Abstract

The authors developed assist steering bogie system that is built into ordinary bogie angle linked steering system, and carried out running tests to improve curving performance on narrow gauge line railway vehicles. This examination results have shown the effect of assist steering bogie system capable of reducing the lateral force at transition curve sections. We are considering that these steering bogie systems is needed to extended to practical use with regarding fail-safe function for more high performance on curve sections.

Introduction

Narrow gauge lines in Japan have been laid mostly at mountainous regions or along coastal areas. In earlier days of railway engineering, due to an insufficient level of civil engineering, the railway track constructed to suit to regional natural contours. Consequently, a number of tight curves with limited length of transition curves were inevitable due to geographical constraints.

To maintain high-speed train running on curved sections, it is essential to reduce traveling time for passengers. However, lateral force between wheel-sets and railway contact points tends to increase according to the train speed on curves and dimensions of curvature. In addition, many problems arose on the increased lateral force at curved sections such as derailments, deteriorations of railway track or wear of wheels and railway. For such reasons, it is an indispensable technology to improve curving performance of bogies for speed-up on narrow gauge lines in Japan.

All concerned parties have long studied on forced steering bogie system until today in Japan to improve the curving performance, however not into practical application because of possible risks when the steering controller fails. The safety for passengers is above all for railway operators to avoid possible dangers of derailments. Therefore, the authors have concentrated on a study regarding coexisting of fail-safe function and curving performance improvement by applying a control technology to mechanical steering bogie system.

Ordinary technology of steering bogie

Mechanical steering bogie system that is operated corresponding to the bogie angle has already been developed and practically applicable in Japan [1] (Type 283 limited express tilting diesel car). The system is termed as a bogie angle linked steering.

On curved section, car-body and bogie relatively displace in yawing direction because of the geometrical arrangement of railway track. The bogie angle linked steering system converts the bogie movement to the axle attack angle by rotation of steering levers and steering links. Figure 1 shows the operation of this system. The outer rail side wheelbases expanded by the steering links and inner rail sides contracted. Therefore, the attack angles of wheel-sets are set for the direction to the tangential line of circular curve.

These bogie angle linked steering trucks are very effective for reducing lateral force in circular curves, however, it was pointed out that the system admitted of improvement to a transition curve. It is a major cause that the steering link will not operate effectively because the curvature is gradually changed on a transition curve corresponds to the vehicle running position. In the entrance of the transition curve, bogie angle is not sufficient for steering angle of the leading
axle, so the lateral force will not reduce as assume. In addition, another side the exit of the
transition curve, steering angle of leading axle is too excessive for an ideal attack angle.
Therefore, lateral force of this bogie angle linked steering mechanism shows a tendency to
increase at the exit of the transition curve to compare with ordinary truck for such reasons.

Figure 1: Behavior of bogie angle linked steering system in circular curve.

Assist steering bogie system

Considering the above-mentioned circumstances, we studied on the system that generates
supplementary active steering force to the ordinary bogie angle linked steering mechanism for
reducing lateral force on transition curve sections. We have designated the system as an assist
steering bogie system. The assist steering system supports steering force on transition curves
by hydraulic actuators integrated in parallel with bogie angle linked steering mechanism.

The system is equipped with a position detecting device of vehicle running location and track
information database for assist steering control on transition curve positions without any
operational delay. We consider that the GPS and curvature collation techniques of the next-
generation tilt control system [2, 3] are adaptable to the assist control system for vehicle position
detecting device. The position detecting device has been proved that its positional error is or
less four meters and confirmed steady operation through running tests that was carried out
previously.

The assist steering system settles on a prospective appropriate steering pattern from track
information and the running speed, and controls the assist steering force. The reason that the
ordinary forced steering system is not currently in practical application is that the safety at
controller failure was unsecured. In the assist steering system, the function of a mechanical
bogie angle linked steering mechanism will work despite of the controller failure, therefore,
lateral force decrease on circular curve is to be able to expect. This feature is advantageous in
terms of fail-safe function compared to the ordinary forced steering system.

In addition to these failing mode, we have considered the situations that the failed controller
gives an instruction that moved opposite direction side to correct direction for radial steering.
Then the assist steering actuators are restricted its maximum steering force that will not lead to
fatal obstruction.

We examined two types of installation positions of assist actuators as arranged for the steering
beam and the axle box. Assist bogie steering actuator installed between cross beam of the
bogie frame and the steering beam. The positions where the actuator installed are as shown in
the left side bogie of Fig.2. Two actuators installed oppositely derive the steering force in
pushing and pulling direction. Hydraulic cylinders are applicable to assist actuators of this
system, and controlled by Direct Drive Volume Control unit with pressure control. Hydraulic
circuit of these actuators are switched to free when an assist steering force is not needed so as not to obstruct the motion of bogie angle linked steering since the assist steering system generates steering force only during running on a transition curve section.

Axle box assist actuators installed between the side beam of bogie frame and the axle box, then added the steering control force only in the pushing direction of outer side axle boxes. Namely, the assist actuators are product steering force only to expand outer rail side wheel-base. Actuator rod unconnected to axle box rigidly since the axle box moves in vertical and horizontal direction and there is insufficient space for universal joint. Positions where axle box assist actuator installed are as shown the right side bogie of Fig.2. These actuators are made free against to the external force when an assist steering force is unnecessary to avoid a disturbance of the bogie angle linked steering motion. This motivation complied with the same idea as the assist bogie steering system. Inner rail side actuators that were not needed to product steering force construct its rods.

These two assist steering constructions are the same methods in view of that either composition also controls the bogie angle to the appropriate value on transition curve.

![Figure 2: Composition of assist actuators.](image)

**Results of the running test**

We applied these assist steering system to the ordinary bogie angle linked steering truck, and carried out a test run in the loop test track at the premises of Railway Technical Research Institute. Figure 3 shows an external view of the test truck with assist steering actuators. The assist bogie steering actuator and axle box assist actuator are installed to the same bogie, and we carried out running tests that switched the steering method according to the testing condition.

We carried out test run at a speed of approximately 18(km/h) by normal operation for a locomotive train on test curve that has a radius of 100(m). Figure 4 shows the locomotive train and the car-body that has been adapted to the test truck with the assist steering bogie system.

In this examination, we used cumulative running distance by an axle-driven generator from absolute positional reference point through the running position detection for assist steering control will be applied to the system that the position detect technology as a subsystem of next-generation tilt control system in the future. We settled on the assist steering force pattern beforehand according to the curvature and controlled steering force as adjusted to the pattern. Force control pattern for assist steering was used the pattern that starts up the steering force from entrance part of transition curve and raise to the maximum value of bogie turning torque in lamp shape that was given beforehand.
Figure 3: External view of assist steering system test truck.

Figure 4: Locomotive train and car-body for running tests.

Figure 5 shows the result of test run with assist bogie steering, curvature, leading and second axle yawing angle, outer side lateral force, inner side lateral force and assist steering force displayed with the distance axis. Plotted assist steering force is converted into the turning torque around the bogie center. Yawing angle of the leading axle and the second axle is operated to a desirable attack angle direction for reducing the lateral force in the transition curve by assist steering control, though the behavior of these axles is almost the same in the circular curve to which the steering force has not been added. The bogie angle is also moved to increase its angle by the force that generated by assist steering control in the entrance of transition curve. There are peaks of lateral force in some places; these are influence of track irregularity.
The result of axle box assist steering is as shown in Fig. 6, the display items etc. are common with the assist bogie steering. The motion of wheel-sets and the tendency of observed lateral force were similar to the assist bogie steering. The wheel-sets movement and the bogie angle motion were operated as a normal and assumed though the steering torque was added to only outer side of the wheel-set at the transition curve section, by the function of bogie angle linked steering mechanism.

An average of outer lateral force at entrance transition curve is shown in Fig. 7. The obtained result has reduced to almost half by the assist steering control. Lateral force reduction effect of axle box assist steering seems to be greater than assist bogie steering in the view of converted steering force into turning torque around the bogie center. This reason originates in the difference of the transmission route of assist steering force. Axle box assist steering acts on directly to wheel-sets without mechanical links that for bogie angle linked steering system. These mechanical links that have some rubber bushes caused the reduction of assist steering effect. However, the assist bogie steering system is easy to bring together as for the composition of the steering actuator and hydraulic circuit.
Figure 6: Test result of axle box assist steering.

Figure 7: Average lateral force at entrance transition curve.

Conclusion
1) We composed two methods of the assist steering bogie systems (the assist bogie steering system and axle box assist steering system) that aimed to reduce the lateral force, and carried out test runs on the test track.
2) Either two methods are secured the function of mechanical bogie angle linked steering system in spite of controller failure.

3) Assist steering system is superior in a fail-safe function as compared to the ordinary forced steering bogie, since active actuators are composed in parallel to mechanical links and restricted its maximum steering force with pressure control.

4) These two assist steering system were proven its capability that reduce the lateral force of transition curve almost half respectively through running tests.

5) We are considering to research the effect of assist steering performance at high-speed running situations and an appropriate steering pattern, and to work on practical application in the future.

References

