DEVELOPMENT OF THE BRAKE ASSIST SYSTEM

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Paper Number 98-S2-P-17

ABSTRACT

Investigations and analyses of braking behavior of inexperienced drivers in emergency situations have shown that the Brake Assist System which determines an appropriate emergency braking operation and assists in applying the necessary braking force is effective in terms of active safety. While the system designed to detect an emergency braking operation and to consistently apply the maximum braking force is effective for those drivers who cannot apply sufficient braking effort, the system will make experienced drivers feel disagreeable because the system may work against their intention to control the vehicle. Consequently, we utilized an ABS actuator to develop a type of Brake Assist System with excellent control performance and less disagreement.

INTRODUCTION

Inability of inexperienced drivers to apply sufficient braking effort in emergency situations was reported in various researches and analyses of their emergency braking behavior(1)(2)(3)(4). It was also found that a mere improvement in the braking performance did not produce the sufficient braking force in the emergency situation(5)(6). To overcome these problems, the Brake Assist System using a vacuum booster was developed as a system to detect an emergency braking operation and to assist in the addition of the braking force in such a situation(5)(6)(7)(8)(9). The authors have recently developed a hydraulic Brake Assist System by using a highly versatile ABS actuator(10)(11). This paper will characterize the emergency braking behavior of inexperienced drivers, and outline the control concept and the control procedure of the Brake Assist System.

Characteristics of Emergency Braking Operation

To investigate the braking behavior in emergency situations, inexperienced drivers, both male and female, in a wide range of age group from eighteen to seventy, were invited to a "training session for drivers" for an unannounced test consisting of an obstacle darting out in front of the car. To reproduce the tense atmosphere close to the reality, the connecting road within the test-driving course having the same environment as the city road and the suburban road was selected as the driving course for this experiment. The obstacle was abruptly thrown out in front of the vehicle during while the driver was on its way to the site of the "training session" with relaxed feeling. The pedal effort versus time in emergency and normal situations are compared between the driver who could apply sufficient braking effort and the driver who could not, as a representative example of the test results in (Fig 1.). From this chart, the characteristics of the driver who could not apply sufficient braking effort were derived as follows:

①There was a significant difference in the initial pedal travel speed between normal and emergency situations, and the initial pedal travel speed in an emergency situation was the same for the driver who could apply sufficient braking effort and the driver who could not.

②The initial pedal effort of the driver who could not apply sufficient braking effort was not as strong as the driver who could, and the maximum pedal effort of the former was less than one-third of the latter.

③The driver who could not apply sufficient braking effort tended to weaken the pedal effort during the braking operation.

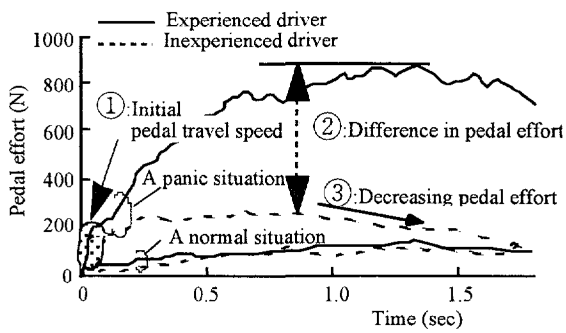

Fig 1. Comparison between in a panic and normal situation.

It was suggested in ① that an emergency braking could be detected by the initial pedal travel speed. Then brake pedal travel speeds and pedal strokes in the test results, under various driving conditions including normal braking operation were compared and sorted out as shown in (Fig 2.). These results indicated that an emergency braking could not be detected adequately by the pedal travel speed alone since the results overlapped with the braking operation during highway driving. However, it was found that an emergency braking can be detected by the travel speed and the pedal stroke.

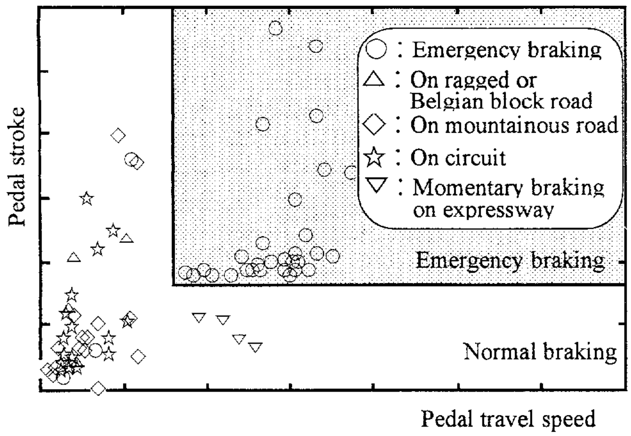

Fig 2. Results of investigation on pedal stroke.

Control Concept

To help inexperienced drivers achieve the stopping distance of experienced drivers while taking into consideration the braking behavior of the driver who cannot apply sufficient braking effort in the emergency situation described above, an assistance in adding the braking force is needed. Thus, the following two control concepts were studied.

(A) The maximum braking force is applied whenever an emergency braking is detected.

(B) After providing assistance in adding a certain braking force, the braking force is controlled to reflect driver's intention.

While the concept (A) would be effective if the driver is not accustomed to applying sufficient braking effort , the experienced driver would feel disagreeable with the System since a certain maximum braking force would be applied without regard to the driver's intention of controlling the deceleration. Consequently, the range for detection of emergency braking had to be extremely limited, which would significantly compromise the advantage of the System. On the other hand, in the concept (B), owing to the control feature, the detection of an emergency braking would not be unnecessarily limited, would work to the advantage of a greater number of drivers, and would help drivers prevent traffic accident. Therefore, the development work was carried out according to the concept (B).

System Configuration

This system is designed to provide assistance in applying the braking force by using an ABS pump. When the expected popularization of ABS in the future is taken into consideration, the system has the widest scope of application, and will be the mainstream system of the future in our opinion.

The system configuration is shown in (Fig 3.).

In this system, the fluid-pressure sensor for detecting an emergency braking, the fluid-pressure shut-off valve (SMC) for providing assistance in applying the braking force, and the inlet valve (SRC) at the end of the pipe connected with the master reservoir were added to the conventional ABS including actuator control valve, pump and reservoir. The motor-driven ABS pump is activated to provide assistance in applying the braking force in excess of the actually-applied braking force.

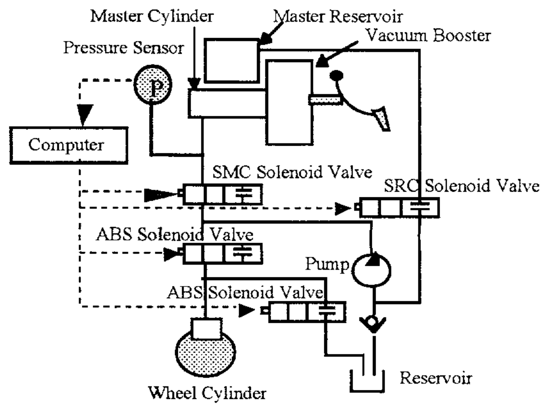

Fig 3. Hydraulic Brake Assist System configuration.

Operating Pattern of the System

Although the control mechanism consisting of the detection of the start and end of control is considered sufficient to provide assistance in achieving the maximum braking force, an mechanism to control the braking force in the way the driver intended is necessary to make most drivers feel agreeable with the system. The basic operation of the system to achieve the controllability of the braking force is shown in (Fig 4.). It shows a change in the brake effectiveness (brake fluid pressure) in each control stage after the start of control. Each control stage (mode) is outlined below:

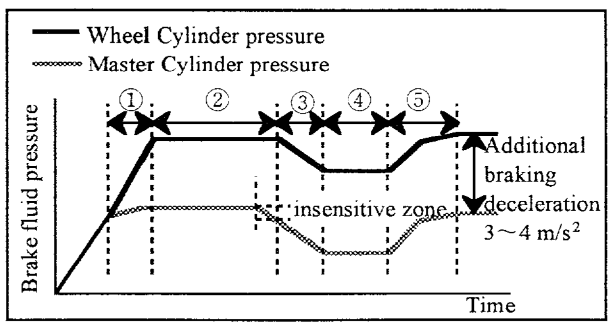

Fig 4. Pressure control pattern in a panic braking.

①Start of pressure increasing mode

When an emergency braking is detected, the brake effectiveness is increased by applying a certain additional braking force by rotating the pump, closing the shut-off valve, and opening the inlet valve to take in the brake fluid from the reservoir. The pressure increasing gradient is fixed in terms of the driving pattern of the inlet valve (Fig 5.).

②,④Pressure retaining mode

When the driver maintains the pedal effort, the shut-off valve and the inlet valve are closed to maintain the amount of system-assisted braking force, and the intake of brake fluid from the reservoir is stopped, and the application of additional braking force is stopped (Fig 6.). The pump keeps rotating in consideration of the response of the pressure increasing control.

③Pressure decreasing mode

When the brake pedal is relaxed, the inlet valve is closed, and the shut-off valve is opened to return the brake fluid to the master cylinder in order to reduce the system-assisted braking force. To emphasize the controllability of the system, the deceleration decreasing gradient is controlled according to the pedal release speed (the brake fluid pressure sensor decreasing gradient), and the reduction in deceleration is controlled according to the pedal release (the decreasing amount of the brake fluid pressure sensor value). By controlling the decreasing gradient of deceleration and the reduction in deceleration in this way, the system intends to have the driver's intention reflected in the actual deceleration. The pressure decreasing gradient is fixed in terms of the driving pattern of the shut-off valve (Fig 7.). However, since inexperienced drivers tend to unintentionally reduce the pedal effort in an emergency braking operation, the system is designed with the insensitive zone to slow the decrease in the system-assisted braking force when the foot pressure on the brake pedal is slowly reduced.

⑤Pressure increasing mode

When the foot pressure on the brake pedal is increased again, the system emphasizes the controllability feature by controlling the deceleration increasing gradient according to the pedal travel speed (the brake fluid pressure sensor increasing gradient), and the increase in deceleration according to the additional pedal effort (the increasing amount of the brake fluid pressure sensor value). By controlling the increasing gradient of deceleration and the increase in deceleration in this way, the system intends to have the driver's intention reflected in the actual deceleration (Fig 5.).

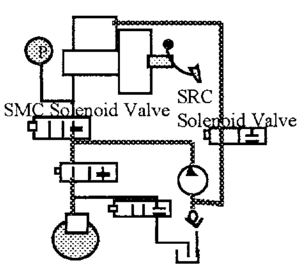

Fig 5. Pressure-increasing mode.

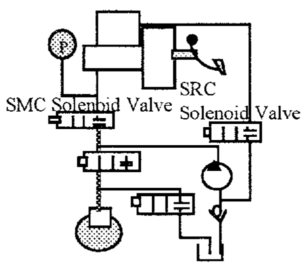

Fig 6. Pressure-retaining mode.

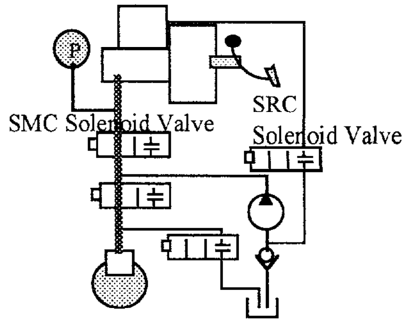

Fig 7. Pressure-decreasing mode.

Key Points in Control Mechanism

To achieve the operation of the control mechanism without making the driver hold unnatural feeling, the following points were taken into consideration in the development of the system.

<u>Setting of Appropriate Start-of-Control Timing</u> - If the control mechanism is switched on too soon after the detection of an emergency braking, the system will not achieve the intended effect, and activation of the control mechanism may even be considered unnecessary for the driver who can apply sufficient braking effort. If the control mechanism is switched on too late, deceleration will be rather bumpy and uncomfortable (See Fig. 8). Thus, the start-of-control was appropriately timed by switching on the control mechanism when the master cylinder fluid pressure gradient (the driver's pedal travel speed) has decreased to a certain level.

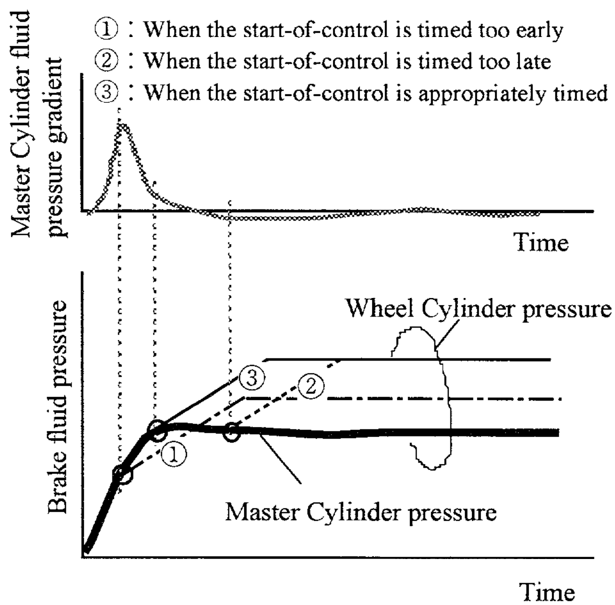

Fig 8. Waveform of cotrolled fluid pressure under different start-of-control timings

<u>Achievement of Optimum Amount of Additional Braking Force</u> - According to body sensing, the initial amount of additional braking force at 3-4 m/s2 in deceleration seemed appropriate. Then, the intake time (T) from the reservoir necessary for the specified amount of additional braking force was determined from the following equation:

$$T = Q / K \times P \times G \qquad (1.)$$

where, Q : The amount of fluid necessary for an increase of the unit fluid pressure in the wheel cylinder (in cc/MPa); K : Delivery capacity of the pump (in cc/s); P: The fluid pressure of the wheel cylinder necessary to increase the unit deceleration as determined by the vehicle specification (in MPa/m/s2); G : Specified system-assisted deceleration (in m/s2)

<u>Pedal Feeling without Disagreement</u> - In this system, the relationship between the pedal stroke and the fluid pressure changes to feed the brake fluid in the reservoir into the brake system. Thus, in the range of pedal effort where the specified amount of intake fluid will sufficiently activate ABS, the amount of intake fluid is estimated from the intake time, and determined so that the intake brake fluid is guarded by the maximum possible deceleration on a dry asphalt road (Fig 9.). In other words, the amount of system-assisted braking force is determined on a map so that the intake amount is decreased as the master cylinder fluid pressure at the start of control is increased. As a result, the system achieved the pedal feeling with little disagreement during the operation of the control mechanism under various road conditions.

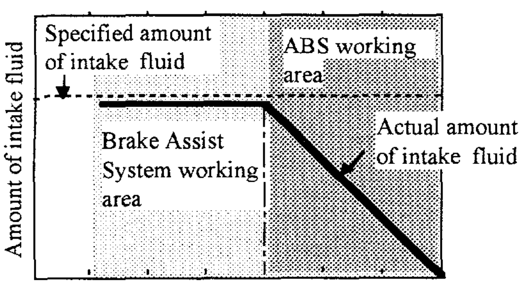

Fig 9. Intake fluid amount control map.

Effectiveness of the System

The relationships between the pedal effort and the deceleration of the vehicle with and without the Brake Assist System are shown in Fig. 10. The chart indicates an additional deceleration of about 3 m/s2 until the pedal effort reaches 160 N. The deceleration remained constant from that point on because the deceleration did not increase due to its dependence on the coefficient of friction of the road surface.

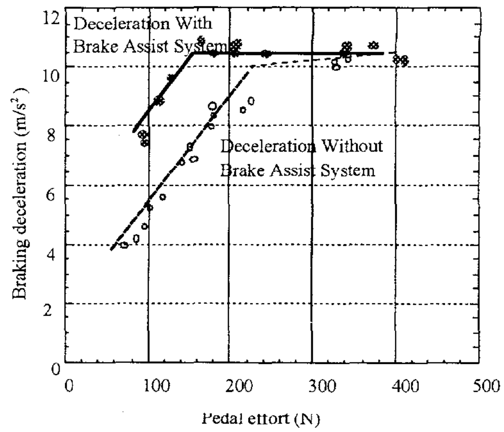

Fig 10. Comparison of braking deceleration between cases with and without Brake Assist System

(Fig 11.) compares the braking distances in the cases of ordinary drivers in emergency braking situations with and without the Brake Assist System. The Brake Assist System was proven effective as the braking distance with the Brake Assist System was shorter than the distance without the Brake Assist System. Since the Brake Assist System did not produce better results for experienced drivers who could stop in a short distance without the System, the System cannot be expected to prove its effects for experienced drivers. Nonetheless, the System will not impair the braking performance of the vehicle.

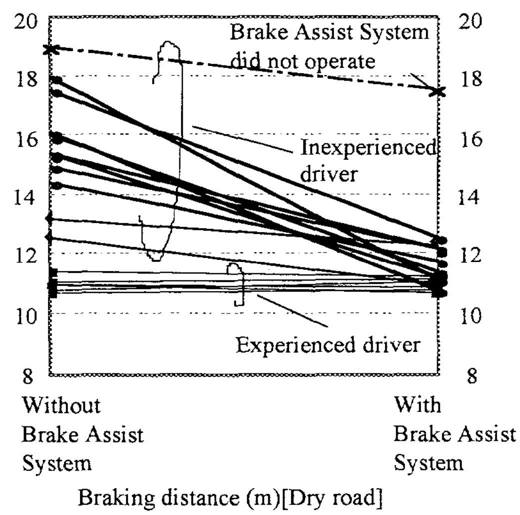

Fig 11. Comparison of braking distance between cases with and without Brake Assist System

CONCLUSION

The investigation and the analysis of the emergency braking behavior of inexperienced drivers demonstrated that an emergency braking is detectable. Controllability was the key factor in this system, and a system based on the brake fluid pressure sensor and the ABS actuator was developed. The newly-developed system showed that it was capable of assisting inexperienced drivers in the braking operation, and producing the braking performance achieved by experienced drivers. While the conventional ABS, traction control system (TRC) and vehicle stability control system (VSC) are the technologies designed to assist the driver by expanding the vehicle stability range, the Brake Assist System is a new type of active safety technology aiming to allow every driver to have a complete command of vehicle's performance. However, the system is by no means capable of exceeding the physical limits. Therefore, it is another goal of ours to make inexperienced drivers more aware of traffic safety without placing too much confidence on the Brake Assist System.

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