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Estimation method of friction coefficient between flange and rail with monitoring bogie -Experimental results with roller-rig test-

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Abstract

The friction coefficient between wheels and rails plays important roll regarding severe wear, corrugation and probability of flange-climb derailment. Therefore, the value of the friction coefficient should be well monitored in service operation. In general, the value of the friction coefficient especially at flange of leading outside wheel is difficult to be measured during service operation. A new monitoring bogie which can measure lateral, vertical and tangential forces between wheels and rails has been developed. This paper presents the possibility of the estimation method using roller-rig at NTSEL. The main feature of the roller-rig is that it can emulate the curving behaviour of railway bogies. The friction coefficient of rollers can be changed by manually applying grease, and therefore the effect of onsite lubrication device can be fully reproduced. While constructing multibody-dynamics simulation model including half-vehicle model and roller-rig, the estimator of the friction coefficient can be built with collected data for building look-up tables. From the results of experiment on roller-rig, the fundamental effectiveness of the proposed estimation method of wheel/rail friction coefficient is demonstrated in this paper.

Keywords: bogie, condition monitoring, friction coefficient, curve, roller-rig.

1 Introduction

When railway vehicles pass through sharp curves, there are some problems such as noise, corrugation on railhead and wheel/rail severe wear. On top of that, flange-climb probability should be well evaluated for sharp curves in terms of lateral and vertical forces of leading wheelset of a bogie. As for these problems, the friction coefficient between wheels and rails play important roll. Therefore, the value of the friction coefficient should be well monitored in service operation. In general, the value of the friction coefficient especially at flange of leading outside wheel is difficult to be measured during service operation. A new monitoring bogie which can measure lateral, vertical and tangential forces between wheels and rails has been developed and been introduced in some commercial lines of Tokyo Metro Company [1,2]. Using the monitoring bogie, long term observation of derailment coefficients became possible. For further application of the monitoring bogie, the estimation of the friction coefficient between flange and rail was proposed using regression model [3]. This paper presents the possibility of the estimation method using roller-rig at NTSEL. The main feature of the roller-rig is that it can emulate the curving behaviour of railway bogies. The friction coefficient of rollers can be changed by manually applying grease, and therefore the effect of onsite lubrication device can be fully reproduced. While constructing multibody-dynamics simulation model including half-vehicle model and roller-rig, the estimator of the friction coefficient can be built with collected data for building look-up tables. From the results of experiment on roller-rig, the fundamental effectiveness of the proposed estimation method of wheel/rail friction coefficient is demonstrated in this paper.

2 Methods

Figure 1 shows an example of the monitoring bogie which has magneto strictive displacement sensors for vertical force P measurement, non-contact gap sensors for lateral force Q measurement, and strain gauges attached to mono-links for tangential force T measurement. Figure 2 shows definition of symbols: Q_{1out}/P_{1out} in leading-outside wheel is the derailment coefficient, Q_{1in}/P_{1in} in leading-inside wheel is called κ which is almost equivalent to the friction coefficient of the inside wheel when the vehicle runs on sharp curves. In this paper, T_1 indicates the average of the longitudinal tangential force of leading wheelset. T_{1out} and T_{1in} acting on inside and outside wheels respectively. The longitudinal force is closely related to the friction coefficient [4,5]. Hereafter, the value of friction coefficient of leading outside wheel's flange and rail is denoted as μ_{1out}. This is the value of the estimation which is normally difficult to be estimated. As shown in the figure 2, if the value of κ is almost constant, small value of μ_{1out} shows small T_1 whereas large μ_{1out} shows large T_1 since the value of T_1 closely related to the steering moment of the leading wheelset. In order to grasp relationships between the friction coefficient and contact forces, multi-body dynamics simulations are carried out and look-up tables for the estimation of μ_{1out} are established in our previous works [3]. Figure 3 shows the flow of the estimation using regression model with multiple look-up tables. It is possible to estimate the value of μ_{1out} from κ and T_1/P_{1in} and etc. which can be obtained by the monitoring bogie.

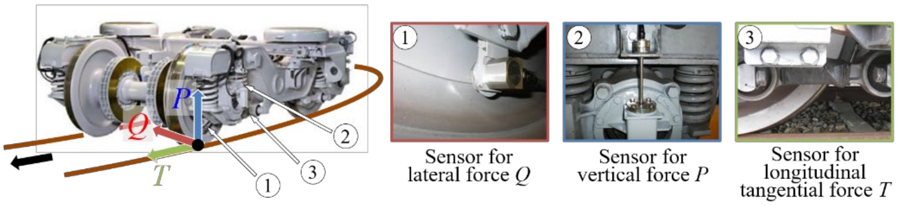


Figure 1 An example of monitoring bogie for measuring wheel/rail contact forces.

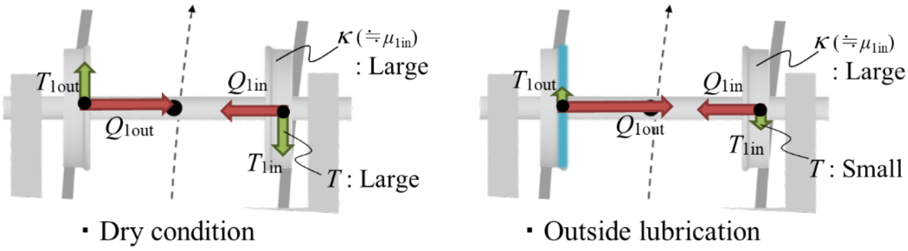


Figure 2 Relationship between friction coefficient of outside wheel and steering moment.

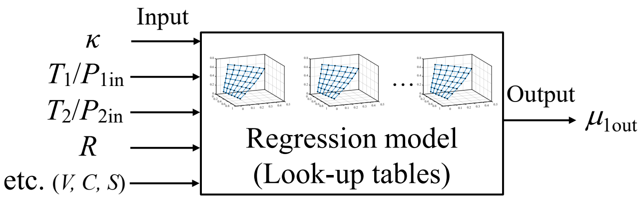
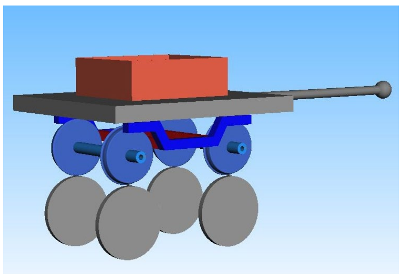


Figure 3 Flow of analysis for the friction coefficient estimation.

In this paper, above mentioned estimation method is evaluated with the experimental data using roller-rig. As shown in figure 4, half-vehicle body with one bogie is mounted on the roller-rig. The yaw angle and rotating velocity for each roller are adjusted to emulate curving conditions. The vehicle and roller-rig model are built with the MBD simulation software SIMPACK. After modelling of the bogie on roller-rig, repetitive simulations while changing friction coefficient of four wheels are conducted in order to build the estimator of μ_{1out}.

a) The roller-rig test stand



b) Simulation model

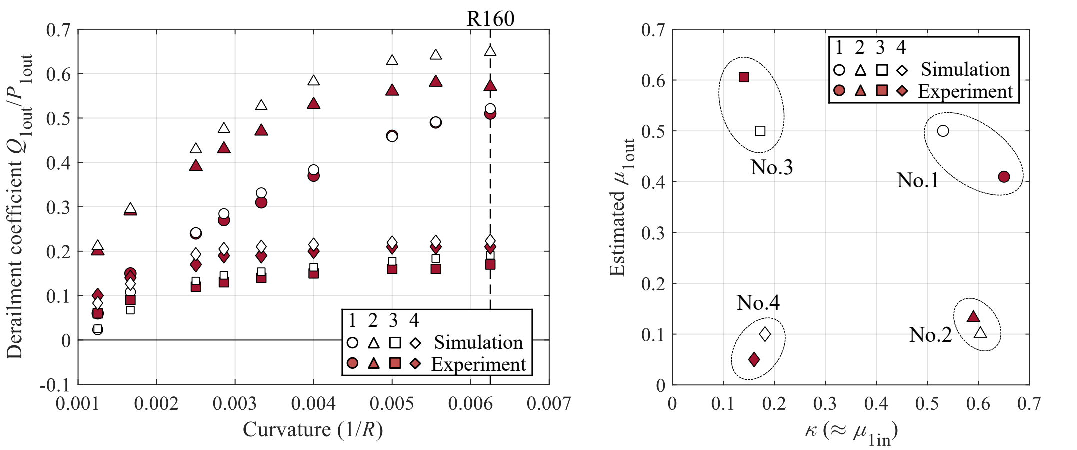
Figure 4 NTSEL roller-rig test stand and its simulation model.

3 Results

In the roller-rig experiment, the grease which is commonly used onsite lubrication device is applied on the roller emulating the effect of onsite lubrication of rails. The condition of the lubrication and assumed friction coefficients are shown in table 1. In these four conditions, condition No.1 means four wheels are running on dry surface of rails. Condition No.2 means only flange of the outer wheel of the leading wheelset is lubricated. Condition No.3 means inner rail is fully lubricated, whereas condition No.4 means inner rail and outer rail contacting to the flange of wheel are both lubricated. Figure 5(a) shows derailment coefficient Q_{1out}/P_{1out} under different circular curve conditions. In the results, when the friction coefficient of inner rail is high, the value of the derailment coefficient becomes large. It seems difficult to distinguish the condition No.1 from No.2, even though the condition No.2 is the case with the lubricated flange of the wheel. Figure 5(b) shows the results of μ_{1out} estimated by the regression model on sharp curve whose radius is 160m. As shown in the figure, condition No.1 and No.2 are clearly separated from each other. As shown in the figure, each conditions of lubrication can be allocated in different clusters meaning each condition can be identifiable with the monitoring bogie and the estimation method. From these experimental results, it can be said that the estimation of μ_{1out} with the monitoring bogie is feasible.

Table 1 Lubrication conditions and assumed value of friction coefficients.

Condition	Markers (simulation)	Markers (experiment)	Leading axle		Trailing axle	
			Outer rail	Inner rail	Outer rail	Inner rail
No.1	○	●	0.5	0.5	0.5	0.5
No.2	△	▲	0.1	0.5	0.5	0.5
No.3	□	■	0.5	0.1	0.5	0.1
No.4	◇	◆	0.1	0.1	0.5	0.1



a) Derailment coefficient

b) Estimated results of the friction coefficient

Figure 5 Experimental results and estimation results.

4 Conclusions and Contributions

This paper presents experimental results of the estimation of friction coefficient between flange of leading outside wheel and rail based on the regression model. Using roller-rig test equipment at NTSEL, it becomes possible to change friction coefficients of each wheels. Based on the experiment on roller-rig experiment, it proves that the high friction coefficient condition can be detected by the proposed method. Using the estimation method and the monitoring bogie running on service operation, high friction coefficient curve resulting severe wheel and rail wear can be detected. After the detection such curves, countermeasures of onsite lubrication can be considered as a typical method to prevent wheel flange and rail wear.

References

[1] A. Matsumoto et al.: Continuous observation of wheel/rail contact forces in curved track and theoretical considerations, Vehicle System Dynamics, Vol.50 (supplement), pp.349-364, 2012.

[2] A. Matsumoto et al.: A new measuring method of wheel-rail contact forces and related considerations, Wear, 265, pp.1518-1525, 2008.

[3] Y. Ichiyanagi et al.: Estimation of friction coefficient between outside wheel flange and rail considering influence of wheel/rail wear, IAVSD2019, No.185, August 2019.

[4] Y. Suda et al.: Feedback friction control between wheel and rail by detecting yaw moment of wheelset, Wear, 265, pp.1512-1517, 2008.

[5] Y. Michitsuji et al.: Analysis on running safety considering the difference of coefficients of friction in a railway bogie (Comparison between experiment and numerical simulation of the roller-rig test), Transactions of the JSME (in Japanese), Vol.83, No.856, 2017.