A Novel Slip Control Method Considering Axle-weight Transfer for Electric Locomotive

Proposal and Experimental Verification of Electrical Axle-weight Transfer Compensation

Michihiro Yamashita
Vehicle Control Technical Div.
Railway Technical Research Institute
Tokyo, JAPAN
docan@rtri.or.jp

Tadashi Soeda
Technical Development Dept.
Japan Freight Railway Company
Tokyo, JAPAN

***Abstract*— When a wheel slip occurs on a certain axle or when re-adhesion control is executed, the tractive force of the wheel-slip axle changes, which causes pitching of the bogie and the carbody. As a result, a change occurs in the weight acting on other axles in adhesion status, and wheel slips are likely to be induced.**

We developed a control system designed to reduce the induction of wheel slip considering axle-weight changes caused by other wheel slips. To verify the effectiveness of the control method, we conducted a water spring wheel-slip test using an EH200-type DC electric locomotive.

Keywords; electric locomotive, slip, re-adhesion control, axle-weight transfer, axle-weight transfer compensation

I. INTRODUCTION

When a wheel slip occurs on a certain axle or when re-adhesion control is executed, the tractive force of the wheel-slip axle changes and a rotating moment acts, which causes pitching of the bogie and the carbody that receives the tractive force. As a result, a change occurs in the weight acting on other axles in adhesion status, and wheel slips are likely to be induced. If re-adhesion control can be conducted in consideration of changes in the weight acting on other axles as a result of axle-weight transfer from the wheel-slip axle, the use of adhesive force can be optimized.

We developed a control system designed to reduce the induction of wheel slip in consideration of axle-weight changes caused by other wheel slips. Specifically, the torque of other axles is increased or decreased based on the acceleration of the wheel-slip axle to suppress the induction of wheel slip. The control method was applied to an EH200-type DC electric locomotive, constituting a re-adhesion control system that suppress the induction of wheel slip.

To verify the effectiveness of the control method, we conducted a water spring wheel-slip test. We obtained the results that the number of wheel slips decreases by about 20% on average, and that the average tractive effort increases by 4%.

II. INFLUENCE ON ADHESIVE FORCE BY TRACTIVE FORCE

A. *Axle-weight Transfer*

The axle-weight transfer consists of the sum of the rotating moment in the truck and the body. As for the tendency of the axle-weight transfer in powering, the value of axles-weight increases in the order of the 1st axle, the 2nd axle, the 3rd axle, and the 4th axle, in the case of a vehicle having 4 axles .

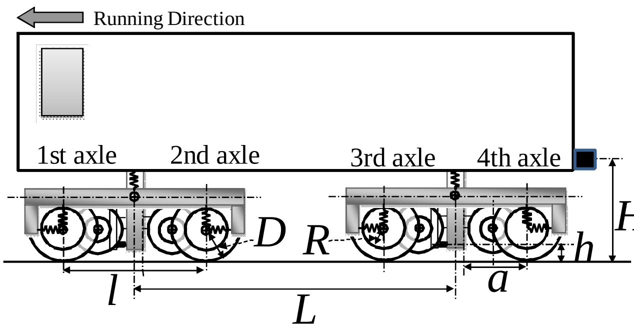

Fig. 1 A vehicle model of EH200-type DC

The values of axle-weight transfer of each axle in powering are as follows based on Fig. 1 [4],[5],[6].

$$\Delta W_1 = -\frac{R}{l}F_{e1} - \frac{R}{l}F_{e2} + \frac{\frac{D}{2}-h}{l}F_{l1} + \frac{\frac{D}{2}-h}{l}F_{l2} - \frac{H-h}{2L}(F_{l1}+F_{l2}+F_{l3}+F_{l4}) \quad [N] \tag{1}$$

$$\Delta W_2 = +\frac{R}{l}F_{e1} + \frac{R}{l}F_{e2} - \frac{\frac{D}{2}-h}{l}F_{l1} - \frac{\frac{D}{2}-h}{l}F_{l2} - \frac{H-h}{2L}(F_{l1}+F_{l2}+F_{l3}+F_{l4}) \quad [N] \tag{2}$$

$$\Delta W_3 = -\frac{R}{l}F_{e3} - \frac{R}{l}F_{e4} + \frac{\frac{D}{2}-h}{l}F_{l3} + \frac{\frac{D}{2}-h}{l}F_{l4} + \frac{H-h}{2L}(F_{l1}+F_{l2}+F_{l3}+F_{l4}) \quad [N] \tag{3}$$

$$\Delta W_4 = +\frac{R}{l}F_{e3} + \frac{R}{l}F_{e4} - \frac{\frac{D}{2}-h}{l}F_{l3} - \frac{\frac{D}{2}-h}{l}F_{l4} \qquad (4)$$

$$+\frac{H-h}{2L}(F_{l1}+F_{l2}+F_{l3}+F_{l4}) \qquad [N]$$

$$F_{en} = \tau_{en}(GD/2)$$

Where,

R:Gear radious [m]

L:Distance between axles in the bogie [m]

D:Wheel radious[m]

G:Gear ratio

L:Distance between centers of two bogies [m]

H:Height distance from top surface of rail to traction device [m]

H:Height distance from top surface of rail to coupler [m]

F_{en}:Tractive force of the n-th axle at wheel tread [N]

F_{ln}:Tractive force of the n-th axle [N]

W_0:Axle load (initial value) 164[kN]

ΔW_n:Changed part of the axle load of the n-th axle (It takes positive, when an axle load increases) [N]

τ_{en}:Motor torque of the n-th axle[Nm]

Fig.2 shows values of axle-weight transfer of each axle when adhesive forces of each axle are 55,000N. Axle-weight transfer is caused 13% at the maximum to initial value of the axle load. The ratio of an axle load to the adhesive force of each axle is shown in Fig. 3. This indicates that it becomes the tendency to slip if the ratio is small, and becomes the tendency to be hard to slip if a ratio is large. If the ratio of each axle differs, use of adhesive force cannot be optimized.

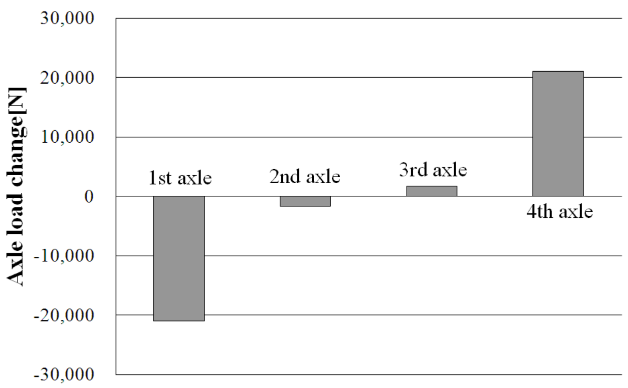

Fig. 2 Value of each axle-weight transfer

Adhesive force of each axle divided by axle load of each axle is as follows.

$$\mu_n = \frac{F_{ln}}{W_n+\Delta W_n} = \frac{F_{e_n}-m\alpha}{W_n+\Delta W_n} \qquad n=1\sim4 \qquad (5)$$

(n means a number of axle)

α:Vehicle acceleration [m/s/s]

m:Equivalent inertia weight of a driving device [kg]

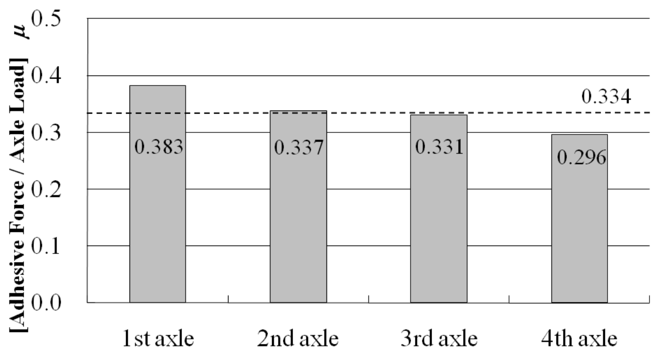

Fig. 3 [adhesive force/axle load] of each axle

B. Phenomenon of slip induction

When one axle of a bogie slips or the slip controller executes readhesion control, another axle sometimes also slips. The readhesion control probably triggers it, and the adhesion force cannot be used effectively. If this phenomenon occurs frequently, the traction force of the vehicle will be reduced greatly.

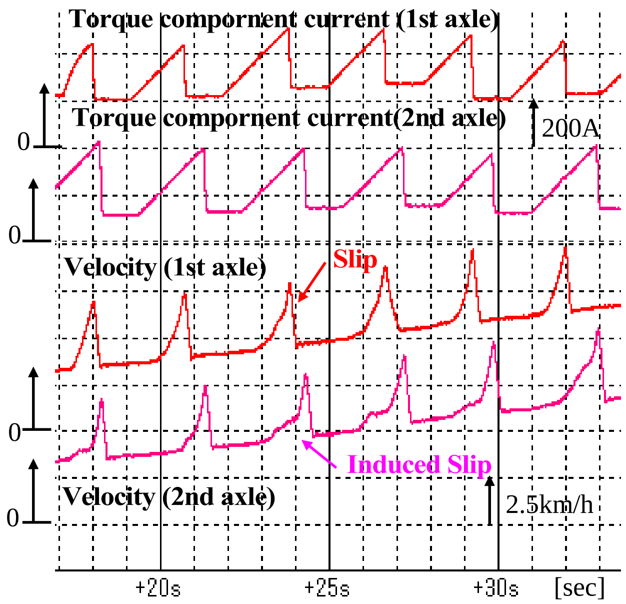

Fig. 4 Phenomenon of the wheel slip one after another

C. Simulation of Slip Induction [7]

We performed simulation to investigate the factor in slip induction from a viewpoint of axle-weight transfer.

When re-adhesion control executed, the tractive force of the wheel-slip axle changes and a rotating moment acts, which causes pitching of the bogie and the carbody that receives the tractive force. Consequently, a change occurs in the weight acting on other axles under adhesive status, and wheel slips are likely to be induced. Fig. 5 shows the simulation result of induction of wheel slip.

This result proved that axle load change in slipping causes slip induction.

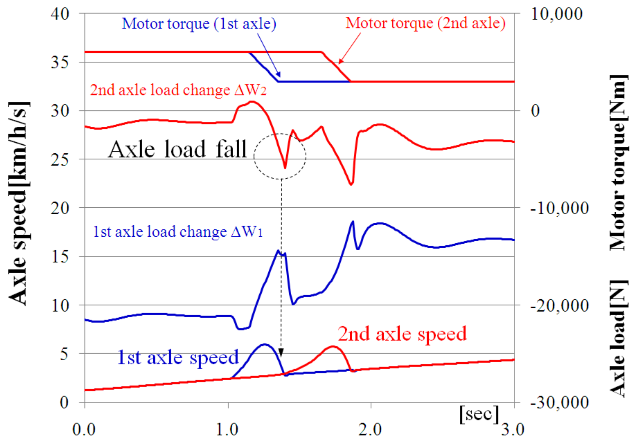

Fig. 5 The simulation result of the induction of wheel slip

III. Control System Designed to Reduce the Induction of Wheel Slip Considering Axle-Weight Transfer

We propose a anti-slip readhesion control method in consideration of axle-weight transfer. Features of the method are as follows.

1) The ratio of an axle load to the adhesive force of each axle is equal. Axle-weight transfer is compensated for by adjusting the motor torque of each axle.
(μ*-current reference computing unit)

2) The value of torque reduction by executing readhesion control is proportional to the acceleration of an slip axle. The torque of other axles is increased or decreased based on the acceleration of the wheel-slip axle to suppress the induction of wheel slip.
(Induced slip suppression controller)

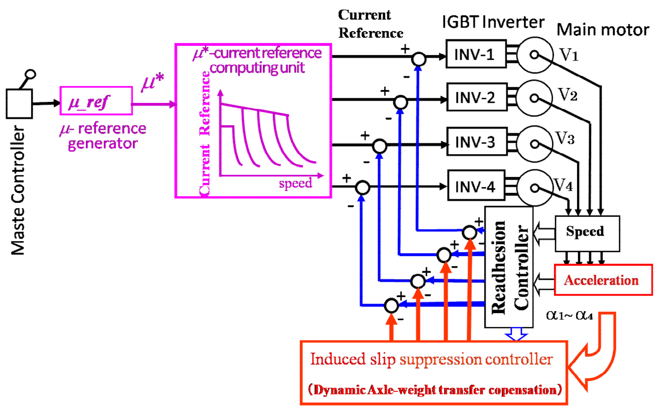

Fig. 6 Fabricated re-adhesion control system

IV. Running Test Results

The proposed method was applied to an EH200-type DC electric locomotive (Fig. 7), constituting a re-adhesion control system that suppress the induction of wheel slip.

To verify the effectiveness of the control method, we conducted a water spring wheel-slip test. We obtained the results that the number of wheel slips decreases by about 20% on average, and that the average tractive effort increases by 4% (Fig. 8).[8]


Fig. 7 Test vehicle (EH200-type DC)

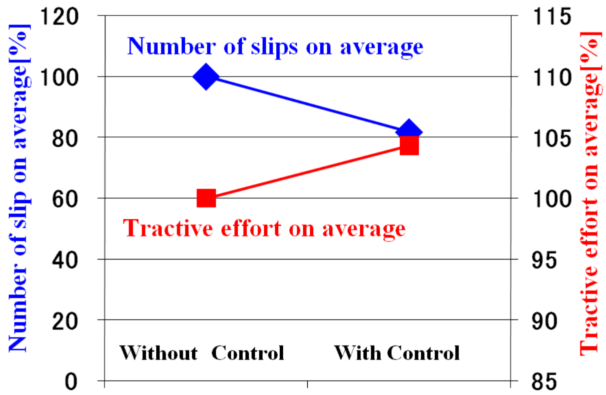

Fig. 8 A Result of the fabricated re-adhesion control

References

[1] Readhesion Control Technology, Technical Report, Vol. 673, Industry Applications, Institute of Electrical Engineers of Japan

[2] Watanabe, T., et al., Control Method to Suppress the Bogy Vibration In Slipping, National Convention1994, IEEJ, ,8-149, p.147

[3] Yasuoka, I., Consideration of Wheel Slip and Re-Adhesion Control for Individual Motor Control Locomotives, Trans. IA, IEEJ. Vol.128, No. 1, 2008.

[4] Hirotsu, T. et al., Adhesion Performance and Dynamic Phenomenon in Slipping of Electric Rolling Stock, Transaction of the Japan Society of Mechanical Engineers, Vol. 41, No.343(1975-3), p.784

[5] Minami, H. Self Excited Vibration of Driving Axle Shaft for Railway Vehicle (A Theoritical Study on Influence of Truck Vibration), Transaction of the Japan Society of Mechanical Engineers, Series C, Vol. 64, No.622(1998-6), pp.46-53

[6] Fukusaki,N. et al., Electric Railcar and Electric Locomotive, Iwanami Shoten,1964

[7] Yamashita, M., Development of a New Traction Method to Suppress the Wheel Slip One After Another, TE08-8, IA, IEEJ 2008

[8] Yamashita, M., et al., Results of Electric Locomotive Control Method to Suppress the Wheel Slip One After Another , National Convention, IEEJ, 2009,5-092, p.147