Method for Shortening Idle Running Time Using Body Suspension Air Spring Pressure

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As one of the measures to quickly stop high speed vehicle in the emergent event such as an earthquake, we have devised a method of reducing brake idle running time by supplying the vehicle body suspension air spring pressure preferentially to the brake cylinder pressure. This paper reports on tests to verify this method aimed at shortening idle running time in braking, carried out with Shinkansen bogies placed on a test plant and shows the result of numerical simulations using data from trains in revenue service.

Keywords: car-body suspension air spring, idle running time, brake control unit, bogie auxiliary air reservoir, double check valve

1. Introduction

The maximum running speed of Shinkansen is currently 320 km/h. This is expected to be increase to 360 km/h in the future. To accommodate this anticipated rise in speed, new braking technologies are being developed [1]. With mechanical disc brakes, the kinetic energy that needs to be absorbed by the brake increases as a function of the square of the increase in vehicle running speed. Based on the anticipated increase in running speed, this means that higher performance disc brakes will be needed especially if the aims is to achieve the same deceleration that is obtained today. In addition, with these higher running speeds, it is necessary to maintain current braking distances of around 4000 m (for the initial braking speed of 300 km/h) when earthquakes are factored in. All these factors pose numerous challenges for the development of new braking technologies.

With this in mind, this study looked at the possibility of shortening idle running time as a way to help shorten braking distances. In a past study [2], a method utilizing the existing anti-skid valve was proposed to help reduce braking distance. That method, however, required the valve to be charged with air pressure before the brake is applied. Therefore, this study sought a method that could be used more widely with fewer limitations.

Idle running time refers to the time elapsed from a brake command to when the braking starts to take effect. Figure 1 shows this as the time consisting of \(t_0\) and \(t_1\), at which the brake cylinder pressure (hereafter “BC pressure”) reaches 63.2% of the specified pressure level. More specifically, \(t_0\) is the time delay between a brake command to when BC pressure starts to rise and \(t_1\) is the time elapsed from when BC pressure starts to rise to when the pressure reaches 63.2% of the specified level.

The idle running time for automobiles is generally considered to be around 0.75 seconds from when the driver notices a danger and steps on the brake pedal to when the vehicle starts to decelerate. For railway vehicles, the idle running time is longer than that, with the design idle running time normally set to 1.5 seconds from the brake command to when a vehicle starts to decelerate. The 1.5 seconds takes into account the following: it takes longer for regenerative brakes to start to take effect; air has a higher compressibility than hydraulic fluid; and lines between the brake control unit and the brake shoes and pads are longer than in automobiles.

The higher the running speed, the greater the impact of idle running time on braking distance. Therefore, the need to shorten idle running time is stronger for Shinkansen trains.

2. Air brake system for Shinkansen vehicles

Figure 2 shows the schematic diagram of an air brake system. Air lines are indicated with blue arrows and command wires with red arrows. Anti-skid valves are omitted from the diagram.

A brake command (braking notch 1 to 8, emergency braking notch) is sent from the brake controller etc. to the brake control unit, which then calculates a command pressure (hereafter “AC pressure”) based on the notch and car
body suspension air spring pressure (hereafter “AS pressure”) under the specific load at that time and has the electro-pneumatic change valve generate the AC pressure through current control and send it to the relay valve. The relay valve then sends a high flow of air pressure directly to either the pressure intensifier or pneumatic calipers and the caliper piston presses the pad with the BC pressure against the disc, generating the braking force. Idle running time results from the time taken for AC pressure to be calculated, generated and sent to the relay valve and for BC pressure to be transmitted from the relay valve through the brake line (about 10 m or longer) to either the pressure intensifier or pneumatic calipers.

At or above a certain running speed, when a brake command is sent, actuating pressure (hereafter “TC pressure”) is also sent to the wheel tread cleaning device. As the TC pressure line has roughly the same length as the BC pressure line, there is a delay before the wheel tread cleaning device starts to operate. The wheel tread cleaning device presses an abrasive block onto the wheel tread to clean and roughen the tread and limit wheel slip and skid, which greatly helps the performance of the adhesive brake on Shinkansen vehicles as they are not equipped with wheel tread brake shoes.

### 3. Air brake system using air spring pressure

#### 3.1 System overview

An evaluation was made of the possibility of using the pressure in the auxiliary air reservoir on the bogie, or AS pressure, as a means of shortening the idle running time. It was determined that the configuration of such a system must meet the following four requirements:

1. The air pipe line must be as short as possible.
2. Pressure regulating valves and control units must not be used.
3. There must be a braking effect even when the BC hosing has broken such as in a derailment or when the brake control unit has failed.
4. Pressure can be detected.

Table 1 shows examples of set BC and TC pressures during emergency braking for Shinkansen vehicles. As shown in the table, all of those pressures are higher than their respective AS pressures for any speed.

This means that supplying AS pressure directly to either the pressure intensifier or the pneumatic calipers or to the wheel tread cleaning device should not generate excessive braking force or cause significant frictional heat and/or skidding.

In addition, given that the differential pressure valve is designed to open at 147 kPa (of differential pressures
measured while running, 98.6% are below 120 kPa), even when there is a maximum pressure difference between the two auxiliary air reservoirs on the bogie frame, AS pressure would be 240–360 kPa when empty and 390–510 kPa when fully loaded, both of which are still below the respective BC pressures. Like BC pressure, AS pressure is monitored continuously by a pressure detection unit, which is also capable of detecting a punctured air spring.

Assuming that AS pressure is available for braking, a high flow of AS pressure would be supplied from the nearest source when a brake command is issued, thereby shortening idle running time. Subsequently, BC and TC pressures would be supplied until the specified levels are reached. The combined form of those pressures is shown in Fig. 3, which indicates that idle running time would be shortened from $t_0 + t_1$ to $t_2$.

To help verify this assumption, comparative simulations were conducted to assess the effect of AS pressure on idle running time when it was available for braking and when it was not. For the simulation, the model of an actual vehicle air brake line on a bogie was created and ran from a compressor to a brake control unit to calipers and, using the model, pressure was measured immediately upstream from the calipers. AS and BC pressures were set to 300 kPa and 400 kPa respectively. Pressure intensifiers were not included in the model.

During the simulation, it was found that idle running time with AS pressure supply was about 0.77 seconds and that without AS pressure supply was 1.2 seconds. With that, a reduction in idle running time of around 36% would be expected by supplying AS pressure for braking (Fig. 4).

Figure 5 shows a schematic of the air brake system (hereafter "AS brake") using AS pressure as proposed in this paper. The auxiliary air reservoir (2) supplies the BC hosing. The auxiliary air reservoir (1) supplies the TC hosing.

### Table 1 Examples of set pressures for emergency braking

| Speed (km/h) | 0   | 70  | 120 | 230 | 300 | 320 |
|-------------|-----|-----|-----|-----|-----|-----|
| AS pressure when empty (300kPa) | 540 | 540 | 540 | 480 | 420 | 400 |
| TC pressure (kPa) | | | | | | |
| AS pressure when fully loaded (450kPa) | 700 | 700 | 700 | 620 | 540 | 520 |
| TC pressure (kPa) | | | | | | 490 |

Note: $\pm$ 20kPa allowable

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**Fig. 3 Combined pressures schematic**

**Fig. 4 Results of AS pressure simulation**

3.2 Bench test on a bogie

#### 3.2.1 Simulation using an actual bogie

Bench tests were conducted using an actual Shinkansen bogie. An air pipe line was drawn from the water pressure test ports on 2 auxiliary air reservoirs (total capacity 140 liters) through double check valves with 3-port solenoid valves (100 VDC) to the BC and TC hosings on the bogie. The idle running time elapsed before actuation of the pressure intensifier and that of the abrasive block, both measured on the actual bogie, were 0.95 seconds and
0.9 seconds, respectively. To simulate this, a time delay was given to BC and TC pressures: the BC pressure supply command was issued 0.25 seconds after the brake command and the TC pressure supply command was issued 0.5 seconds after the brake command. It should be noted that in the simulation, air pressure was actually supplied through the brake control unit on the bogie.

3.2.2 Test conditions

Table 2 shows conditions in which the bench tests were conducted. The tests were conducted under three vehicle loading conditions: empty (no passengers), partially loaded (75% of capacity) and fully loaded (150% of capacity). For each of these conditions, various AS and BC pressures were used. To simulate lateral uneven loading, three cases, (1) to (3) in the table, were used for each of the loading conditions in which there was a pressure difference of 120 kPa (± 60 kPa), the maximum pressure of the range to which the differential pressure valve does not respond, between AS1 and AS2 pressures. Measurements were taken of brake command, BC pressure supply command (pressure supply from brake control unit), TC pressure supply command (pressure supply from brake control unit), AS pressure supply command.
ply command, various pressures, the pressure intensifier pressure, the pressing force of the pad and pressing force of the abrasive block. For each of the conditions, there were three braking sessions.

AS pressure was supplied at the same time as brake commands were issued. In order not to disrupt the pressure regulation of skid control, AS pressure supply was stopped after two seconds and the residual pressure was discharged through the exhaust solenoid valve positioned between the supply solenoid valve and the double check valve. In the simulation on an actual bogie, the BC and TC hoses were connected to the bogie just like on an actual bogie. In the simulation of the AS brake, the hoses mentioned above and the pipes from the auxiliary air reservoirs were connected to the inlets of the double check valves, which were then connected using BC and TC hoses from their outlets to the bogie lines.

### 3.2.3 Test results

(1) Idle running time

Figure 6 (a) shows results that indicate significantly shortened idle running time. Figure 6 (b) shows results that indicate idle running time only slightly shortened and therefore still regarded as being roughly the same as on current vehicles. When the supplied AS pressure eventually reached 63.2% of both the BC and TC pressures, the idle running time was shortened by 0.6–0.7 seconds as shown in Fig. 6 (a).

On the other hand, when the supplied AS pressure failed to reach 63.2% of the two pressures, the idle running time was shortened by only about 0.1 seconds as shown in Fig. 6 (b). That said, even when the results were roughly the same as what could be expected on current vehicles, the supplied AS pressure reached about 40% of the specified BC pressure and about 50% of the specified TC pressure at an early stage. This resulted in a shortening of \( t_0 \), the time delay between the brake command and BC pressure starting to rise, and a certain pressing force generated on both the brake pad and abrasive block, apparently helping to improve braking force. In some conditions, the supplied AS pressure slightly exceeded the specified BC and/or TC pressures but was still within the allowable (± 20 kPa) range.

Figure 7 shows the relationship between the ratio of supplied AS pressure to the specified BC pressure and the idle running time of the pressure intensifier, and that between this ratio and the idle running time of the abrasive block. The "Without AS pressure" in the legend means that the system was equipped with double check valves and not supplied with AS pressure.

When AS pressure was supplied, the idle running time of the pressure intensifier was about 0.2 seconds with a pressure ratio of 0.66 or above, and about 0.7 seconds shorter than on actual vehicles. Likewise, the idle running time of the abrasive block was shortened to about 0.3 seconds with a pressure ratio of 0.66 or above. These results show that in both cases, the idle running time will be shortened with AS pressure exceeding a pressure ratio of 0.632, the reference value for idle running time calculation, while it stays roughly the same as on actual vehicles with a pressure ratio below the reference 0.632.

Figures 8 to 10 show the relationship between running speeds and idle running time based on the relationship between vehicle conditions and specified BC pressures. Idle running time is shown shortened with a running speed of 270 km/h or above on some partially loaded vehicles and fully loaded vehicles, with the idle running distance at 270 km/h estimated to be about 60 m shorter.

(2) Drop in AS pressure

During AS braking, AS1 pressure, the source of BC pressure, dropped as much as 28 kPa and AS2 pressure, the source of TC pressure, as much as 21 kPa (Fig. 11). The magnitudes of the pressure drop are relatively large.
This is probably because bench tests were conducted without the air springs that are typically installed on actual vehicles, resulting in a relatively small total air reservoir capacity. The pressure drop is not large enough to open the differential pressure valve and therefore should not have any practical impact on normal vehicle operation. That said, the observed pressure drop will need to be studied further for any impact on the vertical vibration of car bodies.

3.3 Simulation using revenue service train operation data

Figure 12 shows the simulated idle running times of pressure intensifiers during AS braking based on AS pressure data from a whole train running on revenue service.

The idle running time was obtained based on regulated AS pressures, which are fixed values specific to each station where the train stops, BC pressures of emergency braking for varying running speeds calculated under specific loading and the ratio of AS pressure to BC pressure.

Like the results from in the bench tests on a bogie discussed in the previous section, it was found that the idle running time was shortened to about 0.2 seconds for running speeds of 270 km/h or above and that there was no significant difference in idle running time between the left-hand and right-hand AS pressures.

4. Conclusion

This paper presents a study in which a method for shortening the idle running time using car body suspension air spring pressure was developed as a means of rapidly stopping Shinkansen vehicles during earthquakes or other emergencies.

The method is designed to shorten idle running time
by supplying air pressure, or braking pressure, from the existing auxiliary air reservoirs on the bogie directly to the calipers without going through car body piping or braking pressure controllers.

Bench tests using an actual Shinkansen bogie found that it was possible to shorten the idle running time to about 0.2 seconds from about one second. A similar time-shortening effect was also verified when the braking pressure was supplied to the wheel tread cleaning device.

In a simulation using AS pressure data from a train running on revenue service, a time-shortening effect similar to that installed in the bench tests was observed for running speeds of 270 km/h or more.

Going forward, the devised method will be tested on actual vehicles to verify these effects.

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