Modeling & Dynamic Analysis for Four Wheel Steering Vehicle

Woongsang Jeong(1)*,
Jinhee Jang(2),
Changsoo Han(3)

Abstract

In this paper, we address vehicle modeling and dynamic analysis of four wheel steering systems(4WS). 4WS is one of the devices used for the improvement of vehicle maneuverability and stability. All research done here is based on production vehicles from various manufacturers. To study actual system response, a three dimensional, full vehicle model was created. In past research of this type, simple, two dimensional, bicycle vehicle models were typically used. First, we modelled and performed a dynamic analysis on a conventional two wheel steering(2WS) vehicle. The modeling and analysis for this model and subsequent 4WS vehicles were performed using ADAMS(Automatic Dynamic Analysis of Mechanical Systems) software. After the original vehicle model was verified with actual experiment results, the rear steering mechanism for the 4WS vehicle was modelled and the rear suspension was changed to McPherson-type forming a four wheel independent suspension system. Three different 4WS systems were analyzed. The first system applied a mechanical linkage between the front and rear steering mechanisms. The second and third systems used simple control logic based on the speed and yaw rate of the vehicle. 4WS vehicle proved dynamic results through double lane change test.

(1) Graduate Research Assistant, Dept. of Mechanical Eng., Hanyang Univ., Seoul, Korea and Senior Application Engineer, CIM Div., FADAM Technologies, Inc.

(2) Graduate Research Assistant, Dept. of Precision Mechanical Eng., Hanyang Univ., Seoul, Korea

(3) Assistant Professor, Dept. of Mechanical Eng., Hanyang Univ., Seoul, Korea

1. Introduction

The automobile was considered merely a mode of transportation. Today, the automobile is considered more and more as one of life's necessities. Many countries around the world have immense interest and investments in the automobile industry which affects their industries a great deal. Also, they are focusing on the development of vehicles with improved performance, inceased stability, and enhanced driver pleasure. Such improvements can be achieved on an existing automobile using technology such as active- and semi-active suspensions; anti-lock braking systems; traction control systems; electric-power steering systems; and four wheel steering systems.

Of the forementioned technologies, 4WS systems will be discussed in this paper. Recently, research on 4WS devices is constantly advancing and numerous these have been published. Presently, in Japan and other developed countries heavy research is actively in progress. Especially in Japan, where Honda, Mazda, Nissan and Toyota[1,2,3,4,5] have competitively researched, developed and installed such devices on various production models. Theoretical research on 4WS device has been done by numerous researchers and quite progressive ideas have already been introduced. But, current devices have performance problems which remain to be solved. To understand this system clearly, general understanding and application of vehicle dynamics and control is required. Also, only a few theories about 4WS control have been introduced, a little research has been done which deals in detail with the vehicle dynamical aspects. Because of the present circumstances, this paper focuses on the development and analysis of a dynamical model before considering control aspects. Such results are presented to make the application of the control system on an actual vehicle easier. This research sets a goal of making data helpful to the tangible development of a 4WS device through development and examination of computer simulation model and dynamic analysis.

For the existing 4WS system, a simple bicycle vehicle model was used focusing on dynamic effects and control aspects. But to gain better performance enhancement and definite understanding, a three dimensional full vehicle model is needed.

In this research, the ADAMS program[6] was used to simulate the vehicle model on a computer. First, out of the cars currently in production, a car which is considered common, was chosen, and then a 3-D vehicle model two wheel steering characteristics was created. This model went through simulations and the results were compared with results of real vehicle experiments for the verification of the vehicle model's validity.

Using this elementary model, the rear suspension of the original 2WS vehicle was changed from a 3-link axle type to a McPherson type to allow steering of the rear wheels. First, a mechanical 4WS device was installed. The device transfers the front wheel steering characteristics to the rear wheels to steer them. In this research, a mechanism structure which was installed on a Honda vehicle was selected and modelled to meet the requirements of this paper. Secondly, another 4WS device researched and completed is a vehicle speed sensing type model which determines the vehicle's speed to steer the rear wheels. Finally, a device using a combination of vehicle speed sensing and yaw rate feedback was completed. Using the three dimensional model of these three different 4WS devices, dynamic analysis was carried out with ADAMS to investigate the cruise dynamical aspects. A Flowchart of the work is in Fig 1.

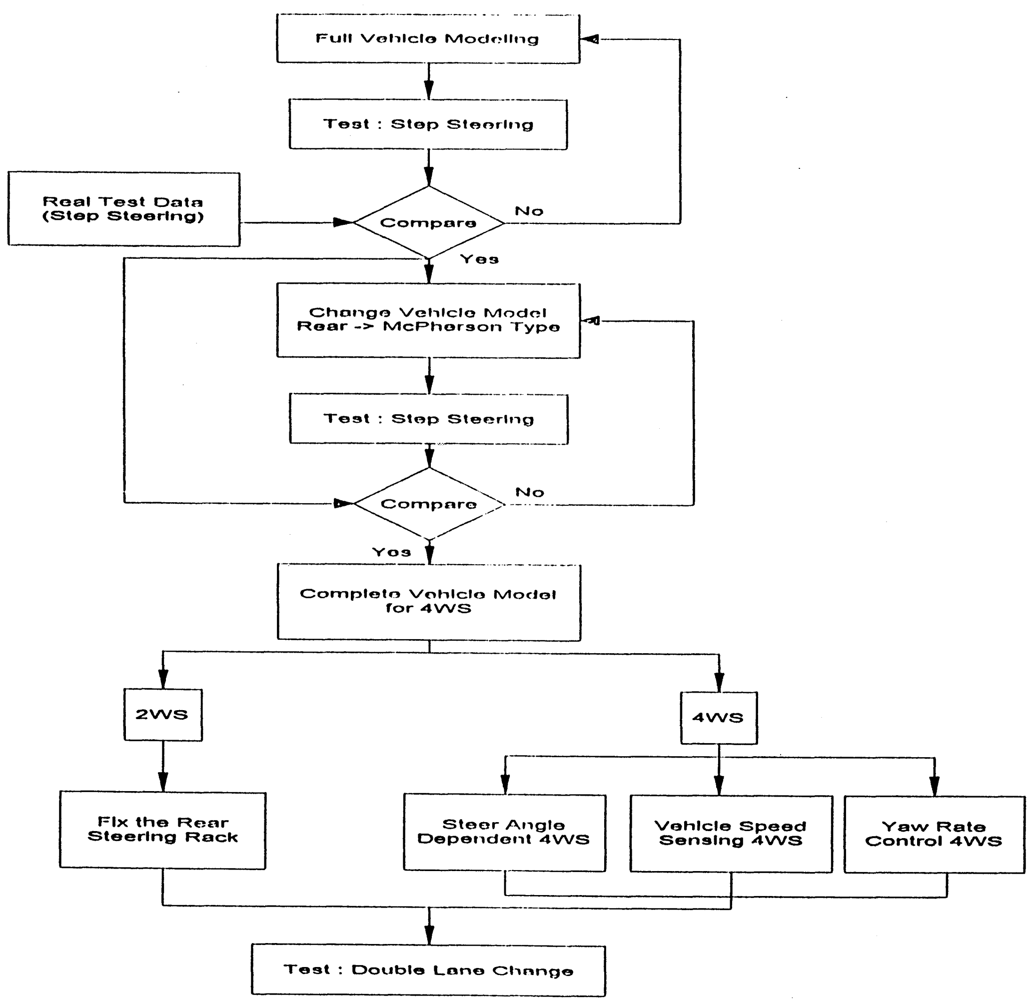

Fig.1 Flowchart of the work

2. Modeling of Vehicle

2.1 Modeling of Suspensions.

2.1.1 Front Model

Front suspension systems can be roughly divided into double wishbone and McPherson type, but the latter is presently considered to be more common in terms of cost and structure. The front suspension system of the vehicle modelled in this resarch consists of McPherson type suspension device which is in Fig.2. Due to the space limitations of front wheel drive cars, this suspension system is generally used. This device consists of knuckle part, LCA(Lower Control Arm), tie rod, and some other elements.

where, R : Revoute Joint
U : Universal Joint
T : Translational Joint
S : Spherical Joint

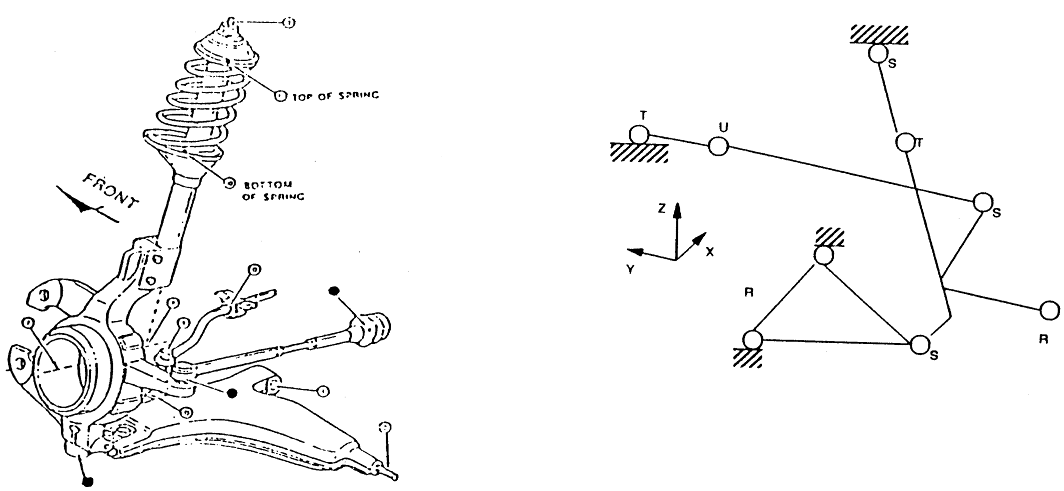

Fig. 2 McPherson type front suspension

2.1.2 Rear Model

For the rear suspension system, a 3-link type device is most commonly used. This device is often used as rear wheel suspension system for the existing vehicles whose rear tires are fixed. The rear tires are connected by a single axle and two trailing arms are connected to the axle. To prevent lateral deformation from occurring in a 3-link rear axle type suspension system, a lateral rod is installed between frame and the rear axle. Fig.3 shows the 3-link type rear suspension layout.

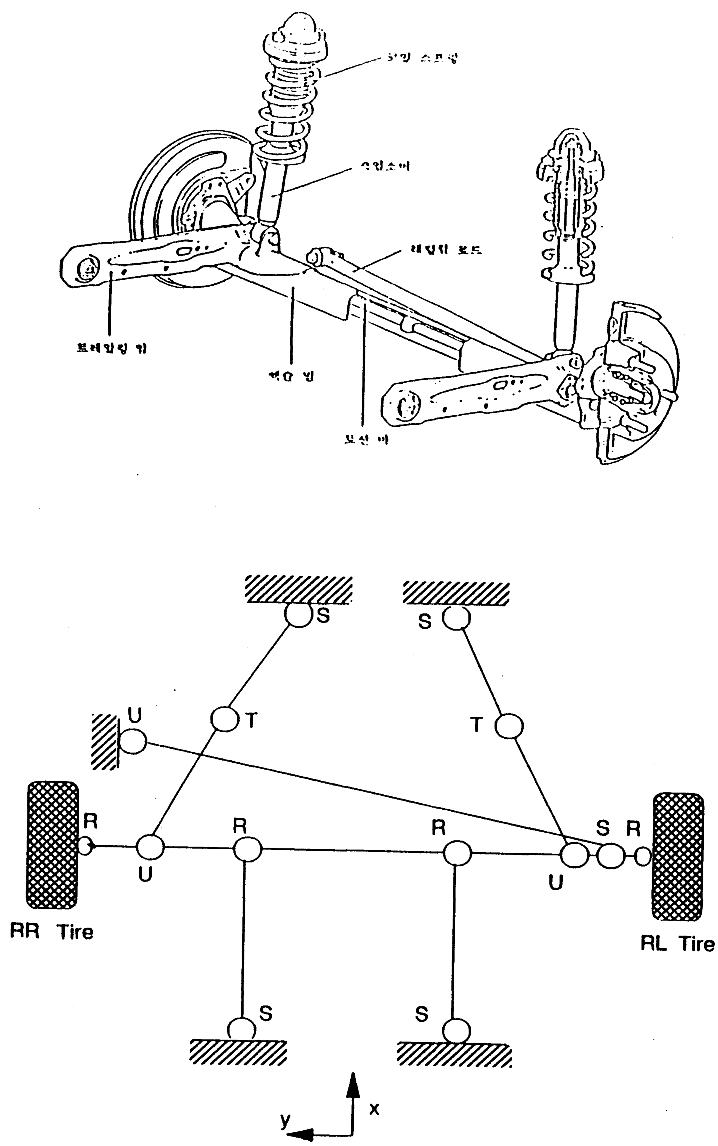

Fig.3 3-link type rear suspension

2.2 Results for Dynamic Analysis

By installing the front and rear suspension model discussed in section 2.1, we get a full vehicle model(see Fig.4). To verify the validity of this model, a simulation was carried out on a computer. Here a step steering test method was used, which applies a 45° steering input on a vehicle cruising at any speed and comparing the characteristics. Vehicle speed was set at 80km/h and 45° steering input was applied after two seconds for 0.2 seconds. These test results were compared with real vehicle experiment results. Comparison with yaw rate is shown in Fig. 5, comparison with lateral acceleration is shown in Fig.6, and comparison with roll angle is shown in Fig. 7.

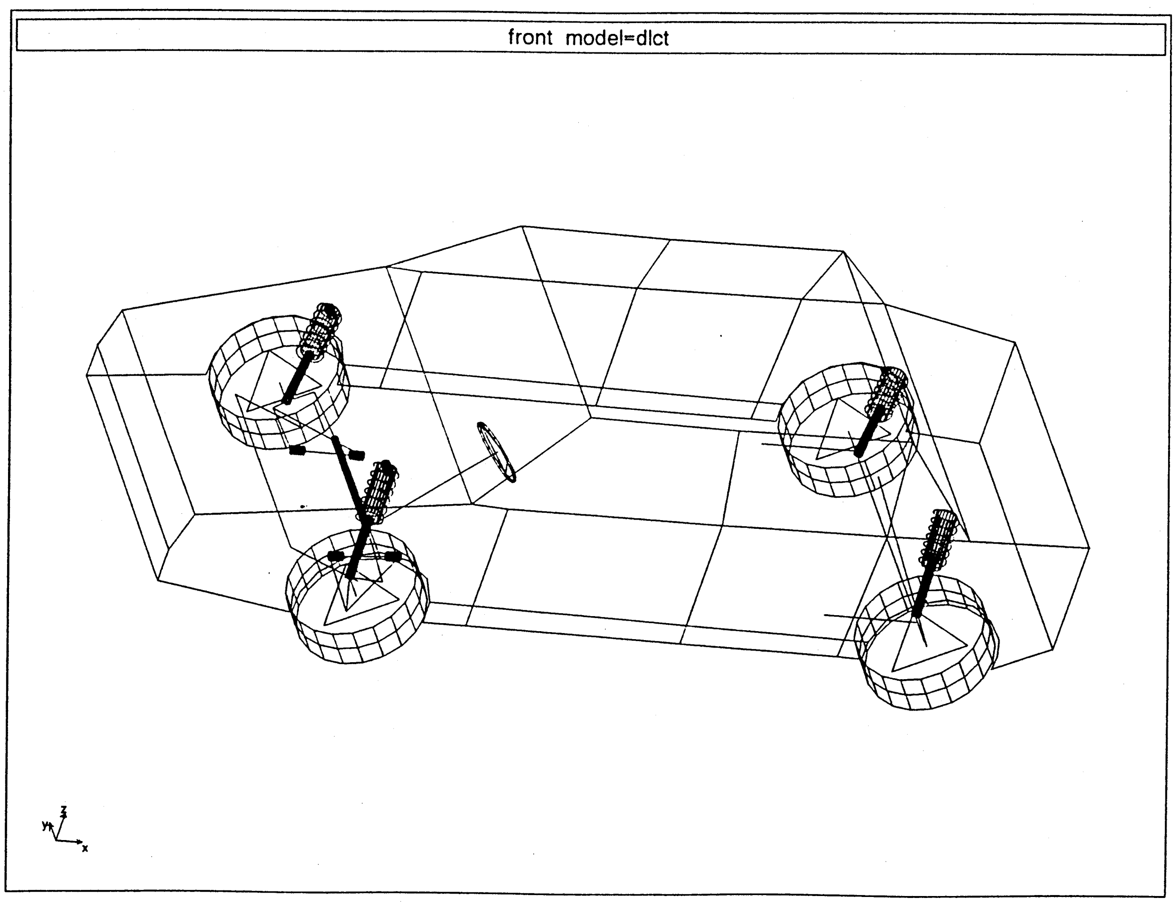

Fig. 4 Full vehicle model

——— : Real test data   - - - : Model test data

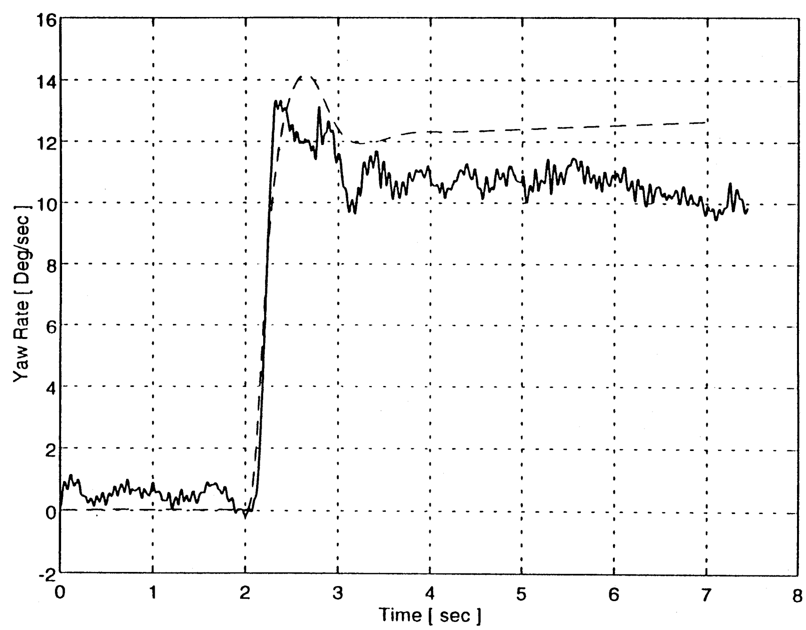

Fig. 5 Result of yaw rate

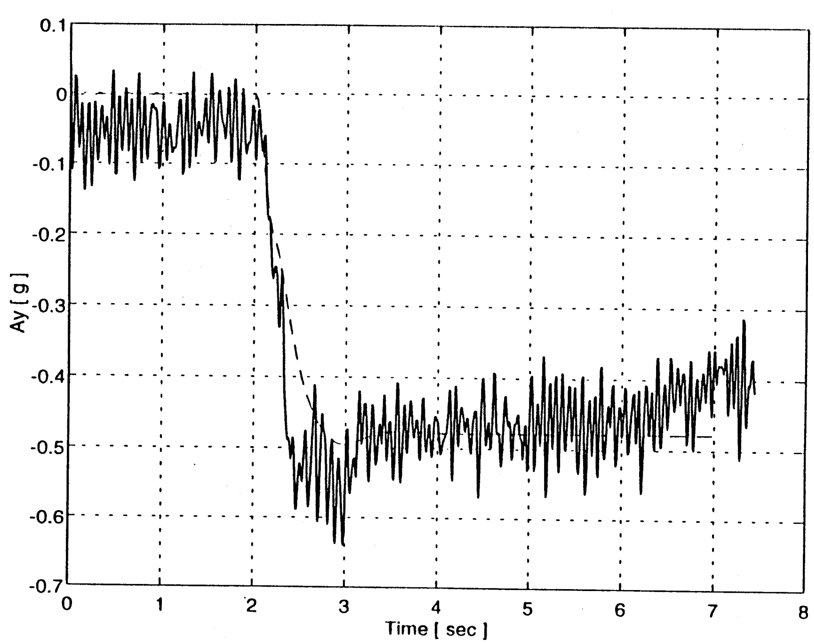

Fig. 6 Result of lateral acceleration

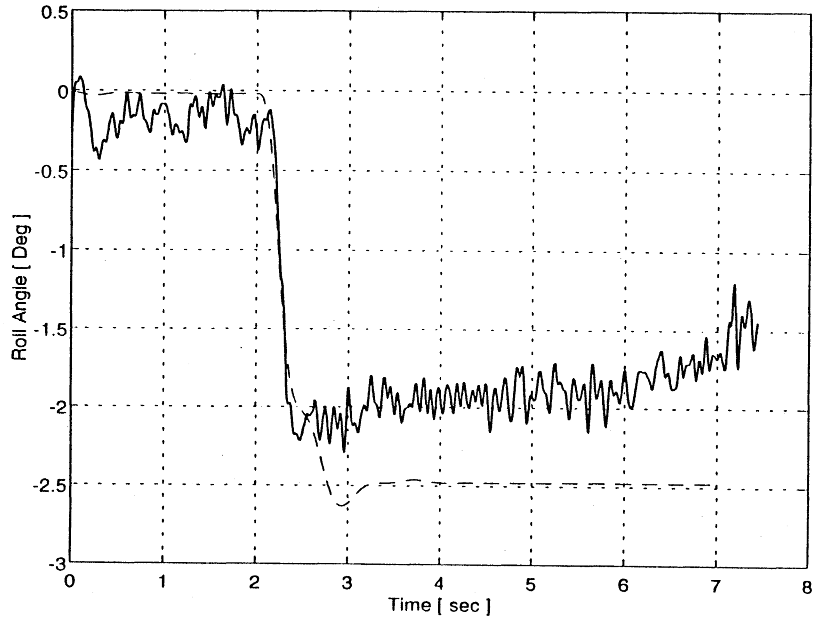

Fig. 7 Result of roll angle

The slight difference between the real vehicle experiment results and the simulated test results is thought to be caused by driver's operation error, error caused by the weight of the test equipment, and the error of the test equipment itself. But except the minor difference during step steering, the results tend to almost coincide, so we can conclude that the model developed in this research is valid. A vehicle model, the validity of which is verified, can be used in the modeling of a 4WS vehicle.

3.Model of 4WS Vehicle

3.1 Vehicle Model with Independent Suspensions

3.1.1 Description of the Model

Unlike the two wheel steering vehicle, a four wheel steering vehicle needs to steer the rear wheels so it requires independent suspensions other than the 3-link suspensions. Every part was installed with previously modelled McPherson type suspensions. The reason for this is that McPherson type is structurally and geometrically simple and is widely used. First, the suspension device discussed in section 2.1.1 was installed on both sides of the rear replacing the 3-link rear axle type suspension device. Also, to diminish the rolling effect, which can occur in an independent type, a stabilizer bar was installed at all four corners.

3.1.2 Results for Dynamic Analysis

Using the resulting independent suspension type full vehicle model, dynamic analysis was performed as done in Chapter 2. Comparisons for yaw rate, lateral acceleration and roll angle are presented in Fig.8-10. These results are in comparison with dynamic analysis in chapter 2.

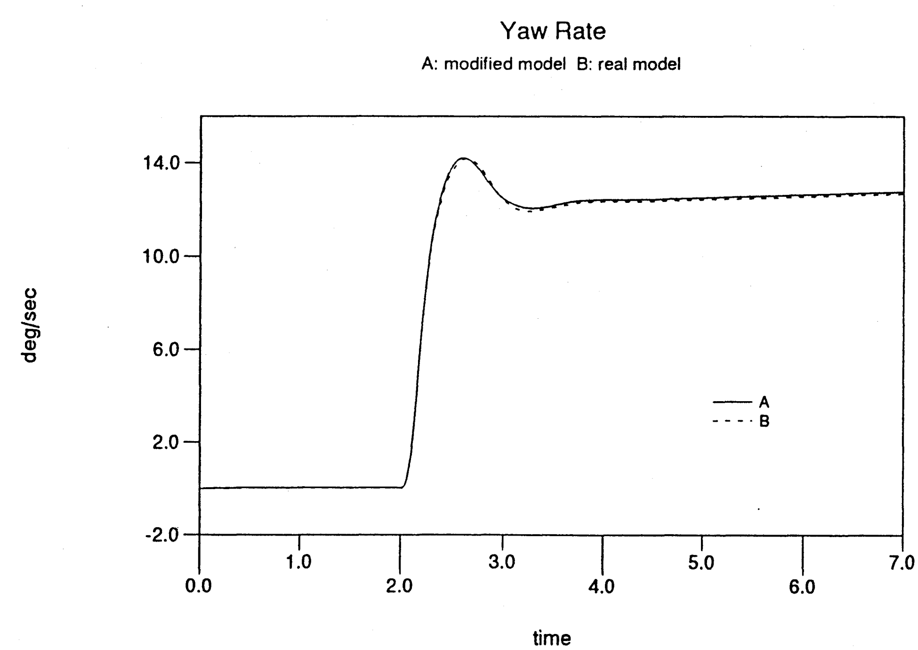

Fig. 8 Result of yaw rate

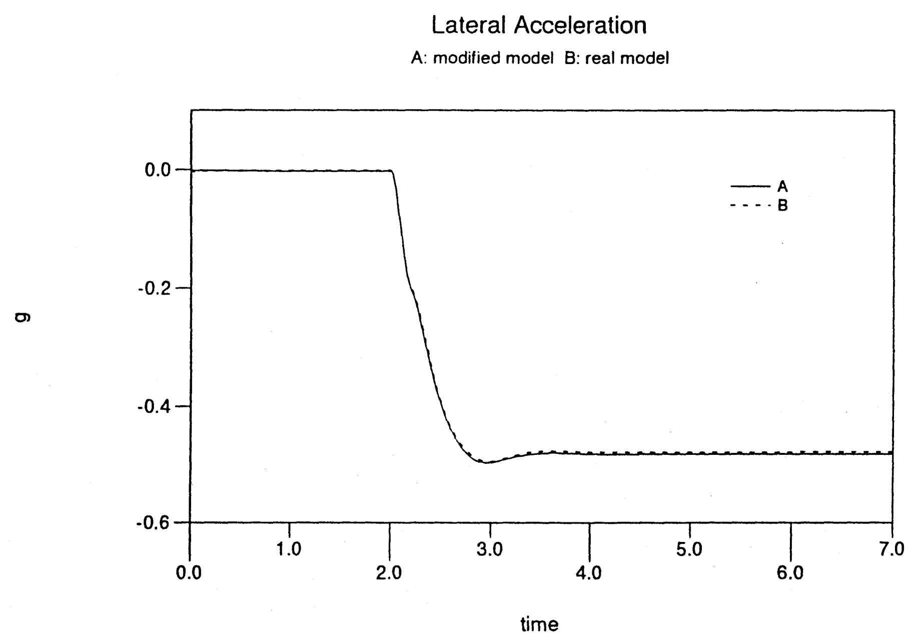

Fig. 9 Result of lateral acceleration

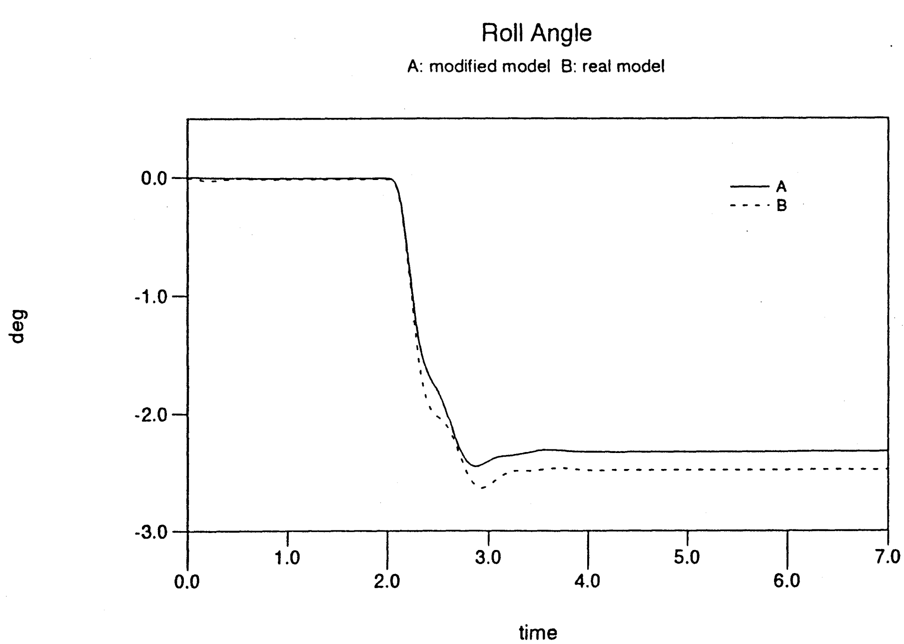

Fig. 10 Result of roll angle

Analysis results show that the yaw rate and lateral acceleration results are quite consistent with each other. But, when we observe the results for roll angle, we notice that the roll effect decreases in the independent suspensions. We can conclude that this was brought about by replacing the McPherson type of suspension device and furthermore installing stabilizer bar to diminish the roll effect. This result shows that the vehicle model with independent suspensions is valid and practical. This vehicle model can be utilized when applying for the four wheel steering vehicle.

3.2 Modeling for 4WS Vehicle

3.2.1 Steering Angle Sensing Type 4WS

In this section a mechanical mechanism was selected, modelled, and applied to steer the rear tires. A mechanical type steering mechanism originally designed by Honda was modelled and installed between the front and rear suspensions. This rear wheel steering mechanism has a unique characteristic and plays the role of transfering the characteristics of the front wheel steering to the rear wheels. The full vehicle model with rear wheel steering mechanism is shown in Fig.11 and the characteristic curve of the rear wheel steering mechanism is shown in Fig.12. This method is genuinely mechanical without control logic and is a method which is most easily applied. But this method is not carried out by sensing the vehicle's dynamic state, so in a situation where the vehicle characteristic drastically changes, the performance can't always be guaranteed.

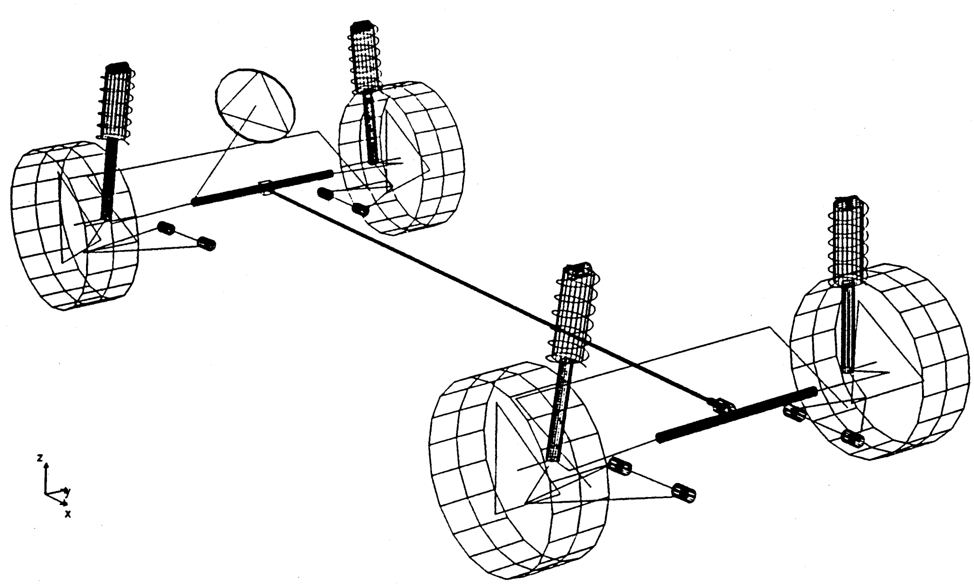

Fig. 11 Full vehicle model with rear wheel steering mechanism

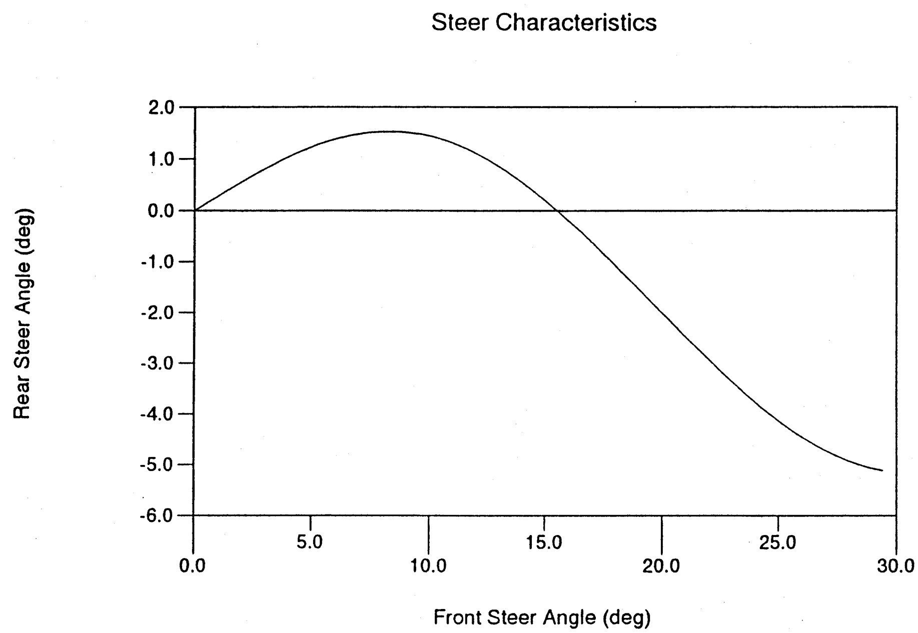

Fig.12 Characteristic curve of steer angle sensing type

3.2.2 Vehicle Speed Sensing Type 4WS

This method changes the steering angle of the rear wheels according to the vehicle's speed. At high speeds, the front and the rear wheels are steered in the same direction, and at low speeds the front and rear wheels are steereed in the opposite directions to improve the stability of the vehicle. For the vehicle model, a model with independent suspension device is used and instead of mechanical steering mechanism, a speed sensor and a controller is needed. This method was researched by Sano and et.al[1] and the steering equation between the front and rear wheels can be obtained from Eq.(1).

$$k_s \equiv \frac{\delta_r}{\delta_f} = \frac{-b + \dfrac{Ma}{C_r L} U_o^2}{a + \dfrac{Mb}{C_f L} U_o^2} \tag{1}$$

where, δ_f : Front steer angle

δ_r : Rear steer angle

a : Distance from front tire to vehicle c.g.

b : Distance from rear tire to vehicle c.g.

L : Wheel base ($L = a + b$)

M : Mass of vehicle

C_f : Effective cornering stiffness at front tire

C_r : Effective cornering stiffness at rear tire

U_o : Vehicle speed

k_s : Ratio of rear to front steer angle(speed sensing type)

In this equation, if we find out how ' k_s' changes according to the speed we can obtain the characteristic curve shown in Fig.13.

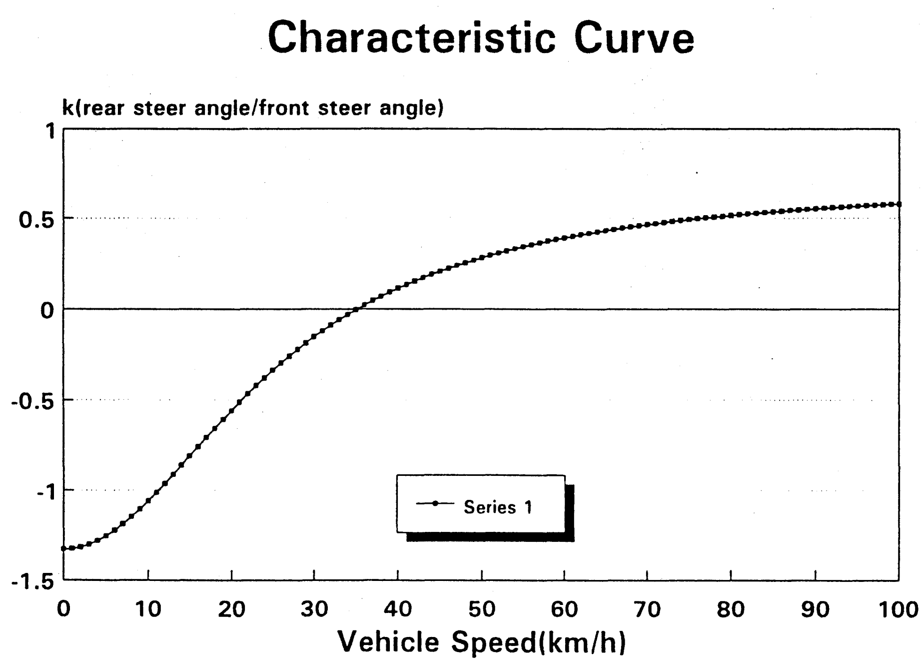

Fig. 13 Characteristic curve for speed sensing type

3.2.3 Speed Sensing + Yaw Rate Feedback Type 4WS

This method combines speed sensing and yaw rate feedback to enhance the operation stability. The speed sensing type is an open-loop control system, on the other hand this method is a closed-loop sysyem. If we put the method used in this research in a mathematical expression, it is same as Eq.(2).

$$\delta_f = k * \delta_{sw}$$
$$\delta_r = \delta_f * k_s + YR * k_y \tag{2}$$

where,

δ_f : Front steer angle

δ_r : Rear steer angle

δ_{sw}: Steering wheel angle

YR : Yaw rate

k : Ratio of front steer angle to steering wheel angle

k_s : Coefficient of speed sensing type 4WS

k_y : Coefficient of yaw rate feedback type 4WS

4. Test and Results

4.1 Test Method

To test the dynamic characteristics of a vehicle with a four wheel steering device, a double lane change test[8] was carried out. The ISO standard was used as a basis for the test and through this analysis we can check the vehicle's cruise stability. This research observed a vehicle passing through two lanes at 80km/h as shown in Fig.14. Table 1 summarizes the data for double lane change test course.

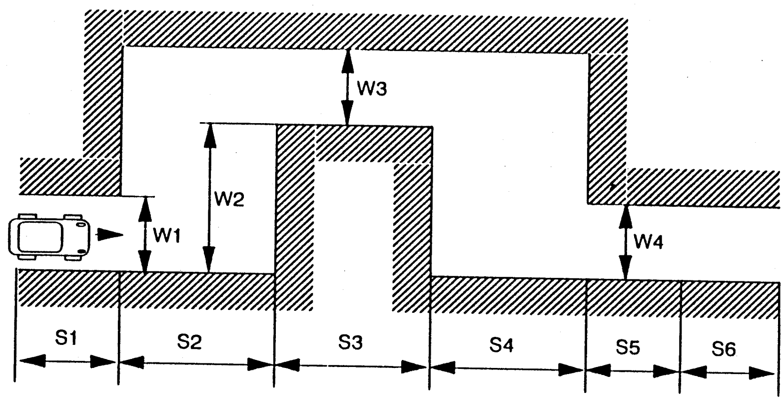

Fig. 14 Double lane change test course

Table 1 Data for double lane change test course, ISO/TR 3888
(Unit : meter)

	Data
S1	15
S2	30
S3	25
S4	25
S5	15
S6	15
W1	1.1*V.W. + 0.25
W2	3.5
W3	1.2*V.W. + 0.25
W4	1.3*V.W. + 0.25

4.2 Results

We observed the results occuring when a vehicle traveling at 80km/h passes through the double lane. A few results acting as decision standard for steering performance are illustrated in Fig.15–18. Fig.15 illustrates the yaw rate when changing lanes. As shown on the graph, we obtained a lower value than the two wheel steering vehicle's yaw rate. This shows that we can get improved performance from a four wheel steering vehicle in terms of vehicle stability. Fig.16 illustrates the lateral acceleration is decreased when changing lanes and this also shows that the speed sensing and yaw rate feedback type demonstrates the best performance. Fig.17 proves that four wheel steering vehicle has more stable performance than two wheel steering vehicle in the roll angle point of view. Fig.18 shows the magnitude of side slip angle for the vehicle's body is decreased. And also, we can find out that the four wheel steering devices cause a little time delaying effect and decreases the side slip angle. This means that the front and rear wheels are effectively steered in the same or opposite direction according to the situation, in 4WS.

where, 4WS–A : Steer angle sensing type
4WS–B : Vehicle speed sensing type
4WS–C : Speed sensing type + yaw rate feedback type

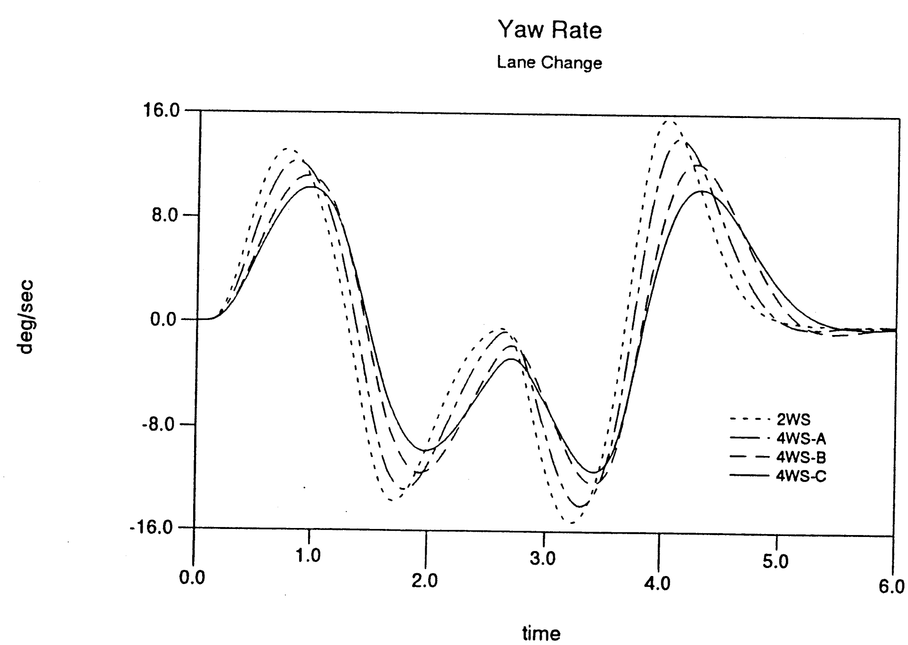

Fig.15 Result of yaw rate

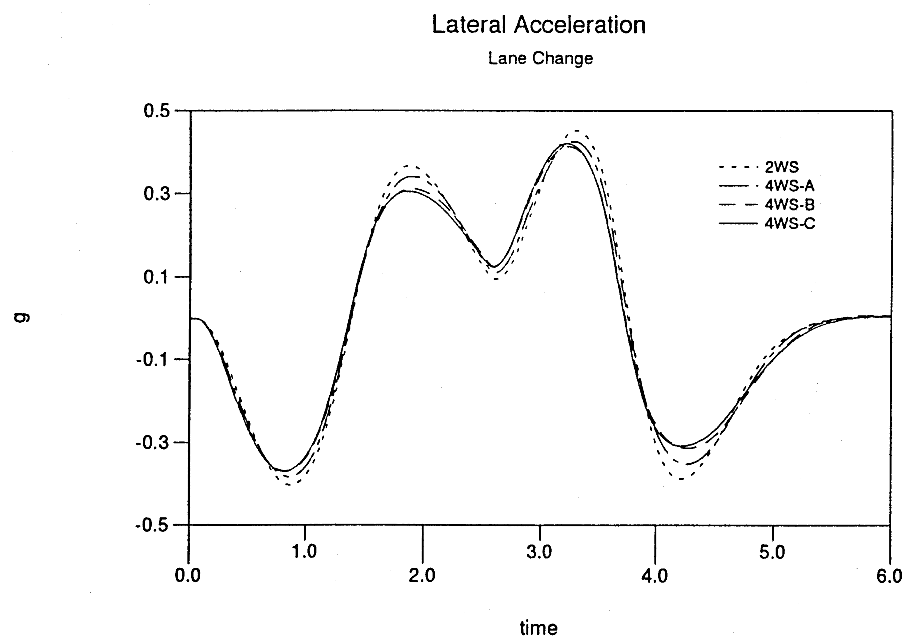

Fig.16 Result of lateral acceleration

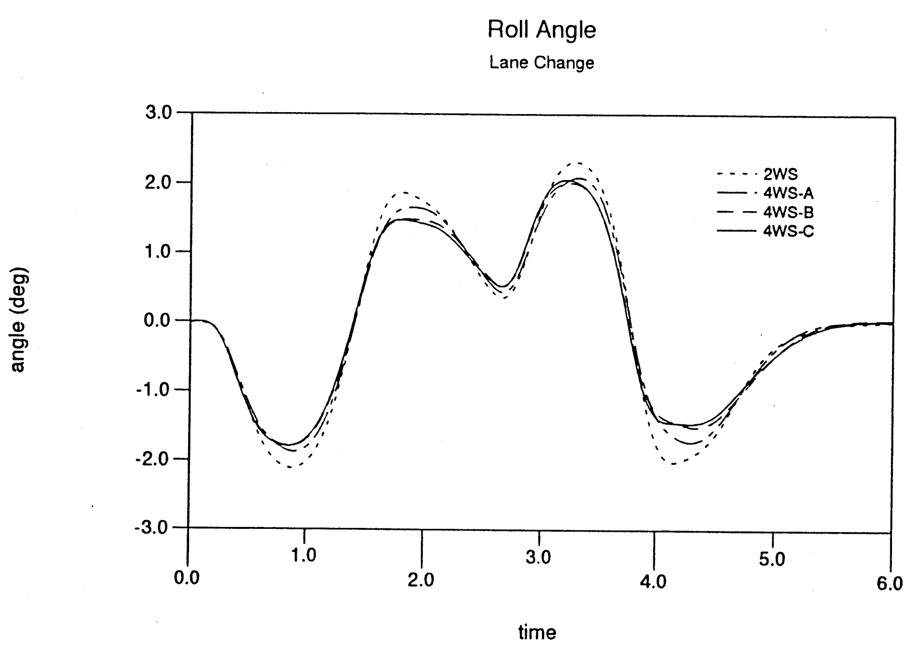

Fig.17 Result of roll angle

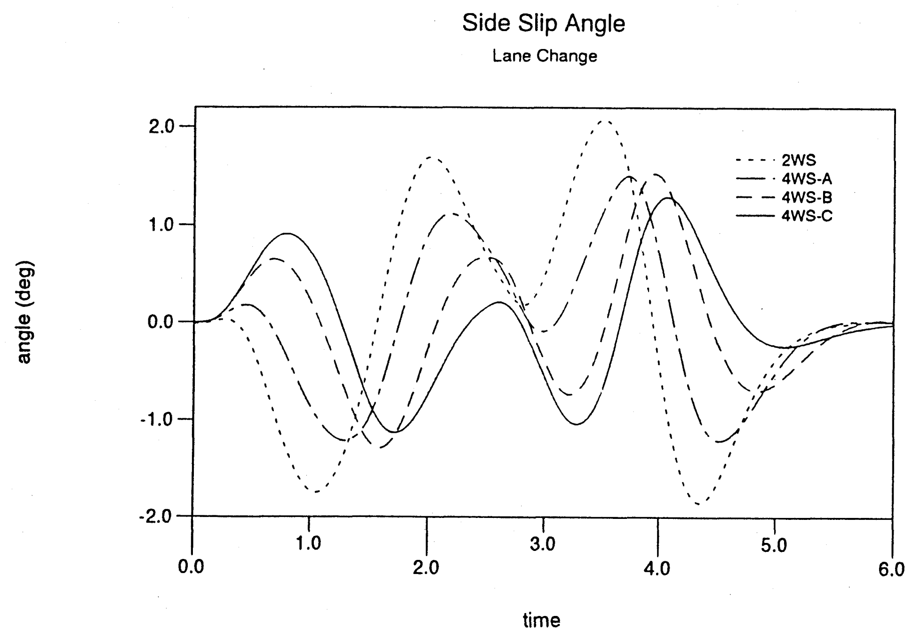

Fig. 18 Result of side slip angle

5. Conclusions

A four wheel steering system is a device which enhances the vehicle's maneuverability and stability. Through this research, a full vehicle with four wheel steering(4WS) which is close to an actual vehicle model was developed instead of the existing simple bicycle vehicle model. First, a two wheel steering (2WS) vehicle model was made and then the dynamic analysis was carried out. These results were compared with the real vehicle experiment data obtained during step steering to verify the model's validity. The ADAMS program for multi-body systems was used for the modeling, analysis, and animation. For rear wheel steering, a McPherson type suspension device was installed in the front and the rear to form independent suspensions. Dynamic analysis was carried out when a step steering input was applied to the developed independent suspension type vehicle model. When comparing these results with the results obtained earlier, we noticed that except for the decrease of roll angle in the independent-type suspensions, they were fairly consistent with each other. The rear steering mechanism for a 4WS system is proposed, and installed for analysis. Then we compared the 2WS and 4WS vehicle model's yaw rate, lateral acceleration, roll angle, and side slip angle, which affect the vehicle's stability, to find out the effects the 4WS system has on the vehicle's dynamic response. Besides the mechanical device, a 4WS vehicle which uses a simple control method of steering the rear wheels according to the vehicle's speed and a 4WS vehicle which uses the speed and yaw rate feedback control was proposed. A simulation of the double lane change test was performed on each of the three 4WS systems. Each vehicles dynamic performance was respectively compared and analyzed. From the analysis, we can conclude that the speed and yaw rate feedback type 4WS vehicle has improved dynamic performance.

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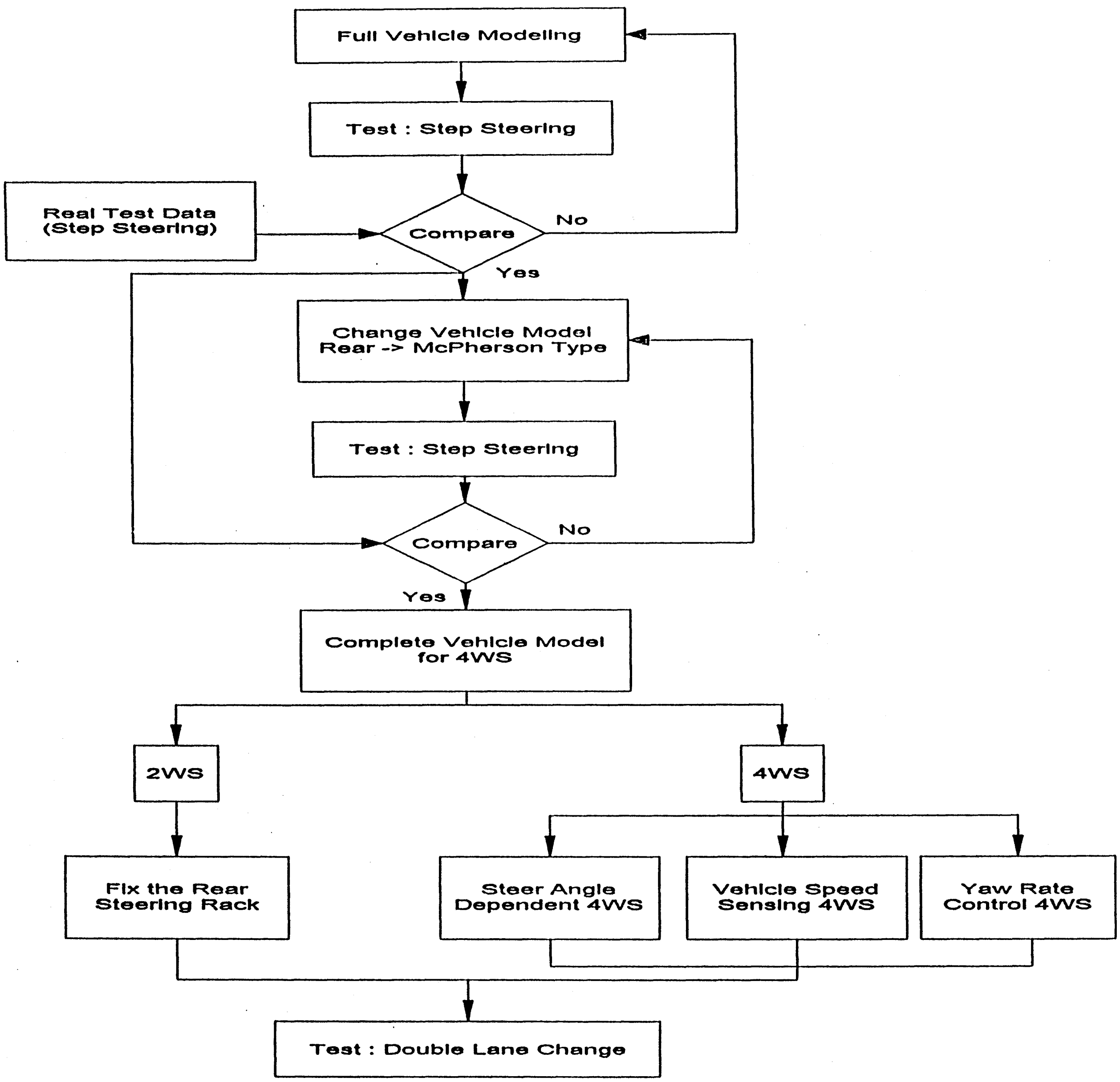

Fig.1 Flow chart of the work