Total Performance Evaluation of the Assist Steering System for Bolsterless Bogie

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In order to decrease the lateral force generated in railway vehicles in curved sections, a simple steering system for bolsterless bogies has been developed. This bogie steering system does not adopt a complex bogie structure, and is equipped with a function to prevent reverse steering. The system is referred to as an “Assist steering system.” It is composed of pneumatic actuators built into mono-links, a mechanical sensor to detect the bogie angle from the relative movement between the bogie and the car body, and a pneumatic control valve that works according to the sensing device.

Keywords: steering bogie, assist steering system, lateral force, mechanical sensing device

1. Introduction

When passenger journey times are shortened on meter gauge lines in Japan, trains must be able to run faster through curved sections, since the Japanese meter-gauge network has many tight curves. Faster running speeds in curved sections however tends to increase the lateral force exerted on the track through the point of contact between the wheel and the rail. Increasing the lateral force in curved sections can lead to an array of problems, such as derailments, screeching, and wheel/rail wear. Consequently, it is indispensable to improve the rotational performance of bogies as speeds are increased on meter gauge lines. Various studies have been conducted, and there has been progress in steered bogies which have helped reduce lateral forces, but systems that apply active steering have not yet been brought into service in Japan. One of the major reasons is because reverse steering mode is considered to be the cause of steering control system failure.

In order to decrease the lateral force generated in curved sections, a steering bogie system was designed that is easily applicable to bolsterless bogies [1]. It is a simple steering bogie system that does not require a complex bogie structure [2], and is equipped with a function to prevent reverse steering [3]. Steering actuators installed between the axle boxes and the bogie frame extend the outer side wheel base on curved section, and turn the wheel-sets in the tangential direction of the curved track (Fig. 1). This steering system is applied to the bogie with mono-link type axle box suspension. The mono-link with the actuator function replaces the ordinary mono-link, and adds appropriate extra steering force to assist the self-steering characteristics of the wheel-sets [4]. The most important feature of the developed system is that the steering force is basically controlled by the relative mechanical movement between the car body and the bogie passing through curved sections, i.e. there is no electrical control. The system has therefore been called an “Assist steering system” [5].

2. Composition of the assist steering system

The assist steering system exercises control according to the state of the bogie angle in a curved section. The system can therefore not go into reverse steering mode. It is composed of pneumatic steering actuators that are built into the mono-links, a mechanical sensor which detects the bogie angle from the relative movement between the car body and the bogie, and pneumatic control valve that works according to the sensing device.

In Japan, axle beam type primary suspension has become main stream [6]. In this paper, a test bogie with a mono-link type primary suspension is examined. If the actuator function is installed in the mono-link, the steered bogie requires only minor remodeling because the steering force is simply given by the bogie frame and the axle box. In addition, the steering actuator does not need to bear the bending moment caused by the axle box lateral displacement in mono-link type primary suspension, so the steering actuator can remain simple. Figure 2 shows the bogie used in the steering system test. The green circles indicate...
the location where the steering actuator and the bogie angle sensing device were installed. The steering actuator works as an ordinary mono-link suspension with a normal longitudinal spring constant when the controller operation is not active. This system does not therefore affect bogie running stability. This feature also acts as a fail-safe function for mechanical problems such as explosion of the air-pipe. A cross sectional view of the steering actuator developed for the running tests is shown in Fig. 3. A tandem cylinder was used for the steering actuator, and pre-loaded springs were installed to secure the spring constant of the primary suspension.

The sensor for mechanical detection of the bogie angle is shown in Fig. 4. This device is composed of two universal joints and a connecting rod that is able to expand and contract, but does not rotate. The upper end of the device is fixed to the base of the car body and the bottom side is joined to the bogie frame. This device is able to transfer only the relative yawing angle between the car body and the bogie, while the other movements (pitching, rolling, and movements in the longitudinal, lateral and vertical directions) are canceled by the motion of the joints and the connecting rod.

The pneumatic control valve for air supply to the steering actuators was directly connected to the output of the bogie angle sensing device. The pneumatic control valve must be sensitive to even the slightest movement because the bogie angle in curved sections is approximately 0.7 degrees in the case of a curve radius of 600 m and typical meter gauge vehicle dimensions. Consequently, the pneumatic valve works as an on-off control valve according to the threshold value of the bogie angle in a curved section. The cross sectional view of the pneumatic control valve is shown in Fig. 5.

3. Performance evaluations from running tests

3.1 Confirmation of fundamental performance

The assist steering system was applied to a test bogie, and fundamental running tests were carried out on the test line at the Railway Technical Research Institute. Figure 6 shows the external view of the test train. Running tests were executed on curved sections with a radius of 160 m or 100 m, and the vehicle-running speed was approximately 18 km/h at the entrance of the circular curved sections.

Figure 7 shows the lateral force of the leading axle with and without steering control in curved sections. The horizontal axis shows the running distance from the absolute position in the line. The average lateral force of each transition curve section and each circular curved section was calculated. The average lateral force was reduced by more than 80% on the circular curve section with a radius of 160 m compared to when there was no steering control. These results mean that almost perfect steering can be achieved, and nearly all turning lateral force can be suppressed. The most suitable pneumatic source pressure for steering control in this case was 400 kPa, which corresponds to an active actuator force of 10 kN. When excessive source pressure was added, the lateral force on the inner rail side changed to a positive value, which means exces-
ative steering.

The outer and inner rail lateral forces peaked in the same place in the circular curved section, and the effect of reducing lateral force was not clear. It is conceivable that the pneumatic actuator was influenced by track irregularity, since the expanded actuator stiffness was supported only by pneumatic pressure.

When the geometrical arrangement between the wheel and rail directions (the angle of attack) was favorable due to steering control, it was possible to restrain the occurrence of excessive longitudinal creep force, which should reduce flange screeching. Screeching was therefore measured in the running tests, and the difference in generated sound pressure was considered to be an indication of the effect of steering control. The C-weighted sound pressure level in curved sections is shown in Fig. 8. There are many factors that affect the sound pressure level such as temperature, humidity, conditions at the wheel/rail contact point, etc. As such, the sound pressure with no steering control varies significantly. Steering control significantly reduced the sound pressure, and the maximum improvement (reduction in sound pressure level) was approximately 5 dB during the running tests.

3.2 Functional improvement in exit transition curve sections

In addition to evaluating the fundamental performance of the system at low speed at RTRI, higher speed running tests were carried out at the Mitsubishi Heavy Industries MIHARA Test Center (Fig. 9). Test circular curved sections were composed of a compound curve with radii of 120 m and 160 m. Figure 10 shows the measured lateral force of the leading axle with and without steering control. By applying the steering control, the average lateral force in the circular curved section with a radius of 160 m was reduced by about 60% compared to no steering control. However, contrary to the effect of the steering control in circular curved sections, the lateral force in exit transition curves increased. It is thought that this phenomenon was due to the steering control being activated with a mechanism where the pneumatic control valve works with a small bogie angle in order to avoid delay in steering control. When the steering actuator expands the wheel base in a circular curved section, the actuator keeps the wheel base even at the exit of a curved section where the bogie angle is smaller than the supply air exhaust angle. Although this was observed to a degree during running tests at RTRI, no large increase in lateral force was observed because the running speed was relatively low. In order for this steering control system to be applied at higher running speeds, it is therefore necessary to improve steering control performance in exit transition curves.

In order offset over steering in exit transition curves, the authors devised a system which added an electrical control device to the mechanical steering control system. The basic concept of the assist steering system is to ensure steering based on the relative geometrical movement between the bogie and the car body to ensure the system is reliable. However, all the air supply to the steering actuator is provided via this mechanical control valve, so that reverse steering cannot occur even when the electrical con-
control device malfunctions. An electrical control device was therefore incorporated into the mechanical steering system in order to improve the performance at the exit of curved sections. Figure 11 shows the composition of the pneumatic piping and electrical control device, while the functions of the electrical control device are described below. The yawning angular velocity of the car body and the running speed are input to the controller, and the curvature at the current running position is estimated. According to the estimated curvature and the differential of curvature, the electrical control device commands to the exhaust valve at appropriate time for reduce the over steering condition.

For verification of the improved performance of the assist steering system, the running tests were carried out at the MIHARA Test Center. Figure 12 shows the lateral force, derailment coefficient and steering force expressed in steering control pressure. When the bogie is approaching the exit of the transition curve section, the radius of which is 160 m at its connecting point with the curved section, the necessary steering control pressure is released by operation of the electrical controller and the exhaust valve to prevent the lateral force increasing after the bogie has passed through the transition curve section. The lateral force after stopping the steering control comes to equal the state without steering control and the assumed effect is obtained.

4. Performance evaluations by MBD simulation

The other advantages of the assist steering system were confirmed through numerical analysis based on MBD software SIMPACK. A three-dimensional steering bogie model was built using this software (Fig.13) and scenarios that cannot be inspected in running tests were reproduced numerically. Performance was also evaluated in terms of energy saving by comparing the kinetic energy consumed when the vehicle passed through tight curved sections. The effect of the steering control on the vehicle’s kinetic energy consumption when passing through a curved section with a radius of 100 m was calculated by numerical analysis. Figure 14 shows the simulation result of the vehicle’s kinetic energy transition from coasting to running in a curved section. Results showed that energy consumption was improved by about 123.5 kJ per vehicle. Kinetic energy was reduced by about 56% after coasting in curved sections in cases where the vehicle was not equipped with steering control, whereas with steering control the kinetic energy saving was 33%.

The wheel wear of the bogie with the steering control should fall over a long period of running because the lateral force and the creep generated at the wheel/rail interface are reduced. Wheel wear was calculated for vehicles running at constant speed through two S-shaped curved sections with radii of 300 m and 600 m. Given the very small amount of wear caused by a single track run, the wheel shape was multiplied by the number of passages. This was input as the updated wheel-rail contact condition for the next step. Iterative calculations were used to clarify the wheel shapes with and without steering control, to understand the effect of the steering control. The worn wheel
shape and designed wheel shape are shown in Fig.15. The contact point of the wheel and rail tends to be concentrated in one specific place because the running track data offered for the numerical analysis is the combination of the simple trapezoid-shaped curved tracks without track irregularity, and the worn wheel shape in Fig.15 is different from the general worn wheel shape of an actual vehicle. In this paper, the focus was on the wheel shape difference between use of steering control and no steering control. The contact point between the wheel and rail shifts to the wheel tread from the wheel flange due to the steering control effect. The relative geometrical positions of the wheel and rail in the circular curved section simulated by the MBD model are shown in Fig.16. The results show that serious wheel flange contact can be avoided by steering control, and the reduction in wheel wear is apparent around the flange.

5. Conclusions

An assist steering system was developed in which the bogie angle can be detected from the relative movement between the car body and bogie using a mechanical sensing device for controlling steering actuators with a pneumatic valve. The authors estimated the system performance through running tests on the test line and numerical analyses based on MBD software, and the following conclusions were obtained.

1. The steering bogie can be simply composed by replacing the mono-link with a link having a steering actuator function.
2. The effect of the assist steering system on the reduction of lateral force in curved sections is a reduction of 80% of the lateral force compared with no steering control condition, which was the result obtained from the running test conducted in a circular curved section with a radius of 160 m.
3. The steering control system is basically operated by mechanical movement, which means that reverse steering is inconceivable.
4. The steering control system significantly reduces flange screeching noise in tight curved sections, and reduces the sound pressure level by 5 dB at most.
5. Calculation results from the numerical analysis of MBD simulations suggest that the kinetic energy consumption in curved sections can be reduced.
6. The steering system also avoids serious wheel flange contact, and reduces wheel wear around the flange. This effect is thought to be a factor towards extending the time between periodic wheel-thread grinding.

Further running tests should make it possible to bring the system closer to approval for use on commercial lines, while design spec optimization of the assist steering system should include an electrical controller.

References


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