

Independent Left and Right Rear Toe Control System

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ABSTRACT

Honda has developed an "Independent Left and Right Rear Toe Control System" that can achieve stable cornering performance and agile handling. We believe the issue that should be resolved in the next generation of ESC is the expansion of stability and agility into the general operation area. We examined how to accomplish this aim, and control of the independent rear toe angle was decided to be an appropriate method. In addition, a method for mounting the system without using a dedicated suspension was proposed. If left and right toe angles can be controlled independently, toe angle control and normal 4WS control become possible at the same time. In this paper, we will discuss the fundamental principle of independent toe angle control and the system configuration. Also, "INOMAMA Handling" (at driver's will) achieved by this system, as well as the fun and safe driving that are achieved as a result will be shown.

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INTRODUCTION

In 1998, Honda installed its "Vehicle Stability Assist" (VSA, hereinafter referred to as ESC) on a production vehicle of the FF car for the first time in the world [1]. Thereafter, ESC was mounted on various Honda car models, including their most compact models. Currently, ESC has become a legally required item. ESC unifies the functions of ABS and "Traction Control System" (hereinafter referred to as TCS), and prevents vehicle instability caused by steering operation such as to avoid danger. ABS and TCS start working after the brake or accelerator is pressed, but ESC monitors the vehicle behavior itself and works regardless of driver input. In other words, ESC is characterized by the ability to deal with a very wide range of conditions, such as unstable vehicle behavior due to rapid changes in the road surface. This characteristic of ESC has helped to reduce real-world accidents.

In the next generation of ESC, what kind of technology is expected? We believe the issue that should be resolved in the next generation of ESC is the expansion of stability and agility into the general operation area. We examined how to accomplish this, and control of the rear toe angle was determined to be an appropriate approach. We have therefore developed an effective and reliable system for general driving situation through rear toe angle control. Named "Precision All Wheel Steer (abbreviated P-AWS hereinafter), it is the world's first Independent left and right toe control system. The core technology behind P-AWS is the 4-wheel steering system (hereinafter referred to as 4WS) pioneered by Honda ahead of the rest of the world. P-AWS is installed in the 2014 Acura RLX flagship model.

GOALS OF THE SYSTEM AND METHOD

There are various methods to control vehicular motion: Active suspension and Electronic Control Dampers, SH-AWD using torque vectoring, Variable Gear Ratio Steering and other forms of front wheel steering control, 4WS, and so on. The aim of our system is to achieve "INOMAMA Handling" through vehicle motion control in the zone of common use and to provide as many customers as possible with driving that is both fun and safe. Based on the following conditions, we have selected a system for achievement of the purpose.

The Conditions for System Adoption

1. Effective in the tires' zone of common use
2. Effect during steady turning
3. Vehicle attitude control
4. Low cost
5. Easy to install

After examining what satisfies the above conditions, we concluded that the best method of achieving our goal would be to use suspension alignment, particularly the rear toe angle. 4WS, which could be said to be a symbol of Honda's originality, uses toe angle control. We assumed that we could build our target system by using the knowledge that we have gained from 4WS to the fullest and by making improvements to various 4WS deficiencies.

Improvement Points of 4WS

Deficit points in 4WS

1. Some drivers feel the behavior is strange.
2. Suspension is designed exclusively for 4WS.
3. Significant change in behavior on failure.
4. Large-scale fail-safe system is necessary.
5. Requires significant energy to function.

As a means of addressing these improvement issues, we proposed control of the toe angle, and therefore devised a system where the rear toe suspension arms are replaced by variable actuators in which both the left and right toe angles are controlled independently. This system is capable of achieving all the operations of conventional 4WS, as well as consistently providing toe angles that are appropriate for any given driving situation. We have made 4WS work by steering feed-forward and vehicle behavior feedback [2],[3]. If the rear toe angle can be controlled, the system enables increasing the vehicle's independent stability before unstable behavior occurs. It is the same as always maintaining proper suspension alignment. Therefore, it is possible to stabilize the car with a small amount of control. From the driver's viewpoint, the feeling that 4WS control is providing stability is changed to a feeling that the vehicle itself is stabilized by toe control. This represents a major improvement over 4WS.

In addition, because the toe angle amount increases friction, the ability to change the toe angle as necessary can be expected to improve fuel efficiency in the future. Further, because making the left and right actuators independent reduces the risks resulting from a failure by one-half, a safe system can be designed. Also, using a configuration in which the toe control suspension arm is changed to an actuator eliminates the necessity for an exclusive suspension and sub-frame, and this makes the system advantageous in terms of cost. The Independent toe control system makes it possible to achieve the performance of conventional 4WS while improving upon deficiencies.

PRINCIPLE OF TOE ANGLE CONTROL

In P-AWS, because the left and right toe angles are controlled independently, the toe angle and thrust angle can be controlled simultaneously. P-AWS control is a combination of thrust angle control and toe-in angle control. Because research on initial toe-in angles and 4WS control methods has been explained in many previous documents [4],[5], here we will explain the principle of toe-in angle control.

First, we computed the unstable yaw moment when longitudinal acceleration occurs during steady turning. The vertical loads during turning accompanied by longitudinal acceleration are as below: [6]

$$W_{rr} = \frac{W_r}{2} + \frac{K\phi_r}{(K\phi_f + K\phi_r)} \frac{h}{d_r} W\alpha_y + \frac{h}{2l} W\alpha_x \quad (1)$$

$$W_{fl} = \frac{W_f}{2} - \frac{K\phi_f}{(K\phi_f + K\phi_r)} \frac{h}{d_f} W\alpha_y - \frac{h}{2l} W\alpha_x \quad (2)$$

$$W_{fr} = \frac{W_f}{2} + \frac{K\phi_f}{(K\phi_f + K\phi_r)} \frac{h}{d_f} W\alpha_y - \frac{h}{2l} W\alpha_x \quad (3)$$

$$W_{rl} = \frac{W_r}{2} - \frac{K\phi_r}{(K\phi_f + K\phi_r)} \frac{h}{d_r} W\alpha_y + \frac{h}{2l} W\alpha_x \quad (4)$$

The balance of the lateral force

$$F_f = (W_{fl} + W_{fr})\alpha_y \quad (5)$$

$$F_r = (W_{rl} + W_{rr})\alpha_y \quad (6)$$

when the above vertical load is substituted for the lateral force equilibrium,

$$F_f = (W_f - \frac{h}{l} W\alpha_x)\alpha_y \quad (7)$$

$$F_r = (W_r + \frac{h}{l} W\alpha_x)\alpha_y \quad (8)$$

At this time, the yaw moment produced by longitudinal acceleration during cornering is expressed by

$$l_f F_f - l_r F_r = (l_f W_f - l_r W_r)\alpha_y - h W\alpha_x \alpha_y \quad (9)$$

At this time, the yaw moment produced by longitudinal acceleration during cornering is expressed by

$$M1 = -h W\alpha_x \alpha_y \quad (9)$$

This is the unstable yaw moment produced by acceleration and deceleration during cornering.

Next, we considered counteracting this moment by the rear toe angle. Cornering power of the right and left should be set individually to consider the respective load movement. If K_{rl} and K_{rr} are respective cornering power of the left and right, and θ is the toe angle, the lateral force of the left and right F_{rl} and F_{rr} are as follows:

$$F_{rl} = -K_{rl} \left(\beta - l_r \frac{r}{v} - \frac{\theta}{v} \right)$$

$$F_{rr} = -K_{rr} \left(\beta - l_r \frac{r}{v} + \frac{\theta}{2} \right) \quad (11)$$

Since the lateral load transfer is proportional to the lateral acceleration, by using constant k determined by the dimensions and roll stiffness, cornering power K_{rl} and K_{rr} are as follows:

$$K_{rl} = K_r (1 - k\alpha_y) \quad (12)$$

$$K_{rr} = K_r (1 + k\alpha_y) \quad (13)$$

As constant k is

$$k = \frac{K\phi_r}{(K\phi_f + K\phi_r)} \frac{h}{d_r} \frac{2l}{l_f} \quad (14)$$

The sum of the lateral force is

$$F_{rl} + F_{rr} = -2K_r \left(\beta - l_r \frac{r}{v} \right) - k\alpha_y K_r \theta \quad (15)$$

The first term on the right side is the balance of the steady turning. Yaw moment M_2 caused by the toe angle is

$$M_2 = -kl_r K_r \alpha_y \theta \quad (16)$$

This M_2 by toe angle is as follows when to be canceled instability yaw moment M_1 by longitudinal acceleration

$$M_1 + M_2 = 0 \quad (17)$$

Therefore toe angle at that time, the basic principle of the proposed control method is to impart a toe angle such that the unstable yaw moment in the first equation above is balanced by the effect of the toe angle as expressed by the second term in the second equation above. The toe angle at this time is

$$\theta = -\frac{hW}{kl_r K_r} \cdot \alpha_x \quad (18)$$

It should be noted that the amount of cornering (steering angle, lateral acceleration, and yaw rate) is not included in this equation. This means that like a conventional 4WS system, the system is able to stabilize the vehicle without cornering feedback, thus minimizing any sensation of discomfort in the drive feel due to feedback delay. In other words, this toe-in control actively moves the toe angle, but because the yaw moment is generated in accordance with the lateral acceleration, the driver does not feel anything unusual, but instead feels that the vehicle is inherently stable.

In order to prove the validity of this toe-in control theory, we carried out the full-vehicle numeric simulation. The simulation compared vehicles with three kinds of characteristics. The 1st (vehicle A) is a vehicle that is equipped with special characteristic tires that generate lateral force constantly without depending on vertical loads. This vehicle does not generate unstable yaw moment from the vehicle acceleration. The 2nd (vehicle B) is a vehicle that applies toe-in control and is equipped with the normal characteristic tires. The 3rd (vehicle C) is a normal vehicle that is equipped with normal characteristic tires and does not apply toe-in control. We carried out the deceleration turning simulation with these three vehicles. Figure 1 shows two characteristics of tires for this simulation and the result.

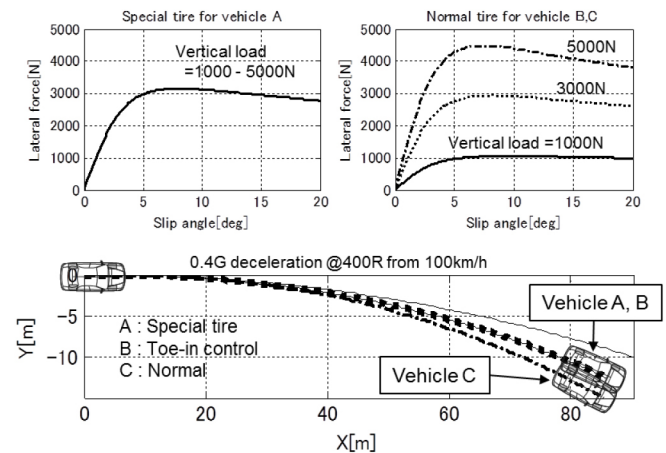


Figure 1. Deceleration turning simulation result

This result shows that the trajectories of vehicle A and vehicle B overlap and that the dynamic character of these two vehicles is the same. This means that toe-in control should be effective in an actual vehicle.

SYSTEM CONFIGURATION

We achieved independent left and right steering of the rear wheels by replacing the toe control suspension arm of a multi-link suspension with an elastic electronic control actuator (Fig. 2).

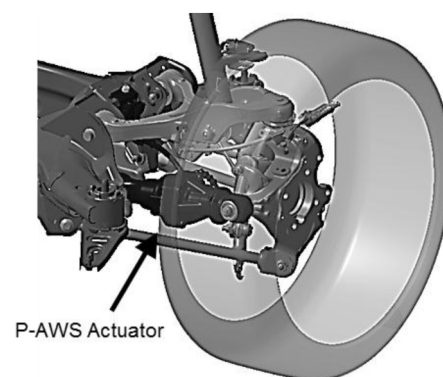


Figure 2. Actuator layout