Application of Braking/Traction Control Systems to the Scaled Active Steering Testbed in the Railway Vehicle

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Abstract: - Active steering system of railway vehicles has proven its ability to bridge the gap between stability and curve friendliness. Generally scaled railway vehicles were developed to reproduce the fundamental dynamic behavior of the full size railway vehicle in laboratory conditions. This paper describes the design of the braking/traction control systems as a part of a 1/5 scaled railway vehicle for active steering testbed which is to alleviate wheel/rail contact forces and to decrease wheel/rail wear. This system consists of two steering actuators, a steering controller, and various sensor systems to detect lateral displacement, vibration, track curvature, and so on. The control strategy of the braking/traction is founded on the velocity difference of two axle speed of the driving bogie. Running test results of 1/5 scaled active steering vehicle on the curved track show that the proposed braking/traction control systems has good performance.

Key-Words: - Braking/Traction Control Systems, Active Steering, Railway Vehicle, Scaled Model, Testbed

1 Introduction

In urban transit systems, rail passenger vehicles are often required to negotiate tight curves. During curve negotiation, the wheelsets of conventional vehicles generally misalign radically with the track increasing wheel/rail contact forces and resulting in increased wheel and rail wear, outbreak of squeal noise, fuel consumption, and risk of derailment.

Braking/traction system of railway vehicles has a crucial role for the safety as well as riding quality of passengers. Its core technology for successful development of the brake/traction system is to design of ECU (Electric Control Unit) containing anti-skid control, brake blending control, load compensating control, adhesion control, and so on. For the design of the ECU system, we first consider the requirement of control system according to the purpose and mission of the brake system of railway vehicle.

Rail vehicles originally have self-steering ability on curved tracks, and this function is originated from the wheel conicity and rigid connection of two wheelsets by an axle. But this mechanism has two problems. One is a hunting phenomenon by a self-excited vibration of the wheelsets and the other is a curving ability by self-steering mechanism. To solve this problem and compromise between stability and curving performance, there are number of studies and developments such as passive, semi-active control, active control, independently-rotating wheelsets (IRW), and so on. To alleviate these problems, modified suspension system designs, application for alternate wheel profiles, active and semi-active steering techniques have been proposed. Active steering system has proven its ability to bridge the gap between stability and curve friendliness. In this paper, we design an experimental testbed with a vehicle and a track of 1/5 scale model and perform the curving performance verification of the proposed active steering control system[1]~[7].

Generally scaled railway vehicles were developed to reproduce the fundamental dynamic behavior of the full size railway vehicle in laboratory conditions using the model similarity method.

This paper contains the construction of the braking/traction control systems of railway vehicles for the performance analysis of adhesion force for anti-skid control using dSPACE. In this paper, 1/5 scaled railway vehicle composed of one driving bogie and one steering bogie is carried out for the development and testing of prototype bogie, and the investigation of fundamental railway vehicle running behavior [26]-[31].

This paper is organized as the followings. Section 2 describes an active steering control system for 1/5 scale model. Section 3 explains the construction of test-bed and section 4 contains the experiment results. The main conclusions are then summarized in section 4.

2 Testbed for the Active Steering Control Systems

Fig.1 shows a block diagram of the active steering control system using MATLAB/SIMULINK for the research vehicle.

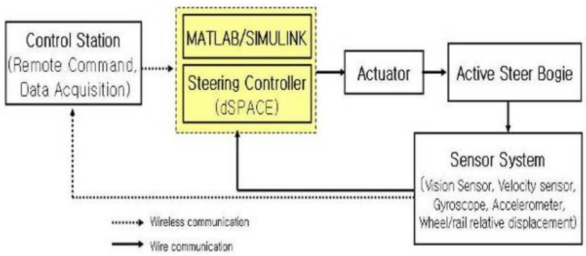
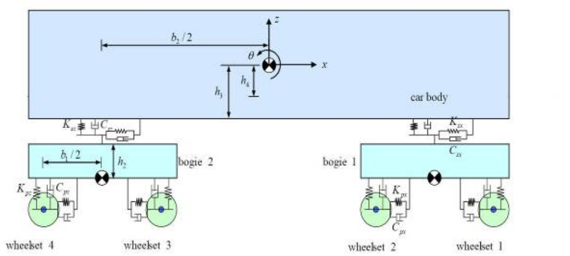


Fig.1 Block diagram of active steering control system



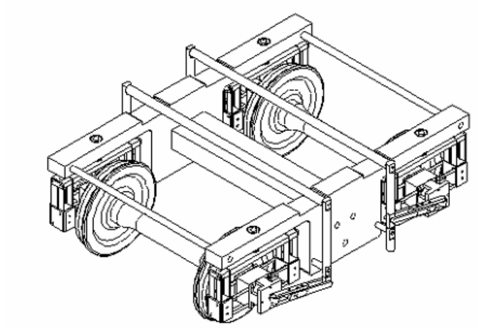
Symbol	Parameter	Values
m_s	wheelset mass(kg)	13.3
M_b	bogie mass(kg)	36.1
I_s	wheelset moment of inertia(kg m²)	0.26
I_b	bogie moment of inertia(kg m²)	1.61
r_0	wheel radius(m)	0.086
R_0	roller radius(m)	0.15
b	half of the primary spring(m)	0.197
c	half of wheel base(m)	0.21
K_x	longitudinal stiffness of spring(N/m)	2.99e4
K_y	lateral stiffness of spring(N/m)	7.14e4

Fig.2 Schematic diagram and its parameter values of a railway vehicle for active steering testbed

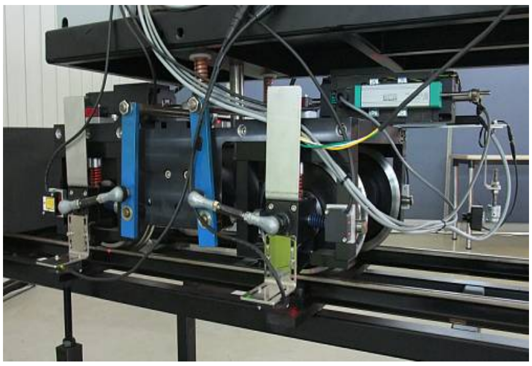
This strategy is founded on the coupling of the lateral and yawing motions of the wheelsets by using the laser sensor signals represented in the wheel/rail displacement. The relative movement between the wheels and the rail measured by laser sensors is considered as the system output. These laser sensors are installed at the both ends of the wheelset for sensing the distance of the laser sensor from axle box to rail head. And this measured value is compared with the reference input. The steering bogie of F-link type which consists of two steering actuators and several links is depicted in Fig.3.

2.1 Steering Bogie Module

The steering bogie of F-link type which consists of two steering actuators and several links is depicted in Fig.3. The basic concept of steering control strategy is to apply a controlled torque to the wheelset in the yaw direction. This can be achieved through longitudinal actuators as shown in Fig.3.



(a) Schematic views



(b) Actual object

Fig.3 Schematic views and its actual object of active steering bogie

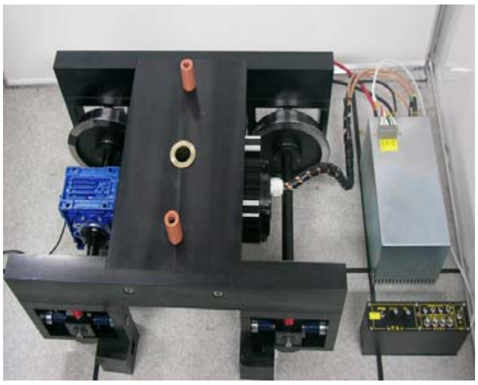
The actuator force is proportional to the input voltage values. That is, the actuator force increases from 0 [N] to 200 [N] approximately proportionally to the actuator command voltage (0 [V] to 4 [V]).

$$F_{act} = 50V_{con} \quad (1)$$

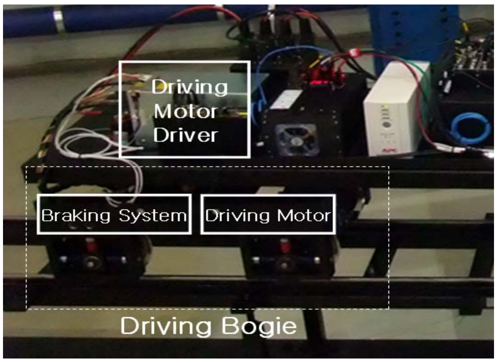
where F_{act} means a actuator force[N] and V_{con} represents a voltage command [V].

2.2 Driving Bogie Module

Driving bogie module consists of a BLDC motor of DC48V 39.1A, a 5:1 reduction gear, a driving motor driver, a braking system and connection panels. The rated output power of BLDC motor is 1.5KW and it rotates with 2000 [rpm] maximally.



(a) BLDC motor and motor driver in the bogie

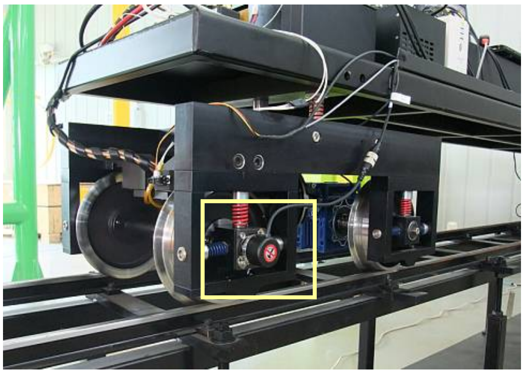


(b) Constitution of the driving bogie

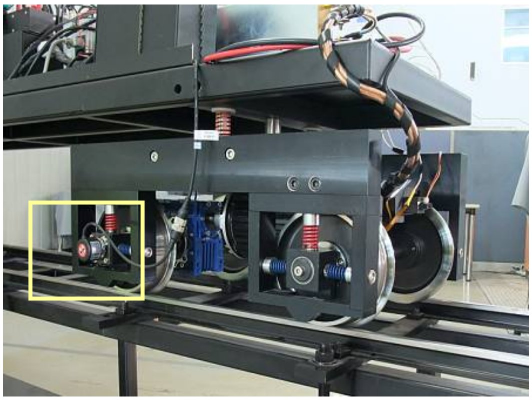
Fig.4 Driving bogie and its constitution

The motor driver is including the motor ON/OFF terminal, the velocity control terminal with 0V~5V and the direction selective terminal (0V and 5V).

Two encoder sensors which is mounted an end side of the two axles is used for calculating the vehicle speed, see Fig. 5.



(a) Encoder position of front wheelset



(b) Encoder position of trailing wheelset

Fig.5 An encoder sensor of the driving bogie

2.3 Brake System Module

Fig. 6 shows the free-body diagram of the wheel, in which W denote the weight acting by the axles, F_{ext} denotes the outside force acting by the axles, F_f denotes adhesive force between the wheel and the rail, N denotes vertical reaction force of the rail, and τ_{ext} is a braking total torque acting on wheel.

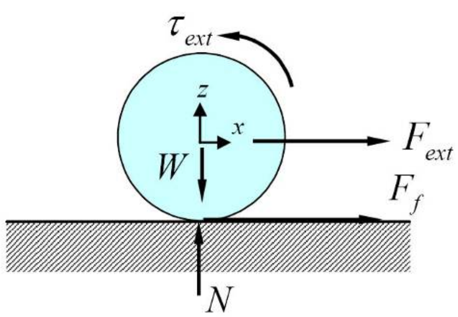


Fig.6 Free-body diagram of a rolling wheel on the rail

From Fig. 6, we may write the equations of motions as follows:

$$m_w \ddot{x} = F_{ext} + F_f \quad (2)$$

$$I_w \ddot{\theta} = \tau_{ext} + rF_f \quad (3)$$

where r is radius of wheel.

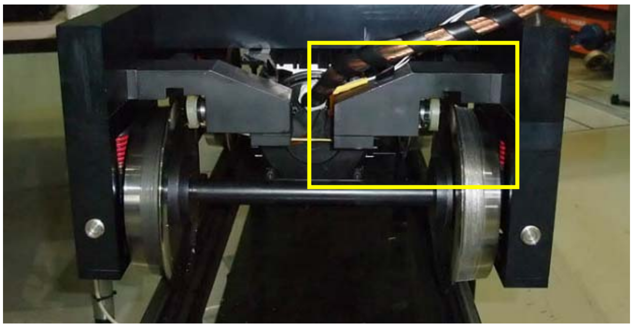
Multiplying equation (2) by r and using $\ddot{x} = -r\ddot{\theta}$, we get following equation of motions without sliding.

$$\left| \frac{m_w r \tau_{ext} + I_w F_{ext}}{m_w r^2 + I_w} \right| \le |\mu_s W| \quad (4)$$

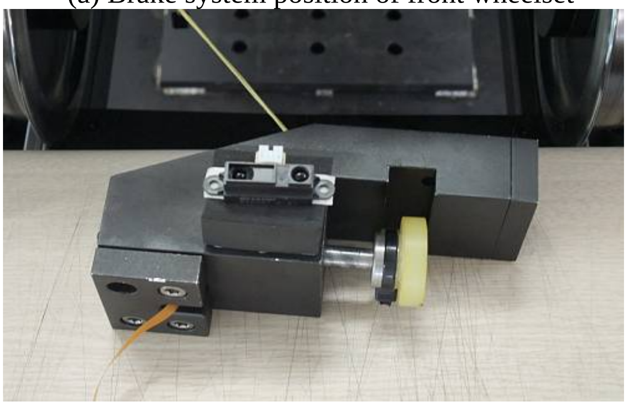
$$m_w \ddot{x}_w = \frac{-m_w r \tau_{ext} + m_w r^2 F_{ext}}{m_w r^2 + I_w} \quad (5)$$

$$I_w \ddot{\theta}_w = \frac{I_w \tau_{ext} - r I_w F_{ext}}{m_w r^2 + I_w} \quad (6)$$

where μ_s is a friction coefficient as a function of vehicle speed.



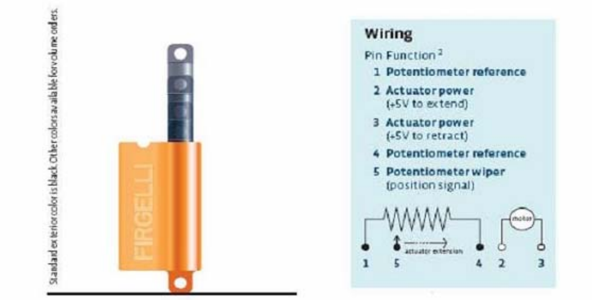
(a) Brake system position of front wheelset



(b) Brake system module

Fig.7 Brake system module for the anti-skid control

The experimental facility for the anti-skid control on the front bogie of the driving bogie is made of the linear motor (Fig. 8) and braking pad with the polyurethane materials as shown in Fig.7.



Specifications Product number	PQ-12f High Force PQ-12-20-63-A
Stroke	20mm
Rated force	15N at mm/s
Max Power Point	18N at 6mm/s
Current draw	250mA
input voltage	5 Vdc
Feedback potentiometer linearity	1%
Mass	75g
Operating Temperature	-10 to 50℃
Duty Cycle	20%
Actuator lifetime	1000,000 cycle

Fig.8 Figure and its specification linear motor for brake operation

The system identifies the wheel speed and vehicle speed as the number of turns by using encoder, and it identifies the braking force using a linear motor applied to the wheel as the input variable. The wheel rotates with an initial angular speed that corresponds to the vehicle speed before the brakes are applied. We used separate integrators to compute wheel angular speed and vehicle speed. We use two speeds to calculate slip

2.4 Curved Track Module

For running test, 30.11 [m] and R=20 curved track is used. This track has not a cant, and consists of the straight track (6.41m), curve track (14.30m) and straight line track (9.41m).

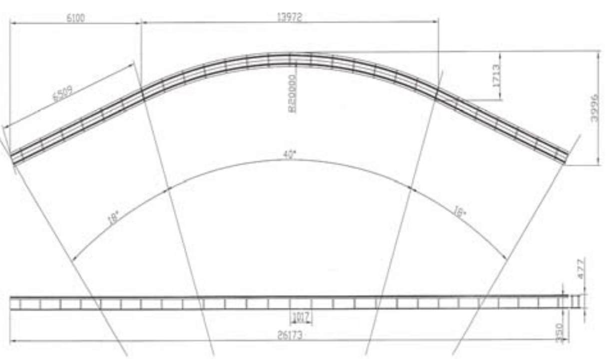


Fig.9 Drawings of the curved track of testbed for running test for active steering control system

Fig.10 The curved track of testbed

2.5 Active Steering Controller

For running test, 30.11 [m] and R=20 curved track is used. This track has not a cant, and consists of the straight track (6.41m), curve track (14.30m) and straight line track (9.41m).

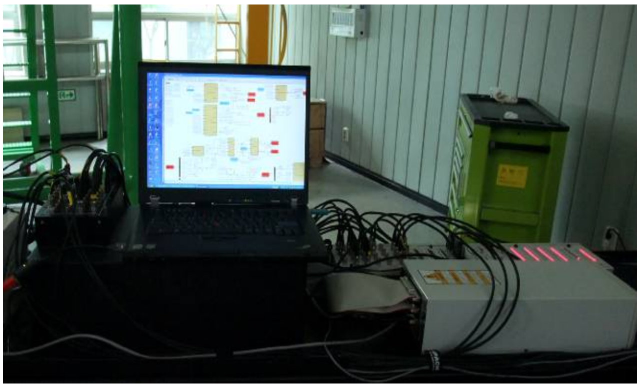


Fig.11 The active steering controller (DS1103 PPC Controller Board and desktop PC)

Table 1 Specification of the DS1103 PPC Controller Board

Processor	Type	PPC 750GX
	CPU Clock	1GHzCache
	Cache	32KB level 1 instruction and data cache, 1MB level 2
	Bus frequency	133MHz Memory
Memory	Local	32MB SDRAM
	Global	96MB SDRAM
ADC	Channels	16 multiplexed channels, 4 parallel channels
	Resolution	16-bitOutput range
	Input range	±10 [V]
	Over-voltage Protection	±15 [V]
DAC	Channels	8 channels
	Resolution	16-bit Output range
	Output range	±10 [V]
Digital I/O	Channels	32bit Parallel I/O
	Voltage Range	TTL I/O Level

The dSPACE system (DS1103 PPC Controller Board) is a powerful controller board for rapid control prototyping. This board is mounted in a dSPACE expansion box to test the active steering control functions in a scaled railway vehicle.

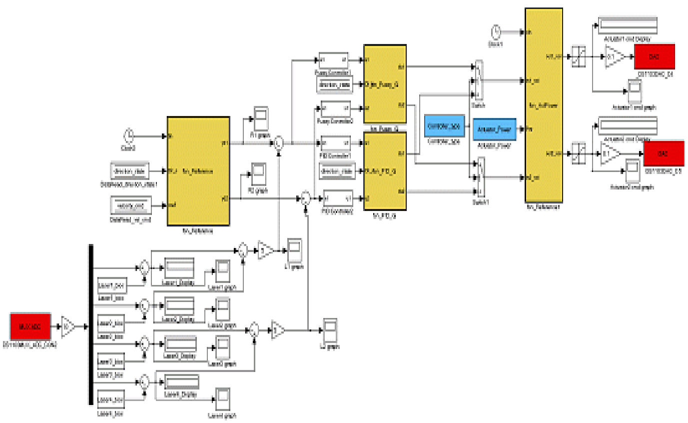


Fig.12 Realization of the active steering control module with MATLAB/SIMULINK)

Table 2 shows the signal list of the embedded system for the active steering controller which includes all the inputs and outputs that the embedded system has and describes their range, resolution, and so on.

Table 2 Signal list for the active steering controller

Name		Range [v]	Physical	Input/ Output
Driving Bogie Module	Veloci -ty	0 ~ 5	0 ~ 3.9 [m/s]	Input
	Directi on	0 , 5	0: Forward 5: Backward	Input
	Brak -ing	0 , 5	0: 0 [N] 5: 18 [n]	Input
Steering Bogie Module	Actuat -or	-3 ~ 3	-3: -150[N] 3: 150[N]	Input
Data Acquisiti -on Module	photoel ectric sensor	0 , 10	0 , 10	Output
	Laser displac ement sensor	-4 ~ 4	10 ± 4[cm]	Output
	Magnet -ic sensor	0 , 10	0 , 10	Output
	Gyrosc -ope sensor	0 ~ 5	-100 ~ 100 [deg/sec]	Output
	Acceler -ation Sensor	0 ~ 4	0 ~ 4 [g]	Output
	Wire -less Camera	-	320×240 [Pixel]	Output

3 Experiments of Test-bed

In the running test of the research vehicle, the testbed for the active steering control system can be tried and validated under real-time condition.

3.1 Experiment Environment

Fig. 13 shows the testbed for the braking/traction control systems as a part of the active steering control system. The measuring signals of the rotation signal of driving bogie axles are transmitted to the dSPACE controller via A/D converter, these signals are process based on the control algorithm, and finally the signals are retransmitted to the BLDC motor driver through D/A converter.

Fig.13 The 1/5 scaled testbed for the active steering control system

3.2 Experimental Results

The steering bogie of the vehicle model was driven by the driving bogie at 2 [m/s] speeds.

Fig.14 The experimental results: the relative displacement between wheel and rail, longitudinal and lateral movement of the first suspension

Fig. 14 and Fig. 15 show the relative displacement between wheel and rail, longitudinal and lateral movement of the first suspension, the experimental results of the moving distance, and the brake command signals, respectively.

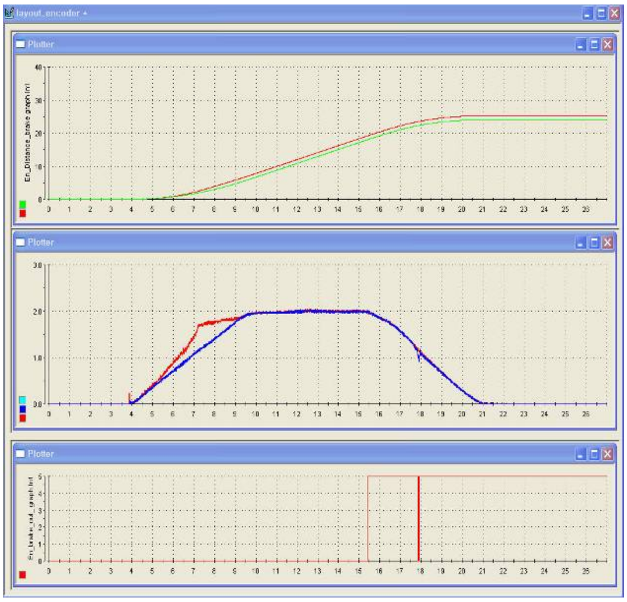


Fig.15 The experimental results: the moving distance, the vehicle speed, and the brake command signals

The experimental results of the moving distance of the driving axle and braking axle are shown in Fig. 16, respectively. The moving distance of the driving axle is longer than that of braking axle because of slip phenomenon of the force of traction.

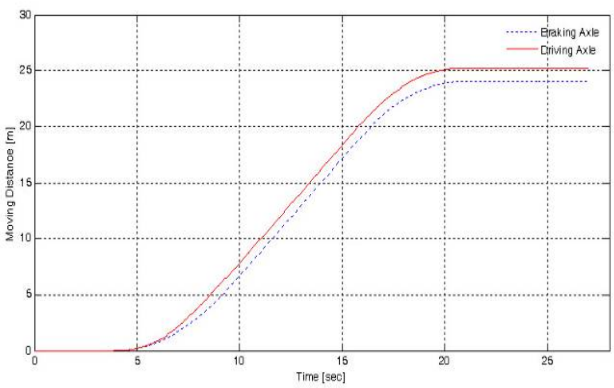


Fig.16 The experimental results: the moving distance of the driving axle and braking axle

Fig. 17 shows experimental results of the braking/traction control systems through comparison of the moving velocity of the driving axle and braking axle, and enlargement to analyze the performance of the anti-skid control unit when it applied the brake command to the wheel-disk. The measuring signals of the rotation signal of driving bogie axles are transmitted to the dSPACE controller via A/D converter, these signals are process based on the control algorithm, and finally the signals are retransmitted to the BLDC motor driver through D/A converter.

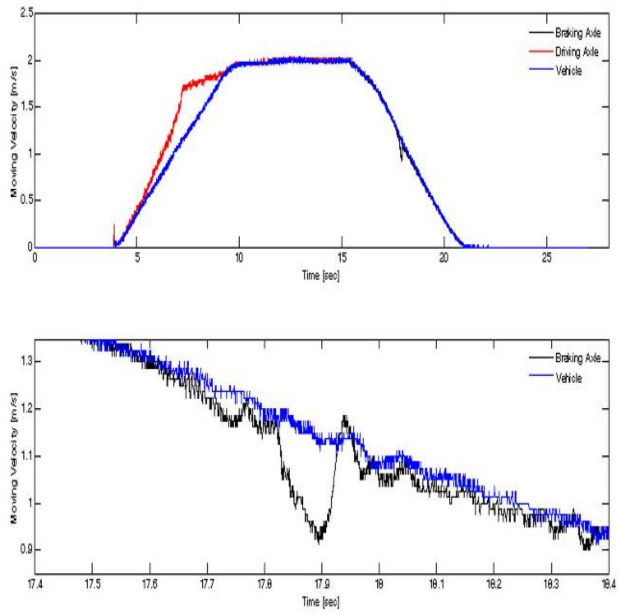


Fig.17 The experimental results: the moving velocity of the driving axle and braking axle, and enlargement to analyze the performance of the anti-skid control unit

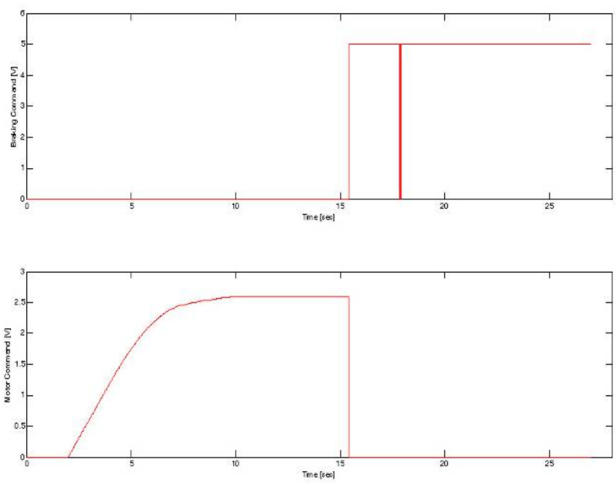


Fig.18 The experimental results: the brake command signals [v] and the driving motor command signals [v]

The experimental results of the brake command signals and the driving motor command signals are shown in Fig. 18, respectively. Especially, the brake command signals is changed 5 [v] into 0[v] for a moment as detecting the difference between vehicle speed and rotational speed of braking axle. It is confirmed that the proposed braking/traction control method can be realized in the scaled testbed resulting in the effective anti-skid control.

4 Conclusion

Braking/traction system of railway vehicles has a crucial role for the safety as well as riding quality of passengers. Its core technology for successful development of the brake/traction system is to design of ECU (Electric Control Unit) containing anti-skid control, brake blending control, load compensating control, adhesion control, and so on.

Generally scaled railway vehicles were developed to reproduce the fundamental dynamic behavior of the full size railway vehicle in laboratory conditions. In this paper, 1/5 scaled railway vehicle is carried out for the development and testing of prototype bogie, and the investigation of fundamental railway vehicle running behavior.

In this paper, we present the design of the braking/traction control systems as a part of a 1/5 scaled railway vehicle. Control strategy to the adhesion/anti-skid control system based on two encoder sensor signals which is mounted an end side of the two axles. The dSPACE system is used for implementing the braking/traction control systems. The proposed testbed for the braking/traction control systems is tested in the 1/5 scale research vehicle and R=20 curved track, and we could verify the effectiveness and performance of the proposed system.

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