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The articulated vehicle dynamic analysis using the AWS (All Wheel Steering) ECU (Electronic Control Unit) test †

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Abstract

An AWS (all-wheel-steering) system is applied to the articulated vehicle to satisfy the required steering performance. AWS ECU (electronic control unit) controls the hydraulic actuator according to vehicle driving environment, such as driver steering angle, articulating angle, and vehicle velocity. In this paper, the test platform devloped for the AWS ECU black box test in an HIL(hardware in the loop) environment is explained. Using the developed test platform, the control algorithm of the AWS ECU can be evaluated under the virtual driving condition of the articulated vehicle. Also, the maneuver of the vehicle is investigated by using the developed AWS ECU test.

Keywords: All wheel steering; Articulated vehicle; Vehicle dynamics; ECU test

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1. Introduction

Most vehicles that consist of two axles have the 2WS system, and some vehicles have the 4WS system. In the 4WS system, the out-of-phase rear steer is used for improving the maneuverability at low-speed and the in-phase rear steer is used for improving cornering stability [1].

The AWS (all-wheel-steering) system, steered by three axles, is adopted in the articulated vehicle. Some buses and trucks, which have a long wheel-base, make use of the AWS system [2]. The AWS system has out-of-phase rear steer at low-speed and zero-phase rear steer at high-speed. The out-of-phase rear steer may cause decreasing of the turning radius and lane width of the articulated vehicle [3]. The articulated vehicle can be operated safely in the downtown area because of these effects of the AWS system.

An AWS system consists of ECU, hydraulic actuator, and steering linkages. AWS ECU controls the hydraulic cylinder according to the vehicle driving environment, such as driver steering angle, articulating angle, and vehicle velocity. The AWS system, which plays an important role in the maneuverability of the vehicle, is electronically controlled hydraulic equipment. The verification process of the device is required for safety of the vehicle.

In this paper, the test platform is developed for the AWS ECU black box test. The test platform is built on a HIL (hardware in the loop) environment. Using the developed test platform, the control algorithm of the AWS ECU can be evaluated under the virtual driving condition of the articulated vehicle. The control algorithm of the AWS ECU is applied to a multibody dynamics model of the vehicle, and the dynamic characteristics of the vehicle can be analyzed. Also, the reliability of the dynamic model has been verified by comparison with the track test results.

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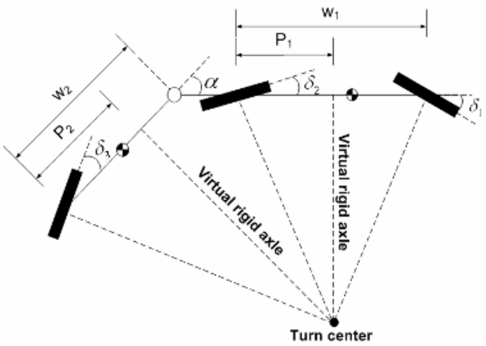

Fig. 1. Bicycle model of the articulated vehicle.

2. Concept of the aws system in the articulated vehicle

The steering angles of the second and third axles in the articulated vehicle are calculated from the bicycle model, as shown in Fig. 1. The steering angle of the second axle is determined by the front steering angle. And the steering angle of the third axle is calculated by the articulation angle. The direction between front steer and rear steer is the opposite; it is available at low-speed of the articulated vehicle. However, no rear steer may be safe at high-speed condition in order to avoid the instability of the articulated vehicle.

A center of turn must lie on the projection of the rear axle in case of FWS (front wheel steering) [4]. A center of turn is assumed to lie on the projection of the virtual rigid axle in case of AWS. The center of turn of the vehicle is the intersection of two virtual rigid axles. The steering angles of the second and third axle are established from Eqs. (1) and (2).

$$\delta_2 = -\tan^{-1}\left(\frac{P_1 \times \tan\delta_1}{w_1 - P_1}\right) \tag{1}$$

$$\delta_3 = -\tan^{-1}\left(\frac{P_2 \times \tan\alpha}{w_2 - P_2}\right) \tag{2}$$

3. AWS ECU test

3.1 Test platform setup

The hardware part of the test platform includes the ECUs, hydraulic systems, and steering linkages. The hydraulic system is assembled by tank, pump, motor, cylinder and control valve block. The steering linkage has a pitman arm and a tie rod.

By the use of the software part in the test platform, input signals are created for the AWS ECU. The input signals both of the vehicle and the test platform should be the same in order to operate the ECU. Some signals must be created by software part; such as CANopen, velocity, front steering angle, articulation angle and digital signals. Fig. 3 shows completed test platform of AWS ECU.

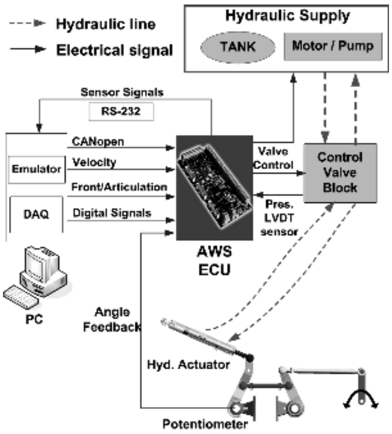

Fig. 2. AWS ECU test platform schematic.

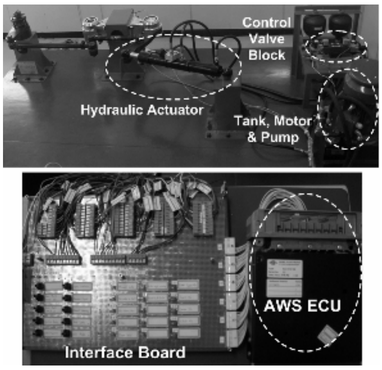

Fig. 3. AWS ECU test platform.

3.2 Test method for the AWS ECU

Driving condition of the articulated vehicle is considered in the AWS ECU test. It is regarded as the driving condition to put velocity and steering angle signal into the ECU. The vehicle velocity can be provided from zero to 80km/h in increments of 1km/h. As mentioned in the previous section, the ECU of the second axle should be considered the front steering angle signal. Also, the ECU of the third axle should be provided the articulation angle signal. The test can be done according to change in the velocity and front steering angle. The system response of the AWS ECU is the rear steering angle change depending on the movement of the hydraulic cylinder. The signal of the rear steering angle is feedback to the ECU as shown in Fig. 2.

3.3 Test result for the AWS ECU

The ECU of the second axle with various velocities is illustrated in Fig. 4. This Fig. shows that the steering angle of the second axle is moved according to the steering angle of the front axle and vehicle velocity. Where, the ideal value means the calculation result using Eq. (1). The test results are the steady state response of the AWS ECU, as shown in Fig. 4. In particular, the rear axle has no movement within ±5 degree of the front axle. That may be a dead-zone, which maintains zero degree for the second axle steering angle. The rear axle should be fixed within tolerance of the front steering angle. From Fig. 4 the steering angle of the second axle has about 47% of the steering angle of the first axle. The rear steering angle decreases from 30km/h to 45km/h, and then the rear axle has no steering angle above 45km/h.

4. Vehicle driving simulation

4.1 Multibody dynamics model

Using the test results of AWS ECUs, a multibody dynamics model of the articulated vehicle has been prepared to analyze the maneuverability of the vehicle. Front and rear suspensions of the vehicle are both double wishbone type, which is an independent suspension system. Suspension and steering parts are connected by joints and bushings. Since the vehicle dynamics model requires the test results of AWS ECUs, such as Fig. 4, a procedure as shown in Fig. 5 is used. From the test results, the desired angles, which are actual second and third steering angles, can be decided. A hydraulic cylinder stroke is calculated according to the rear steering angle, because the steering linkages are connected kinematically. The rear axles can be moved to the desired angles due to the movements of the hydraulic cylinder.

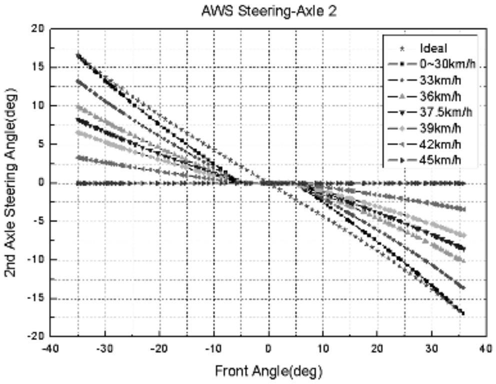

Fig. 4. Test result of the 2^{nd} axle AWS ECU.

4.2 Dynamics model verification

The reliability of the multibody dynamics model, which is applied to the AWS control algorithm, has been verified by comparison with the track test. The dynamic analysis has been done under the same driver input conditions, which consist of front steering angle and vehicle velocity.

Fig. 6 shows the steering angle of the second axle. As shown in the figure, the algorithm of AWS ECU of second axle is considered as reliable. Fig. 7 shows the articulation angle. As shown in the graph, the maximum error between test and simulation is 3%.
Fig. 8 shows the steering angle of third axle. The steering angle error of the third axle may be affected by the articulation angle error.

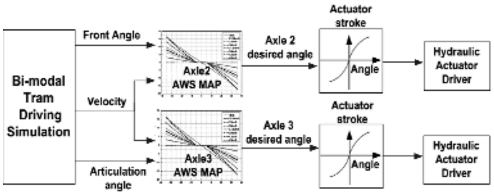

Fig. 5. AWS control procedure in dynamics model.

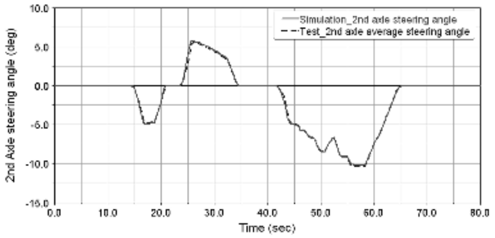

Fig. 6. 2^{nd} axle steering angle comparison.

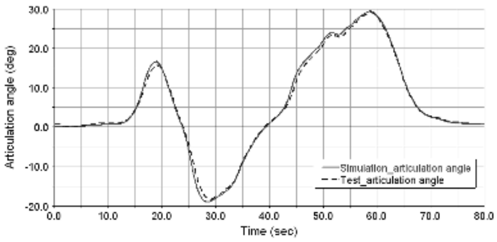

Fig. 7. Articulation angle comparison.

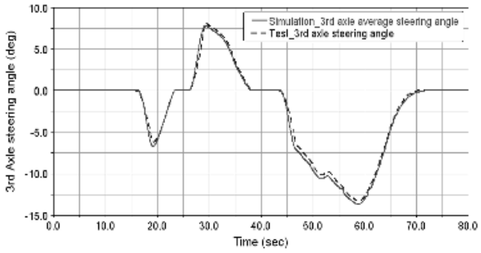

Fig. 8. 3rd axle steering angle comparison.

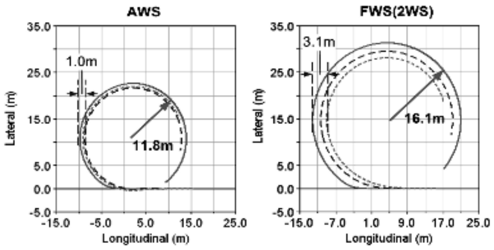

Fig. 9. Trajectory comparison.

4.3 Driving simulation

A J-turn simulation was carried out at low-speed condition, using the multibody dynamics model. Both AWS and FWS were considered as the steering system type in the simulation. The initial velocity was given as 10km/h. Fig. 9 shows the 11.8m of the turning radius and FWS system has about 16.1m, in other words, the difference is calculated as 4.3m. In particular, the lane width of the vehicle should be minimized for safe operation in the downtown. The bigger lane width of the articulated vehicle will cause more contacts with obstacles. As shown in Fig. 9, the lane width is 1.0m in case of AWS and 3.1m in case of FWS, that is, the difference is about 2.1m.

Lane change simulation was performed from 20km/h to 50km/h. In this simulation, the AWS was adopted below 30km/h and the rear steering angles decreased up to 45km/h, and then FWS was adopted above 45km/h. Fig. 10 shows the front, second and third steering angles and the articulation angle. According to the AWS control algorithm, the steering angles of rear axles asymptotically decrease from 7.5 seconds. The rear axles have no steering angle from 9.5 seconds, where the velocity is 45km/h.

5. Conclusion

In this paper, a test platform built on an HIL environment has been developed for the AWS ECU black box test. The AWS ECU test was carried out by using the test platform, and the AWS algorithm was predicted. Using the vehicle dynamics model containing the algorithms of AWS ECUs, the maneuverability of the vehicle was analyzed.

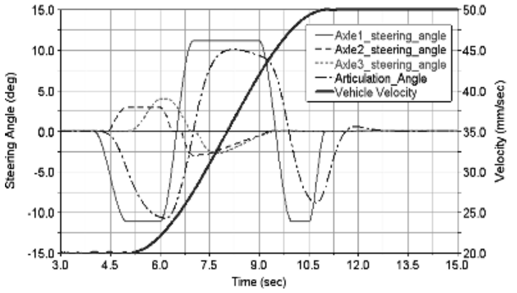

Fig. 10. Steering angle and velocity.

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References

[1] S. Shoichi, F. Yoshimi and S. Shuji, Four Wheel Steering System with Rear Wheel Steer Angle Controlled as a Function of Steering Wheel angle, SAE Paper, No. 860625, SAE, (1986).

[2] D. R. Pillar and E. E. Braun, All-Wheel Steering System for Heavy Truck Applications, SAE Paper, No. 952680, SAE, (1995).

[3] T. Kaneko, H. Iizuka and I. Kageyama, Steering control for advanced guideway bus system with all-wheel steering system, Vehicle System Dynamics, 44 741-749, Taylor & Francis, (2006).

[4] T. D. Gillespie, Fundamentals of Vehicle Dynamics, SAE, (1992).

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