A Method to Apply Friction Modifier in Railway System

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Controlling the friction between wheel and rail is direct and very effective measures to improve the curving performances of bogie trucks, because the curving performances of bogie truck depend much on friction characteristics. Authors have proposed a method, “friction control”(1), which utilizes friction modifier (KELTRACKTM HPF(2)) with onboard spraying system. With the method, not only friction coefficient, but also friction characteristics are able to be controlled as expected. In this paper, results of fundamental experiments are reported which play an important role to realize the new method.

Key Words: Friction, Lubrication, Rolling, Railway, Friction Modifier, Creep

1. Introduction

In Japan, because of the social structure that depends greatly on railway, railway network is very developed in urban area. It means couple of lines exists in almost the same route. And as the result, transportation with railway in urban area is very convenient for the customer, but the train operation companies of the lines must compete in shortening of running time and transportation fare. On the point of the shortening time, compatibility between high-speed stability and curving performance is the severe task ahead of urban railway that has high-speed section in suburbs and so many tight curves in urban area.

Speed up in curves causes many problems such as increasing lateral force acting between wheel and rail which involves the danger of derailment, occurrence of squeal noise and progress of rail/wheel wear or corrugation on the top of rail. Most of the train operation companies have taken a measure that applying grease on the gage corner of high rail in order to prevent the wear of rail/wheel or loud flange noise, and on the top of the low rail for the purpose of decreasing the lateral force or preventing the occurrence of corrugation. Although lubrication between wheel and rail is a traditional method to resolve these problems, it has a restriction of place to apply. For example, in the case that lubricant is applied to a track just before the station, it contains a fear of skid that makes a flat on the contact face of the wheel and gives severe damage to the rail.

In this study, authors have proposed a method “friction control” between wheel and rail with friction modifier to improve curving performances in tight curve. Friction modifier can maintain appropriate friction coefficient between wheel and rail, and has positive characteristics on creep force against creepage as shown in Fig. 1. Although there have been various proposals to improve steering ability without lack of high-speed stability, friction control with friction modifier is very advantageous because most of them has difficulty in application to the existing railway system, i.e. they need major modify of cars or system.

To realize the concept of friction control, authors selected a system with onboard type device of train, in which liquid type friction modifier is sprayed onto the top of high rail from the nozzle behind the last axle of train, and the following train receives the benefit of it (Fig. 2). Figure 3 shows the scene that commercial train equipped onboard friction control system running through a test curve section with spraying friction modifier.

The advantages of this onboard friction control system are as follows: the friction modifier can be supplied...
onto rail uniformly through the curve by control of its amount in proportional to the vehicle’s velocity, the train with friction control device can supply the friction modifier immediately to any curve of the service line where wheel/rail contact condition should be improved unexpectedly, and the supply of friction modifier or maintenance of the device could be performed in equipped place of a car depot.

In this system, the balance between supply and consumption of friction modifier is very important. It is natural that to obtain the enough effect of friction modifier, some amount of friction modifier is required. But if the amount of supply is excessive or consumption between a spray to next is too little, the friction modifier cannot play an expected role because coefficient of friction is too low and positive characteristics is spoiled. To recognize the phenomenon, authors carried out some experiments with two-roller-rig testing machine regarding the balance between supply and consumption of friction modifier. In this report, phenomenon observed in experiments with 1/10-scaled model vehicle and two-roller-rig testing machine are introduced.

2. 1/10-Scaled Model Vehicle Tests

2.1 1/10-scaled experimental equipment

In order to evaluate the effect of the method authors proposed, running test was performed on experimental equipment as shown in Figs. 4 and 5. This equipment was manufactured with scaling down the actual railway system for 1/10 size and has a tight curve (3.3 m radius). Model vehicle imitates a one-bogie model without any motive power itself, i.e., the vehicle run through the curve by the force of inertia. Some sensors are put on the vehicle and rails so that various dynamical properties can be measured when the train passes there.

2.2 Result of the tests

Authors carried out series of running tests with the experimental equipment. Before the test 21st and 51st, friction modifier was applied to the top of low rail through the curve. As the effect, the car behavior had changed drastically as shown in Fig. 6 to Fig. 10.

Figure 6 shows the changes of $Q/P$ (lateral force divided by wheel load) at inside wheel of leading axle through the series of tests measured by strain-gage put on the rails. Traditionally, $Q/P$ at the inside wheel shows the friction coefficient supposedly, because flange of inside
wheel doesn’t contact with rail surface. With this result, $Q/P$, i.e. friction coefficient, was obviously decreased just after the friction modifier had been sprayed. But as the tests going on after the 21st test, $Q/P$ had been increased gradually over the level of DRY condition, and with the effect of the spray before the 51st test, the $Q/P$ was decreased again. This result points out the importance of the timing to spray in order to obtain the effect of friction modifier effectively.

Figure 7 shows the relationship between $Q/P$ at inside wheel and lateral force which is dominated flange contact force. With the effect of decrease of friction coefficient, lateral force occurred at outside wheel of leading axle was reduced drastically.

Figures 8 and 9 shows the change of displacement and attack angle of each axle. With the effect of friction modifier, lateral displacement of trailing axle was decreased as shown in Fig. 8. And as the effect, attack angle of leading axle was increased as shown in Fig. 9. This means that friction control effect not only on lateral force but also on posture of bogie. It was supposed that friction control changed the balance of moment.

Figure 10 shows the relationship between rotations of each axle and $Q/P$ at inside wheel. This is very curious.
phenomenon that friction control enlarges the differences of rotations between leading axle and trailing axle. This result indicates the possibility that differences of rotations could be a parameter of the friction control.

### 3. Fundamental Test

Experiments with 1/10-scaled model vehicle impressed authors that the balance between supply and consumption of friction modifier is very important. If the timing to spray friction modifier is inappropriate, friction control doesn’t work well as described in section 2.2. Authors carried out fundamental tests focused on the balance between supply and consumption of friction modifier with two-roller-rig testing machine.

#### 3.1 Two-roller-rig testing machine

The two-roller-rig testing machine (shown in Fig. 11) was developed to evaluate the creep characteristics under various contact conditions between wheel and rail, such as dry, wet and lubricated by conventional grease. Especially, the creep force characteristics of friction modifier applied to the contact region were investigated.

The testing machine can produce small slip accurately between two rollers, and measure the creep force generated by the slip. The diameters of both two rollers are 172 mm. Profile of wheel-roller is cylindrical and that of rail-roller has 100 mm convex single arc. These profiles of two rollers are designed considering the contact face ellipse and the contact pressure to model the actual wheel/rail contact.

The procedure to analyze the relationship between creep force and slip-rate was as follows: First, two rollers are driven with given rolling speed and contact pressure. Then, controlling the differential gear mechanically produces required slip. As the result, the torque force of the rail-wheel can be measured in real time, and creep curves, as shown in Fig. 1, are acquired with these measured data.

#### 3.2 Test procedure

To evaluate the creep force characteristics of friction modifier, the following test procedures were conducted: 1) The surface of each rollers are ground by sandpaper. 2) Two rollers are rotated with a certain creep rate without friction modifier until the coefficient of traction becomes approximately constant that means the conditions of two rollers surface becomes stable. 3) Friction modifier is applied on the surface of the rail-roller to evaluate creep force characteristics.

The spray nozzle, which was used in tests with commercial train in practical, was used to spray friction modifier to rail roller as a mist. The relative position between rail roller and spray nozzle was as shown in Fig. 12, and principal parameters to spray are described in Table 2.

#### 3.3 The amount of friction modifier to be sprayed

In order to examine the adequate amount of friction modifier to be sprayed, authors carried out fundamental tests to evaluate the friction characteristics in case of 0.2, 0.4 and 1.0 sec spraying time. Other parameters in the tests are as follows: test time for contact rolling was 40 sec, contact force was 500 N and slip rate was 0.5% constant. Results of the tests are shown in Fig. 13.

In this figure, the timing of spraying friction modifier is shown by ↓ symbol, and it is clear that the traction coefficient is drastically decreased by the timing shown by the symbol. Although, the friction modifier in contact re-

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**Table 2 Parameters to spray friction modifier**

<table>
<thead>
<tr>
<th>Friction Modifier</th>
<th>KELTRACK™ HPF SPRAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Pressure</td>
<td>200 [kPa]</td>
</tr>
<tr>
<td>Height of Nozzle</td>
<td>0.4 [m]</td>
</tr>
<tr>
<td>Spray Time</td>
<td>0.2, 0.4, 1.0 [sec]</td>
</tr>
<tr>
<td>Diameter of Rail / Wheel Roller</td>
<td>0.172 [m]</td>
</tr>
<tr>
<td>Radius of the Top of the Rail Roller</td>
<td>0.1 [m]</td>
</tr>
<tr>
<td>Rolling Velocity of Rail Wheel</td>
<td>300 [rpm]</td>
</tr>
</tbody>
</table>
Fig. 13 Dependency on the amount of friction modifier

Fig. 14 Creep characteristics after the tests

Fig. 15 Effect duration of friction modifier

The dependency on the amount of friction modifier was consumed very fast with the contact rolling of 40 sec after the first spray that could be distinguished by the rate of traction coefficient, a tendency is investigated that the range of traction coefficient in time transition is getting smaller with the effect of spraying friction modifier repeatedly at regular intervals. And the traction coefficient just after spraying friction modifier, which is shown as “A value” in this figure, is converge to the value that depend on the spraying time. The point of these phenomena, the value of convergence is affected by the amount of friction modifier rest in the rail roller. That is to say, if the amount of friction modifier is too much, the friction modifier exist in contact region by one shot spray cannot be consumed completely within the time of contact rolling; as a result, it is supposed that the cycle of supply and consumption cannot be balanced, or conditions of two rollers’ surface is changed by the too much amount of friction modifier. At least, in order to obtain the effect of friction modifier stably, the balance of supply and consumption is very important; especially “A value” which affect on the convergent value of traction coefficient depends on the amount of supply. With this regard, in the case that friction modifier is applied to an actual railway system; the amount of friction modifier to be sprayed must be decided with consideration of the condition of curve (e.g. radius of the curvature).

Just after the tests described above, authors carried out tests in which slip rate is changed 0% to 2.0% continuously after the spray of friction modifier. The test results are shown in Fig. 14 which shows creep characteristics of each condition. With the results, there is no difference between 0.4 sec spray and 1.0 sec spray. That is to say, creep characteristics of these conditions are realized that of friction modifier. But the test result of 0.2 sec spray shows the intermediate characteristics between dry condition and friction modifier. It is very curious fact that the creep characteristics with friction modifier can be controlled by the amount of spraying.

3.4 Effect duration of friction modifier

To evaluate the effect duration of friction modifier for different slip rate, long time tests are conducted. The test result is shown in Fig. 15. With the result, as the given slip rate becomes larger, the time to reach the peak value of coefficient of traction is shorten. It means that consumption (or required amount) of friction modifier depends on slip rate. That is to say, various elements related to slip rate, e.g. radius of curvature, velocity of the vehicle etc., must be considered to decide the amount of friction modifier to be sprayed.

3.5 Consumption of friction modifier

In the tests introduced in section 3.3, even in the condition of 0.2 sec spray, traction coefficient is still decreasing as shown in Fig. 13. In this section, authors carried out same tests but spraying time is 0.2 sec constant and rolling time with contact is changed by 40 sec, 60 sec and 80 sec. The transitions of traction coefficient obtained by these tests are shown in Fig. 16.

The test condition is as follows; 500 N contact force, 0.5% slip rate and 0.2 sec spraying time. By the results of Fig. 16, there is a tendency of saturation in transition of
traction coefficient in the cases of 40 sec and 60 sec running tests. But in the test of 80 sec test, there is no difference of transition from 1st test till 7th test. This is the result of friction modifier in contact region is completely consumed. It could be judged by the value of traction coefficient just before the each spray which is almost the value of dry condition.

After the tests of Fig. 16, authors carried out the same test to Fig. 14. Results of the tests are shown in Fig. 17. By the results of Figs. 16 and 17, the time of contact rolling, which means the number of trains (or wheels) passed the friction controlled section in actual railway system, affect on the saturated value of traction coefficient in one term from spray till next spray. That is to say, friction condition of certain curve in actual railway could be controlled to the one expected by handling the interval of spraying.

4. Conclusion

As the conclusion, the facts confirmed in the tests introduced in this paper are as follows;

(1) The effectiveness on curving performance of friction modifier sprayed to the top of low rail was confirmed by the tests with 1/10-scaled model vehicle tests.

(2) The phenomenon was recognized in model tests with 1/10-scaled model vehicle or two roller rig machine that the effects of friction modifier is decreased with the number of wheel/rail contacts observed in tests with commercial train.

(3) With the results of 1/10-scaled model vehicle tests, a possibility was indicated that differences of rotations could be a parameter of the friction control.

(4) With the results of tests with two-roller-rig machine, the creep characteristics with friction modifier can be controlled by the amount of spraying.

(5) With the results of tests with two-roller-rig machine, friction condition of certain curve in actual railway could be controlled to the one expected by handling the interval of spraying.

References
