# Remote Sensing of the Lateral Force for the Scaled Active Steering Railway Vehicle

Min-Soo Kim. Hyun-Moo Hur, Joon-Hyuk Park, and Won-Hee You

***Abstract*—** This paper describes the performance measurement system of the active steering railway vehicle with the scaled test bed using the acquisition telemetry system about the wheel lateral force. Active steering system of railway vehicles has proven its ability to bridge the gap between stability and curve friendliness. This scaled test-bed system consists of two steering actuators, a steering controller, and various sensor systems to detect lateral displacement, vibration, track curvature, and sensor systems. To compare with the various control strategies, we installed the telemetry systems on the steering wheelsets to detect the wheel/rail lateral force. Running test results of 1/5 scaled active steering vehicle on the curved track show that the proposed measuring system has good performance.

***Keywords*—**Telemetry System, Lateral Force, Active Steering Controller, Railway Vehicle, Scaled Model.

## I. Introduction

STUDIES on the steering system of the railway vehicles are difficult field to solve in the process of the realization. Several studies have been made on applying the active controller to the steering mechanism in the late 1970s, main research was started in the mid 1990s. The environment-friendly vehicle dynamics techniques are likely to become part of the mainstream as a track friendly, the research of the railway vehicle is focusing on ECO4 which means Energy, Efficiency, Economy, and Ecology.

In urban transit systems, rail passenger vehicles are often required to construct 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. To alleviate these problems, modified suspension system designs, application for alternate wheel profiles, active and semi-active steering techniques have been proposed. Over the past few decades, a considerable number of studies have been conducted on the effects of the active steering system of railway vehicles. And the active steering system has proven its ability to bridge the gap between stability and curve friendliness [1]~[8].

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

In this paper, we designed a scaled test-bed which consists of a driving bogie, a steering bogie, and various sensor systems with a telemetry system for measuring the wheel lateral force, and tested the performance of the various active steering strategies on the a curved track.

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

## II. Active steering control systems

The control strategy for an active steering mechanism is divided into three categories. When the wheelsets of the vehicle moves a curved track and the pure rolling can lead when the tangential velocity of the outside wheel is faster than that of the inside wheel because of radius difference by the gauge which is defined as the distance between the inside track and the outside track. But the inner and outer side wheels have the same rotation speed because the wheelsets of the conventional railway vehicle is under constraint, consequently the pure rolling turns it into a possibility through the bigger radius of the outside wheel than that of the inside wheel. That is, in order to go on smoothly over curve section a difference of a radius of rotation takes place by moving the wheelsets in the right and left direction based on the wheel conicity.

The proposed active steering control system is constituted a steering controller module in charge of steering control algorithm as the core part including A/D and D/A input/output terminals, a control station module having function of remote command and data acquisition, actuator module for driving the steering bogie corresponding to the controller output signals, and various sensors system module.

The basic concept of steering control strategy is to apply a controlled torque to the wheelsets in the yaw direction. This can be achieved through longitudinal actuators as shown in Fig.2. This strategy is founded on the coupling of the lateral and yawing motions of the wheelsets by using the laser sensor

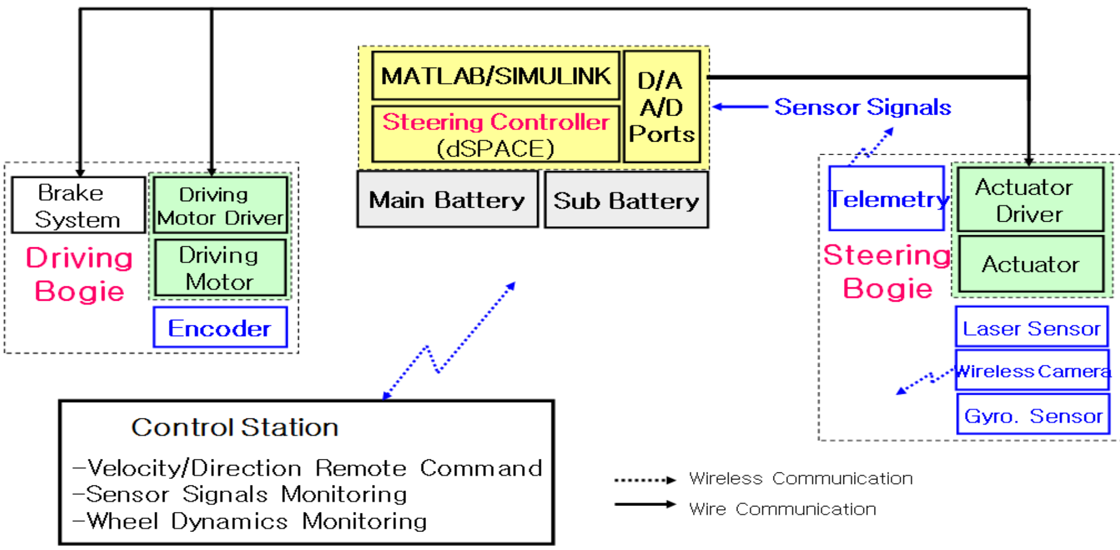



Fig. 1 block diagram of the proposed active steering control systems

signals represented in the wheel/rail displacement.

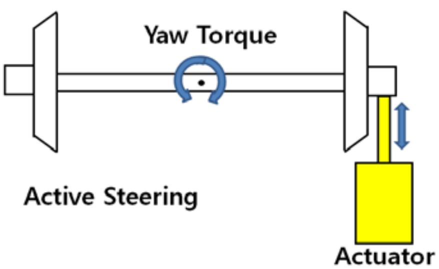



Fig. 2 active steering control strategy: longitudinal actuator method

As the feedback signals, the relative movement between the wheels and the rail are considered in the development of controllers using the measured distance of the laser sensor from axle box to rail head.

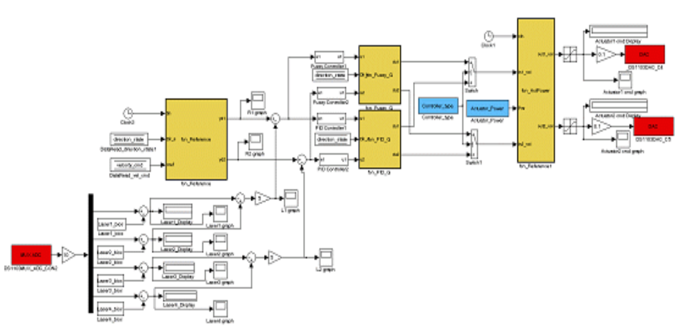


Fig.3 realization of the active steering control module with MATLAB/SIMULINK

Fig.3 shows a realization of the active steering control module with MATLAB/ SIMULINK for scale model.

## III. Construction of Test-Bed

Test-bed is carried out for the development and testing of active steering bogie. A block diagram of test-bed for the active steering control system is given in Fig.4.

Fig.4 research test-bed: the 1/5 scale active steering vehicle and the curved track

### A. *Curved Track*

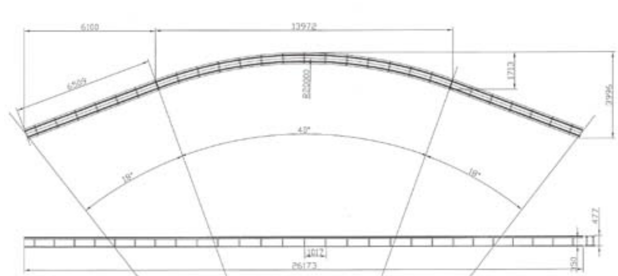


Fig.5 drawings of the curved track of test-bed for running test for active steering control system

For running test, 27.11 [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 (6.41m).

### *B. The Scaled Research Vehicle*

The scaled research vehicle is consisted of the diving bogie module, the steering bogie module, the controller module, the sensor system module, and car-body module.

First, driving bogie module consists of a BLDC motor of DC48V 39.1A, a 5:1 reduction gear, a driving motor driver, and a braking system. Two encoders which are mounted two wheel side of the driving motor axle are used for calculating the vehicle speed.

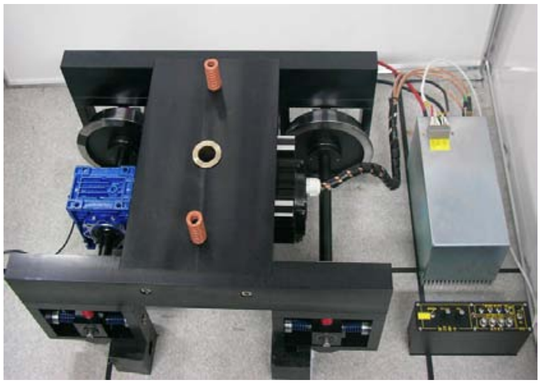


Fig.6 a driving motor and a motor driver

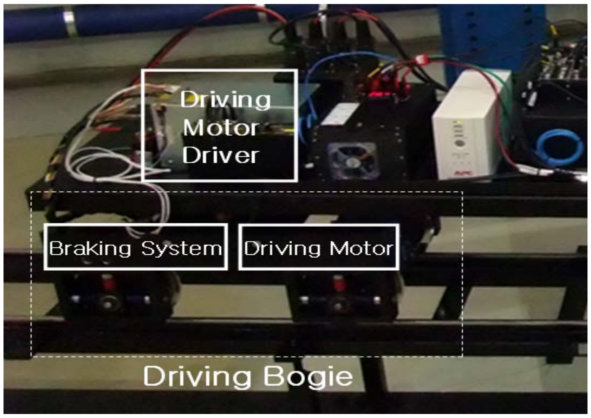



Fig.7 a driving bogie module

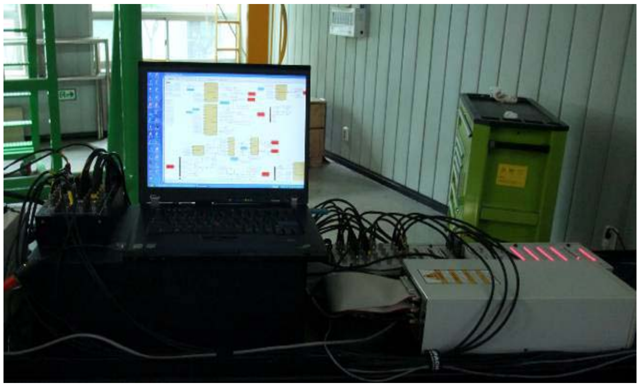


Fig.8 an active steering controller (DS1103 PPC Controller Board and desktop PC)

Second, the dSPACE system (DS1103 PPC Controller Board) is mounted in a dSPACE expansion box to control the active steering bogie in a scaled railway vehicle[29]. The research vehicle has an active steering controller that works in coordination with control signals of the steering controller to alleviate wheel/rail contact forces and to decrease wheel/rail wear. The role of the active steering control module is followings:

▪ Generation of steering command to actuator based on the control algorithm.

▪ A/D and D/A input/output terminals.

▪ MATLAB/SIMULINK and dSPACE as a rapid control prototyper.

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 |

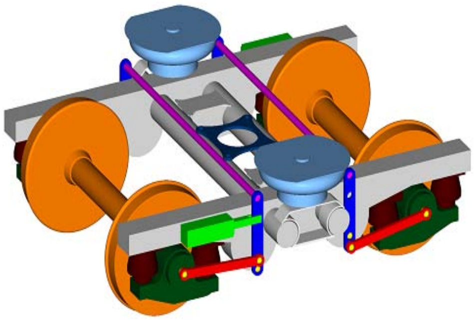


Fig.9 schematic views of the active steering bogie module

Third, the steering bogie of F-link type which consists of two steering actuators and several links is depicted in Fig.9. 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.10.

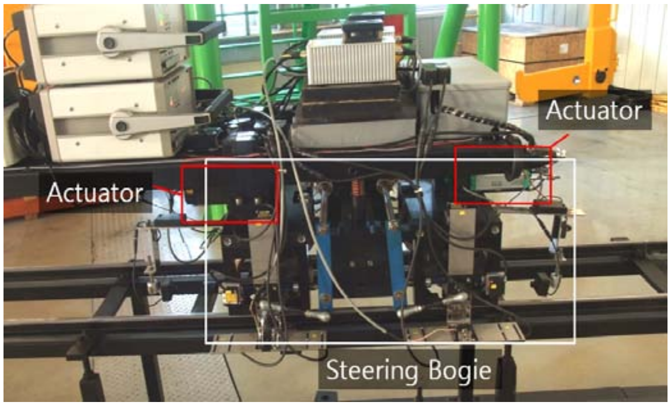



Fig.10 an active steering bogie module

The actuator force $F_{act}$ 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 ($V_{con}$, 0 [V] to 4 [V]).

$$F_{act} = 50V_{con} \tag{1}$$

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

Finally, the sensor systems of the test-bed for measuring the lateral displacement, wheel dynamics, and yaw angle mainly consist of four components:

- Wheel/rail relative displacement measurement using laser sensor
- Car-body vibration characteristic measurement using accelerometer sensor
- Yaw angle measurement of the steering bogie using gyro sensor
- Detection of the start/end point of the curve track using magnetic sensor
- Wheel/rail dynamics monitoring using wireless camera systems

### C. Measurement System of the Wheel Lateral Force

For active steering control of the testbed, it is vital to confirm the performance of the various steering strategy and control algorithms.

Fig. 12 shows the signals flow and bridge circuits for the measuring the later force and illustrates the bridge circuits for wheel load and lateral force measuring.

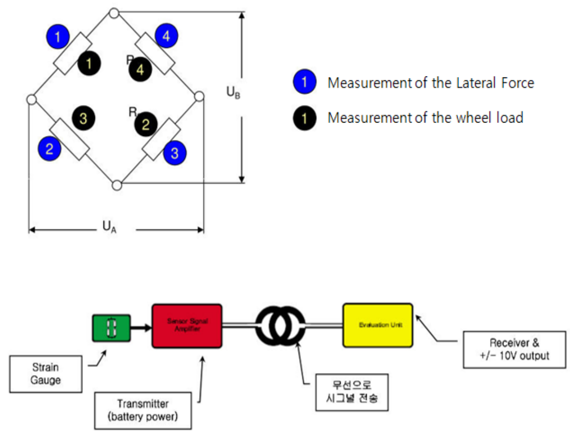



Fig.12 the signals flow and bridge circuits for the measuring the wheel load and the lateral force

Since wheel-rail forces occur in three dimensions, the key to using strain gauges is to install the gauges in specific configurations to measure axial loads as well as lateral forces independently.

First, to measure axial loads, a strain gauge is installed in the vertical position in the wheel inner surface. This gauge configuration eliminates the effects of any lateral bending that could reduce or exaggerate a strain reading taken on only one side of the wheel axial load.

Next, measuring lateral forces is more complicated than measuring vertical wheel loads. Lateral forces are applied by the head of the rail to the wheels. The installed strain gauge for measuring the lateral forces can be susceptible to the change of the axial loads. The generally accepted practice is to install gauges on the calibration equipment.

Fig. 11 the scaled vehicle with various sensor systems

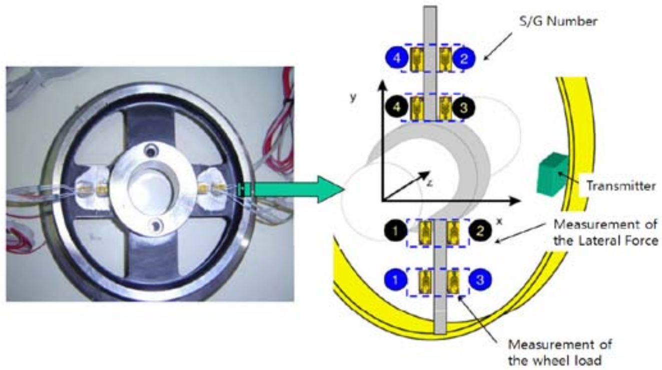



Fig. 13 lateral force measuring system and its prototype

Two separate gauges are installed, in the insides of the wheel, then wired together to complete the bridge circuit. This gauge configuration eliminates the effects of any lateral bending that could reduce or exaggerate a strain reading taken on only one side of the rail.

## IV. Experiments of Test-Bed

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

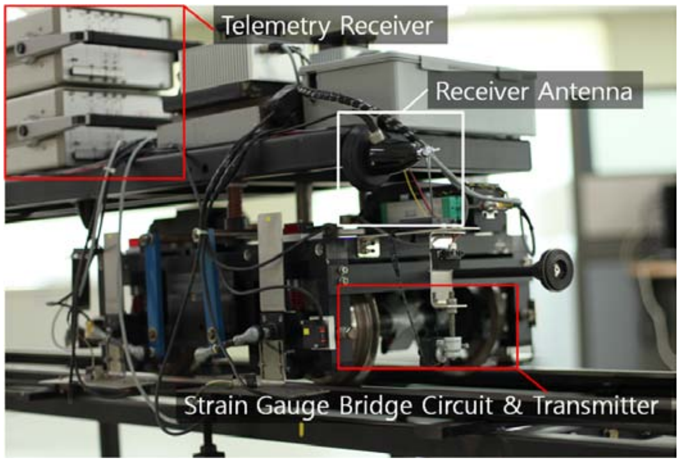



Fig. 14 lateral force measuring system

Fig. 14 shows the lateral force measuring system. This system consists of the main strain gauge bridge circuit and transmitter, signals receiver antenna, and telemetry receiver. Fig.15 illustrates an actual object of the wheel load and lateral force measuring systems.

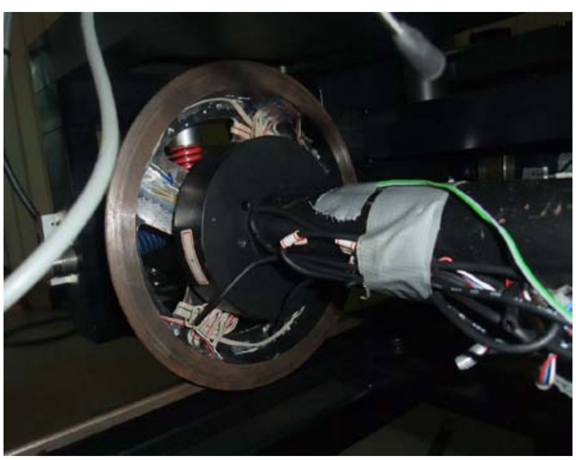


Fig. 15 a prototype of the lateral force measuring system which contains bridge circuits, signals transmitter, antenna, and battery

The experimental results of the vehicle speed and the moving distance are shown in Fig. 16.

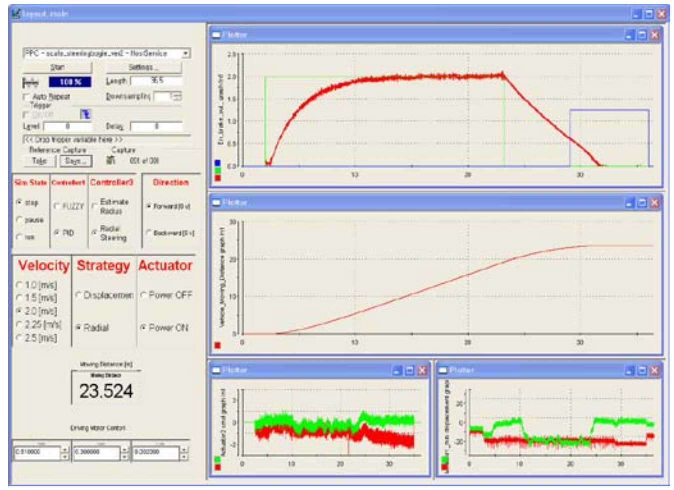



Fig. 16 the experimental results: the moving distance of the driving axle and braking axle

Fig. 17 shows experimental results of the lateral force data of the four wheels to analyze the performance of the steering bogie using the measuring system. The measuring signals of the telemetry are transmitted to the dSPACE DAQ via A/D converter.

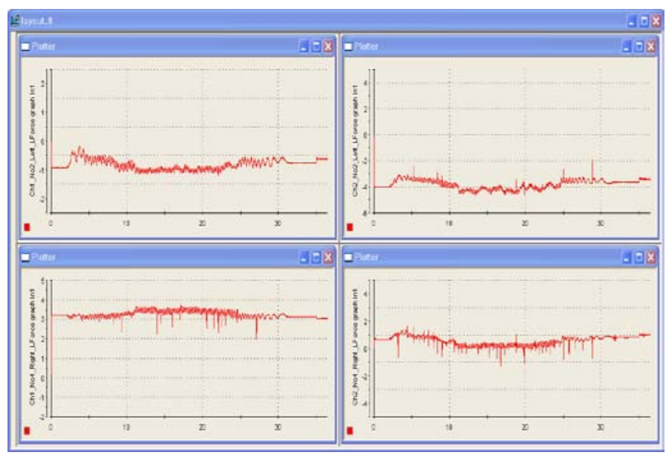
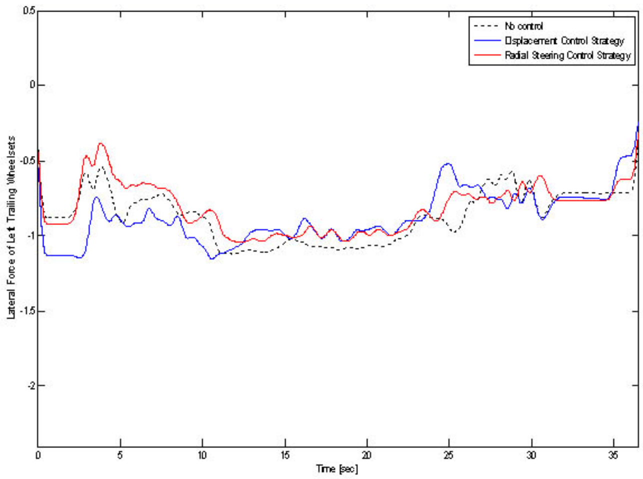
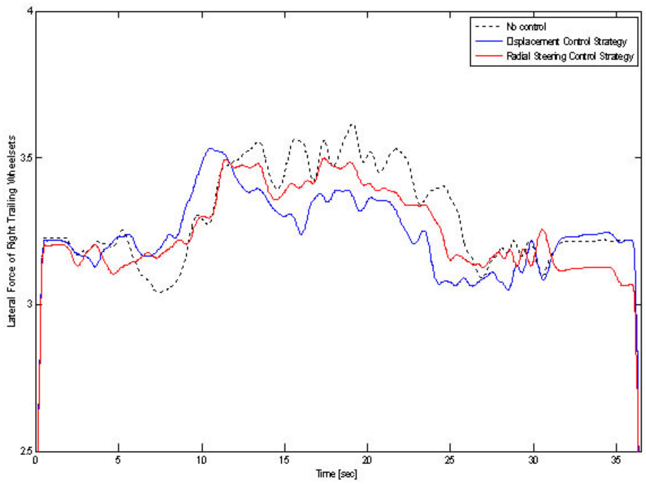


Fig. 17 the experimental results: the lateral force of the wheel using the measuring system in case of applying the displacement control strategy

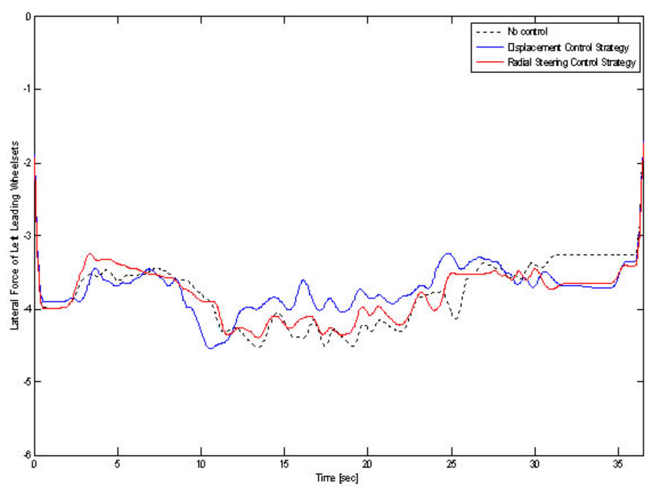
As a performance measure of the various control strategy, we make a comparative study of the lateral forces measured by the proposed telemetry system and collected data from the various control strategies which are passive systems (no control), a displacement control strategy, and a radial steering control strategy experimental results. Fig. 18 shows the experimental results of the lateral force measured by the telemetry system for comparing the active steering performance.



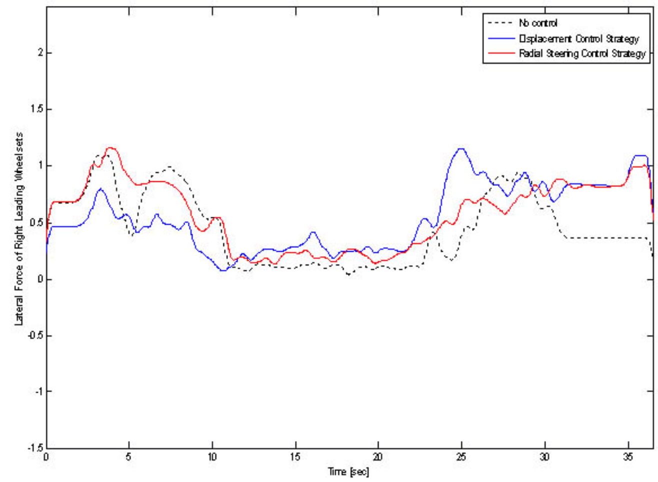

(a) in case of left trailing wheel




(b) in case of right trailing wheel




(c) in case of left leading wheel




(d) in case of right leading wheel

Fig. 18 the experimental results: measurement of the lateral force using the telemetry system

As a performance measure, the experimental results of the lateral force of the left trailing wheel for comparison with the various steering strategies (i.e. no control, displacement control strategy, radial steering control strategy) to produce the pure rolling are shown in Fig. 18-(a). A good steering strategy is one that provides low values (low lateral force) for running on the curved track. From the results above, it appears that 'Displacement Control Strategy' is the best of the three strategies.

## V. Conclusion

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

In this paper, we present the performance measurement system of the active steering railway vehicle on the scaled test bed to collect the wheel lateral force. Control strategy to the active steering system based on two axle vehicle attached to actuator of the yaw torque considering the riding quality has been applied. Experiment results show that the proposed measuring systems yields good performance through comparing with the passive system, the displacement control strategy, and the radial steering control strategy.

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**Min-Soo Kim** received the B.S., M.S., and Ph.D. degrees in electrical engineering from Soongsil University, Seoul, Korea in 1995, 1997, and 2003, respectively. From December 2005 he is a senior researcher at the Vehicle Dynamics & Propulsion Research Department at Korea Railroad Research Institute, 360-1 Woram-dong, Uiwang-si, Kyonggi-do, 437-757, Korea (corresponding author to provide phone: +82-31-460-5205; fax: +82-31-460-5299; e-mail: ms_kim@krri.re.kr). His research interests include control systems design of railway vehicle and dynamometer test for the railway brake components.

**Hyun-Moo Hur** received his B.S. and M.S. in Mechanical Engineering from Yonsei University, Korea, in 1988 and 1990 respectively. He then received his Ph.D. from Ajou University, Suwon, Korea in 2009. He is currently a principal researcher in Korea Railroad Research Institute, 360-1 Woram-dong, Uiwang-si, Kyonggi-do, 437-757, Korea (corresponding author to provide phone: +82-31-460-5245; fax: +82-31-460-5299; e-mail: hmhur@krri.re.kr). His research interests include railway vehicle dynamics and wheel/rail interface.

**Joon-Hyuk Park** received the B.S. degree from KAIST, Daejeon, Korea in 1998, and the M.S. and Ph.D. from Yonsei University, Seoul, Korea in 2000, 2005, respectively, all in Mechanical Engineering. He is a senior researcher at the Vehicle Dynamics & Propulsion Research Department in Korea Railroad Research Institute, 360-1 Woram-dong, Uiwang-si, Kyonggi-do, 437-757, Korea (corresponding author to provide phone: +82-31-460-5276; fax: +82-31-460-5299; e-mail: jhpark@krri.re.kr). His research interests are related to vehicle dynamics including the mechatronic railway vehicle and running test and evaluation technology for railway vehicles.

**Won-Hee You** received M.S. and Ph.D. from Yonsei University, Seoul, Korea in 1884, 1993, respectively, all in Mechanical Engineering. He is a chief researcher at the Vehicle Dynamics & Propulsion Research Department in Korea Railroad Research Institute, 360-1 Woram-dong, Uiwang-si, Kyonggi-do, 437-757, Korea (corresponding author to provide phone: +82-31-460-5670; fax: +82-31-460-5299; e-mail: whyou@krri.re.kr). His research interests are related to vehicle dynamics including the mechatr-onic railway vehicle and railway noise and vibration.