) Acceleration of the car body and the bogie frame.
Wheel load and lateral force were measured using an instrumented wheelset. Displacement was measured using optical displacement meters. Acceleration was measured using a strain accelerometer.

3.2 Result of the test

3.2.1 Function controlling decrease in wheel load

Figure 8 shows the measured wheel load on the outer rail as the test train ran through the target test section at 30 km/h. In this figure, the wheel loads were normalized by the static wheel load, because the static wheel load on the developed bogie and the normal bogie differed. The static wheel load was the mean of the wheel load on the outer rail and inner rail, which was obtained from measurements made during preliminary running tests of the train at a very low speed. The figure shows that not only were decreases in wheel load on the developed bogie smaller than on the normal bogie but fluctuations in wheel load as well.

Figure 9 shows the measured results of the maximum reduction in wheel load ratio at each speed in the target test section. In this figure, the concentrated plotted data means that there was greater decrease in wheel load indicating lower safety performance. The figure illustrates that the decrease in the wheel load ratio of the developed bogie was lower compared to the normal bogie at all running speeds. It was also confirmed that, because of the
controlling function, the decrease in the wheel load was lower than on a normal bogie by about 40% on the average at all running speeds. The maximum decrease in the wheel load ratio was observed at the exit of the curve for both the bogies. The wheel load decrease control function was confirmed in all curved sections on the developed bogie because the wheel load of the developed bogie was heavier than the normal bogie in any circular curve.

Figure 10 shows the measured maximum decrease in wheel load ratio for each running speed in the curved sections except the target test section. In this figure, data regarding curve R2 and data with a negative value were not included, because curve R2 does not have an exit transition curve and the focus of this study was on the decrease in wheel load. The tendency observed for the maximum decrease in wheel load ratio was different between the target test section and the other curved sections. This is because the running speed of the test train and the specifications of the curves are different between them. The decrease in the wheel load ratio of the developed bogie was lower by about 30 ~ 40% than the normal bogie in all curves.

Running tests with reduced lateral forces were also conducted on the MTC test line, using an "assisted steering bogie system [4]" until the cumulative test run mileage reached about 5,400 km.

No changes were observed during these tests regarding wheel load decrease control function on the new bogie. These results therefore confirmed the satisfactory performance of this function.

3.2.2 Riding comfort

As mentioned above, the developed bogie is equipped with a rotating mechanism. Acceleration on the floor of the car body was measured when the test vehicle was running at standard velocity (i.e. balancing speed in the curve, about 80 km/h in the straight section), and calculated the ride quality level, to confirm that the rotating mechanism did not worsen ride comfort.

The ride quality in each position on the floor of the car body is shown in Fig. 11. The ride quality with the developed bogie scored an "excellent" (i.e. ride quality under 88 dB) or "good" (i.e. ride quality between 83 dB and 88 dB) in each direction (i.e. lateral, vertical). No clear difference was observed in the ride quality between the developed bogie and the normal bogie. These results confirmed the satisfactory ride comfort of the developed bogie.

3.2.3 Running stability

The bogie frame rotating mechanism on the new bogie uses sliding bearings. For this reason, the junctions of the side beams and the cross beam must have a tolerance. If the junctions of the side beams and the cross beam are loose, stability may be affected. Acceleration on the bogie frame and lateral force were measured when the test vehicle was running at 80 km/h in the straight section, to confirm that running stability is not worsened by the rotating mechanism.

Results from these measurements confirmed that there was no hunting motion nor any sign of hunting motion. The speed in these tests could not exceed 80 km/h, or 50 km/h below the target speed of the bogie (i.e. 130 km/h), because of the limitation in performance of the towing vehicle used. These results therefore at least confirmed sufficient running stability of the bogie for speeds below 80 km/h.
4. Conclusions

RTRI has developed a bogie capable of controlling the decrease in wheel load for use on meter-gauge lines (1067 mm) aimed at preventing derailment. Satisfactory performance of the bogie in the operational speed range was confirmed through experiments conducted on test lines. The results of these experiments can be summarized as follows:

1. Tests were conducted by running through transition curves exiting sharp curves (radius 160 m; cant 107 mm; gauge widening 15 mm; cant reduction ratio 560 times) to examine the wheel load control function of the developed bogie. The result showed that the decrease in the wheel load ratio of the developed bogie was always lower (reduction of the decrease in wheel load ratio by about 40% on average) than for the normal bogie at each of the running speeds.

2. Running tests at standard speed were conducted on a test line to examine the ride quality using the new bogie (i.e. balancing speed at in curved sections and about 80 km/h in the straight section). Result showed that the ride quality was “excellent” (i.e. ride quality under 88 dB) or “good” (i.e. ride quality between 83 dB and 88 dB), in all directions, which confirmed the ride quality of the bogie. In addition, no clear difference in ride quality was observed between the developed bogie and the normal bogie.
(3) Running tests were conducted in which the test vehicle ran through a straight section on the test line at 80 km/h to examine bogie’s running stability. Results showed that no hunting motion nor any sign of hunting motion occurred, confirming the satisfactory running stability of the developed bogie.

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References


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