Analysis of the Wheel/rail Adhesion Characteristic using the Scaled Adhesion Tester

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Abstract: - Railway vehicles driven by wheels obtain force required to propulsion and braking by adhesion force between wheels and rails, this adhesion force is determined by multiplying adhesion coefficient of the friction surface by the applied axle load. In railway system, the adhesion coefficient is usually defined as the maximum traction/braking coefficient. To obtain the adhesion coefficient of the maximum traction/braking coefficient, it is necessary to determine the values primarily wheel load and the friction coefficient on contact point. Scaled adhesion test-bench is an experimental device that contacts mutually with disc rollers that are equivalent to wheels and rails of railway vehicles, and rotates mutually by friction by driving each motor connected with roller axes. In this paper, a scaled adhesion tester was developed in the twin disc type to verify the measuring performance of the tester. Test procedure is following; First, the wheel disc's (radius 0.15 [m]) initial speed is set in 500 [rpm] after applying the axle load of wheel/rail as 142.63 [kgf], then reduce the rail disc's speed from 500 [rpm] to 475 [rpm] (generates slip) for one minute while maintaining the speed of wheel disc. The adhesion coefficient was analyzed according to various speeds and the dry and wet condition of the contact area.

Key-Words: - Adhesion Coefficient, Slip, Slide, Skid, Axle Load, Railway Vehicle, Wheel/rail

1 Introduction

Railway vehicles driven by wheels obtain force required to propulsion and braking by adhesion force between wheels and rails, this adhesion force is determined by multiplying adhesion coefficient of the friction surface by the applied axle load. That is, adhesion coefficient is determined by environmental conditions (such as temperature, humidity and surface conditions) and slip velocity (defined as difference between the driving wheel speed and the vehicle speed) [1][2].

According to the slip velocity increase, adhesion coefficient increases to a certain area (the maximum value), it is well known to have a characteristic that after reaching the maximum point it decreases gradually.

In the operation of railway vehicles, slip and slide (or skid) phenomenon are inevitably occurs. This phenomenon in railway vehicles occurs when the maximum driving force applied between the wheel and rail more than the maximum adhesive force, or when the braking force applied less than the maximum adhesive force.
If these slip and slide phenomenon are excessively generated, these cause excessive wear of contact area or it is a factor for reducing tractive force and braking force due to destabilizing control characteristics of driving/braking system.

In addition, this phenomenon provides direct causes for vehicle accident, have an important influence upon system safety and economic efficiency. Therefore, many researchers have made great efforts to investigate these effects using the test equipment that can simulate characteristics of slip and skid and have been used to analyze the driving and braking characteristics of railway vehicles and adhesive characteristics in various environments [4]~[6].
In this paper, a scaled adhesion tester was developed to analyze adhesive characteristics of wheel and rail, and the adhesion database that is based on rotation with friction was established.

This paper is organized as the followings. Section 2 describes the design of the scaled adhesion tester for analyzing the wheel/rail contact. Section 3 deals with experimental results for measurement of adhesion coefficient. The main conclusions are then summarized in section 4.

2 Scaled Adhesion Tester

2.1 Structure of the Adhesion Tester

Scaled adhesion tester is an experimental device that contacts mutually with disc rollers that are equivalent to wheels and rails of railway vehicles, and rotates mutually by friction by driving each motor connected with roller axes.

Therefore, the adhesion tester was composed to a part of braking motor, a part of driving motor, a part of control of the axle load, and a part of control of attack angle, and it designed as the mainly purpose of the research about contact characteristics of wheel/rail and adhesive coefficient. Fig. 1 shows the developed adhesion tester.

Fig.1 Scaled adhesion tester for analyzing the adhesion characteristic

Rail shape and linear dimension of the tracks for test specimens are designed with the 300[mm] diameter size with reference 60 [kg] rail from KSR 9106 standard rail.

Fig.2 Specimens of wheel and rail for the scaled adhesion test-bench

Fig. 2 shows the shape of specimens of the scaled adhesion tester representing wheel and rail of the twin disc adhesion tester.

A part of braking motor and a part of braking motor perform the roles that make the rotation speed differences between wheel-rail by rotating disc to simulate the wheel and rail. A part of driving motor consists of a driving motor, a driving motor axis, torque sensor, an encoder and wheel specimens, and a part of braking motor consists of a braking motor, a braking motor axis, torque sensor, an encoder and rail specimens.

To generate contact force (i.e. axle load) between wheel and rail, a feedback control method which makes movement the entire braking motor axis to another axis in order to simulating the delivered load from wheels to rails is used. The part of control of the axle load consists of the two disc-weights, and it is designed to simulate transmission of the load from wheel to rail.

Table 1 Performance of experimental apparatus

Materials	Properties
Rotational speed (rpm)	0~1780
Torque (Nm)	0~196.1
Contact load (kgf)	0~500
Attack angle (degree)	-3~3
Slip ratio (%)	0~95

2.2 Test Procedure

The adhesion test was carried out under the conditions of different wheel/rail contacts, such as various speeds, axle loads, and contamination situation (oil, water, sand, etc.). In order to generate slip, we adapt a method which the rotation speed of the part of the braking motor decrease to zero while maintaining the initial rotation speed of the part of the driving motor constantly to generate speed difference. For example, firstly, the motor of the driving motor axis with a wheel disc rotates 1000 [r.p.m], and the motor of the braking motor axis with a rail disc rotates 1000 [r.p.m]. Then, decrease to the rail disc's speed of rotation to 30 [r.p.m] slowly with 200 [kgf] of axle load.

In this process, adhesion coefficient was measured by measuring the value of torque sensors that are installed in the axis of the driving motor and the axis of the braking motor.

Slip has a value between 0 and 1, 0 means same rotation rate, and 1 means fully sliding state when one axis of rotation speed becomes zero.

The torque of the wheel is not equal to the torque of the roller. The torque of the driving motor axis M_w is given by (1).

$$M_w = Fr_w \tag{1}$$

where F is the traction force (or adhesion force) and r_w is the radii of the wheel, respectively.

The adhesion coefficient μ is calculated by dividing the tangential force by the normal load as (2)

$$\mu = \frac{F}{N} = \frac{M_w}{Nr_w} \tag{2}$$

where N is axle load.

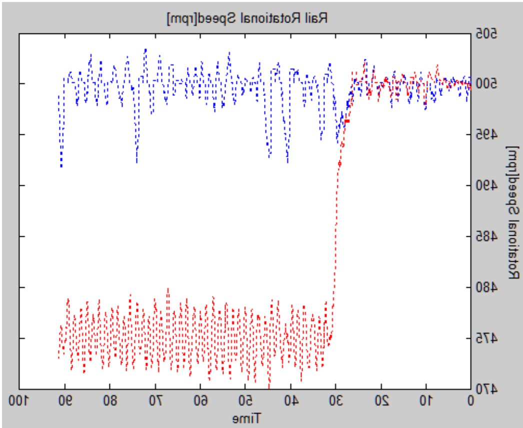
3 Experimental Results

Fig. 3 shows the velocity graphs measuring the encoders of the driving and braking motor axis, and rail the torque graphs colleting the torque sensors installed between motor and the wheel/rail specimens.

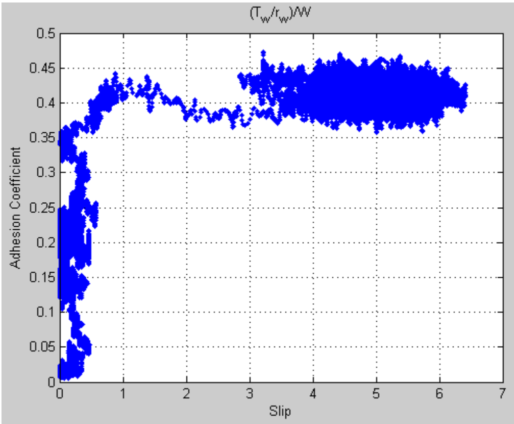
In this paper, test procedure is following; First, initial speed of the wheel disc with radius 0.15 [m] is set in 500 [rpm] applying the axle load of wheel/rail as 142.63 [kgf], then reduce the speed of the rail disc with radius 0.15 [m] from 500 [rpm] to 475 [rpm] for 30 seconds (i.e. generates slip) while maintaining the initial speed of wheel disc. The adhesion coefficient were collected and analyzed according to variation of the slip from 0 to 1.

Fig. 3 Experimental results: wheel and rail speed, torque, and axle load

Fig. 4-(a) and 5-(a) illustrate the rotational speed of wheel disc and rail disc, and Fig. 4-(b) and 5-(b) represents the calculated slip ratio by converting linear velocity vs. adhesion coefficient based on torque sensor values at the contact point in each dry and wet conditions. When the slip varies from 0[%] to 5[%], the characteristic of the adhesion coefficient are well expressed in Fig.4-(b) and 5-(b), respectively.



(a) rotational speed of wheel disc and rail disc



(b) adhesion coefficient

Fig. 4 Experimental results: rotational speed and adhesion coefficient in dry condition

Table II Data comparison of experimental results

Condition	Properties	1st	2nd
Dry	Mean values of wheel load (kgf)	137.867	137.855
	Mean values of slip ratio (%)	5.116	5.097
	Mean values of adhesion coefficient	0.412	0.417

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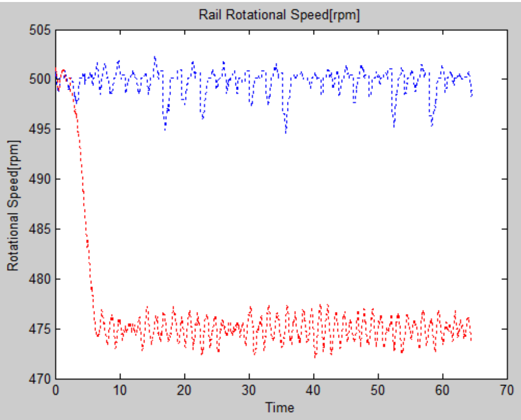
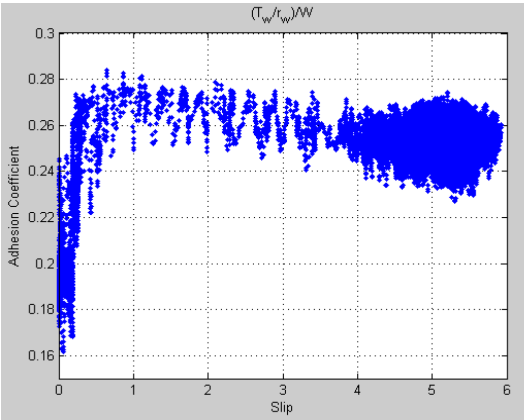
Wet	Mean values of wheel load (kgf)	137.317	137.12
	Mean values of slip ratio (%)	5.089	5.109
	Mean values of adhesion coefficient	0.255	0.221



(a) rotational speed of wheel disc and rail disc



(b) adhesion coefficient

Fig. 5 Experimental results: rotational speed and adhesion coefficient in the wet condition

Table II indicates the data comparison of the experimental results after the several adhesion tests (dry and wet condition).

4 Conclusion

In this paper, a scaled adhesion tester was developed in the twin disc type to verify the measuring performance of the tester. Test procedure is following; First, the wheel disc's (radius 0.15 [m]) initial speed is set in 500 [rpm] after applying the axle load of wheel/rail as 142.63 [kgf], then reduce the rail disc's speed from 500 [rpm] to 475 [rpm] (generates slip) for one minute while maintaining the speed of wheel disc. The adhesion coefficient was analyzed according to various speeds and the dry and wet condition of the contact area.

References:

[1] Simon Iwnicki (2006) Handbook of Railway Vehicle Dynamics (Eds), Taylor&Francis

[2] H. Harrision, T. McCanney, and J. Cotter (2002) Recent developments in coefficient of friction measurements at the rail/wheel interface, Wear 253, pp.114 ~ 123.

[3] H. Chena, M. Ishidaa, A. Namuraa, K-S Baekb, T. Nakaharac, B. Leband, M. Paud. (2011) Estimation of wheel/rail adhesion coefficient under wet condition with measured boundary friction coefficient and real contact area, Vol.271, Issues 1-2, pp. 32 ~ 39.

[4] Weihua Xhang, Jianzheng Chen, Xuejie Wu, and Xuesong Jin (2002) Wheel/rail adhesion and analysis by using full scale roller rig, Wear 253, pp.82 ~ 88.

[5] H. Chen, T. Ban, M. Ishida, M. Ishida, and T. Nakabara (2002) Adhesion between rail/wheel under water lubricated contact", Wear 253, pp.75 ~ 81.

[6] Kiyoshi Ohishi, Yasuaki Ogawa (2000) Adhesion Control for Electric Motor Coach Based on Force Control Using Distrubance Observer, AMC2000- NAGOYA, pp.323-328.

[7] Yosuke Takaoka, Atsuo Kawamura 92000) Disturbance Observer Based Adhesion Control for Sinkansen, AMC2000-NAGOYA, pp.169-174.

[8] Atsuo Kawamura, Keiichi Takeuchi, Takemasa Furuya (2000) Measurement of the Tractive Force and the New Adhesion Control by the Newly Developed Tractive Force Measurement Equipment, PCC-Osaka, pp.879-884.

[10] M-S Kim and N-P Kim (2012) Design of the Scaled Adhesion Tester for Analyzing the Adhesion Characteristic of Railway Vehicles, The 8th WSEAS International Conference on REMOTE SENSING (REMOTE '12), Prague, Czech Republic, September 24-26.

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