

Development of Two-sensor Crash Detection Method for Motorcycle Airbag System

Yuki KOBAYASHI*

Takumi MAKABE*

ABSTRACT

An airbag system for a motorcycle was developed by establishing a crash detection method using two accelerometers, which reduced the number of sensors compared to the previous system. In the previous system, the Safing Judgment method was employed based on signals from four accelerometers. In the newly developed system, the judgment method was established with only two sensors by utilizing the difference in characteristics of the waveforms of sensor outputs. Installation freedom for the sensors was enhanced due to the space for installation gained by the removal of two sensors.

1. Introduction

Exploratory studies of motorcycle airbags began in the 1970's. In those studies, airbag concepts were examined. The crash detection method was also studied as a vital element of an airbag system. In the studies previously conducted, preliminary crash detection methods were proposed based on impact measurements in a front wheel-suspension system⁽¹⁾⁻⁽³⁾.

Kuroe et al. proposed a system with accelerometers installed on each suspension fork leg, and preliminary studies of an impact sensing system for a large scooter type and a large touring type motorcycle were conducted^{(4), (5)}. This system used the averaged value of the signals from the two accelerometers on each of the two front suspension fork legs to remove the influences of the rotational movement of the steering system, which occurs during a collision. Based on these detection methods, Honda developed a crash detection method that used the signals from a total of four accelerometers, two on each front suspension fork leg⁽⁶⁾. This system was applied to the 2006 Honda Gold Wing, which was released as the first airbag system for a production motorcycle. Figure 1 shows the configuration of the airbag system applied to the Gold Wing.

Four sensor signals were utilized in the system to satisfy several requirements, such as a reduction of the influence of the steering motion in a crash event and inclusion of a fail-safe function. However, this system was only applicable to particular models because the space availability for the installation of accelerometers depended on the structure of the motorcycle. In many cases, the space availability was limited because of the suspension arrangement, such as inverted telescopic, trailing links, etc., the suspension length, and pre-installed devices, including brake calipers.

This study was intended to overcome those restrictions and we tried to establish a crash detection method using the signals from just two accelerometers, one each on the right and the left front suspension fork legs.

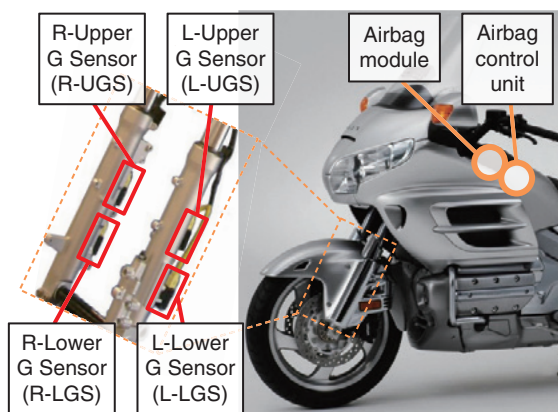


Fig. 1 Configuration of first airbag system for Gold Wing

2. Previous System

Table 1 shows the major specifications of the motorcycle shown in Fig. 1.

In this section, the data was measured using this motorcycle.

2.1. Crash Detection Method

Figure 2 shows a block diagram of the crash detection method for the previous system.

This system makes a crash judgment by means of four

* Motorcycle R&D Center

Table 1 Specifications of test motorcycle

Length	(mm)	2,630
Width	(mm)	945
Height	(mm)	1,525
Wheelbase	(mm)	1,690
Curb mass	(kg)	425
Engine displacement	(cm ³)	1,832

accelerometers: R-LGS (Right-Lower G Sensor), L-LGS (Left-Lower G Sensor), R-UGS (Right-Upper G Sensor) and L-UGS (Left-Upper G Sensor).

The Main Judgment was used to determine whether a crash had occurred that was severe enough to require deployment of the airbag.

The Safing Judgment acted as a fail-safe function to prevent the unwanted deployment of the airbag, due to a malfunction of, or an erroneous signal from, the accelerometers used for the Main Judgment.

2.2. Averaging Process

This method adopted the judgment processes based on the averaged values of the signals from the right and the left accelerometers. The averaging processes effectively compensated for the effect caused by the rotation of the front wheel-suspension system being forcefully steered by the impact in the early stages of a crash.

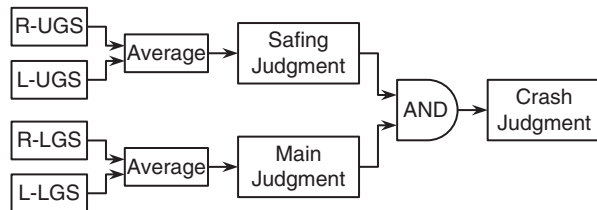
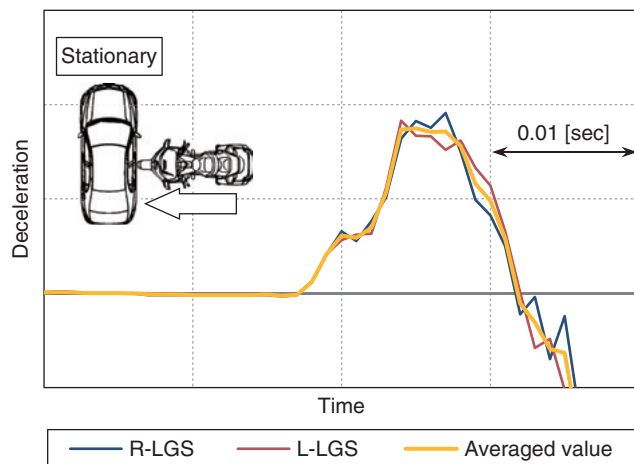
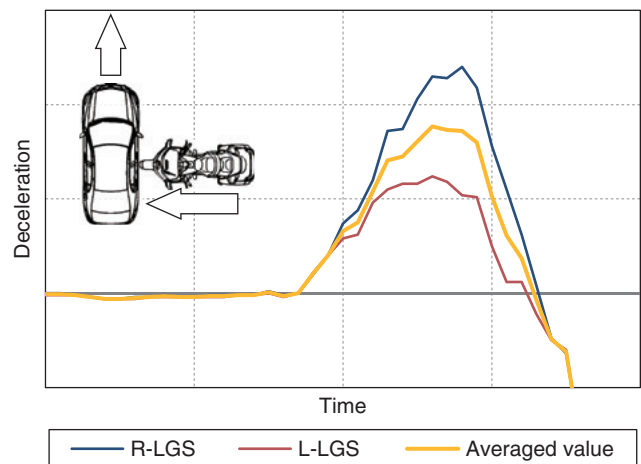


Fig. 2 Block diagram of previous crash detection method



(a) Crash on stationary vehicle



(b) Crash on moving vehicle

Fig. 3 Comparison of LGS deceleration

As an example of this effect, Fig. 3(a) and (b) show the deceleration signals measured at the front suspension fork legs in the two configurations of impact in line with ISO13232⁽⁷⁾. These impact configurations differ in the speed of the opposing vehicle; (a) is stationary and (b) is moving. Other conditions (e.g. motorcycle impact speed, contact point, relative heading angle) are the same between the two configurations.

While the deceleration value of R-LGS was equivalent to that of the L-LGS in the configuration of the stationary car impact, shown in Fig. 3(a), the deceleration value of the L-LGS was lower than that of the R-LGS in the configuration of the moving target impact, shown in Fig. 3(b). This is because the front wheel-suspension system was forcibly steered to the right by the opposing vehicle, which was moving in a lateral direction to the motorcycle. However, the averaged value of the deceleration values from the R-LGS and the L-LGS was equivalent in both impact configurations. Consequently, by using the averaging process, the effect of the steered front wheel was nearly eliminated.

2.3. Safing Judgment

The Main Judgment, which was based on the averaged signals of the R-LGS and the L-LGS, detected a crash erroneously when the R-LGS or the L-LGS output a high deceleration value due to a malfunction of the accelerometer. The Safing Judgment was provided in order to prevent the unwanted deployment of the airbag during normal operation.

In the previous airbag system, in addition to the accelerometers for the Main Judgment, two other accelerometers (the R-UGS and the L-UGS) were installed on the right and the left front suspension fork legs for the Safing Judgment, which operated also based on the averaged value. As crash detection was made by the logical conjunction of the Main Judgment and the Safing Judgment, even if either judgment improperly detected a crash due to the failure, or the like, of one accelerometer, the other judgment prevented an improper deployment signal to the airbag inflator.

The functions required for the Safing Judgment mentioned above are summarized as follows;

(1) Fail-safe function

The Safing Judgment is required to be always OFF in normal riding conditions. This is because the prevention of an airbag deployment is required when the Main Judgment detects a crash incorrectly.

(2) Inhibition of unnecessary prevention of a proper deployment of the airbag

The Safing Judgment is required to be ON under conditions that require proper deployment of the airbag. At the same time, there should not be any prevention of deployment based on crash detection by the Main Judgment.

In order to meet these requirements, the Safing Judgment necessitates the ability to discriminate between collisions and events during normal riding conditions.

3. Two-sensor Crash Detection System

The data used in this section was measured using the same vehicle as introduced in section 2.

3.1. Crash Detection Method

Figure 4 shows a block diagram of the two-sensor crash detection method. Two upper accelerometers were removed from the previous system. Crash detection was performed by the logical conjunction of the Main Judgment, which was calculated using the averaged value of the R-LGS and the L-LGS, and the R-Safing Judgment and the L-Safing Judgment, which were calculated using the output of the R-LGS and the L-LGS. With this configuration, for example, if an output abnormality occurs in the R-LGS, the Main Judgment and the R-Safing Judgment may incorrectly detect the occurrence of a crash. However, because the L-Safing Judgment is OFF, an undesired deployment can be prevented.

In the two-sensor crash detection system, the same judgment process as in the previous system was applied to the Main Judgment. Therefore, the Main Judgment had comparable discrimination performance. However, the averaging process was not applied to the signals for the Safing Judgments. The individual signals from the R-LGS and the L-LGS were inevitably affected by the steering motion of the front wheel as described earlier. This is why it was necessary to develop a different method for this system.

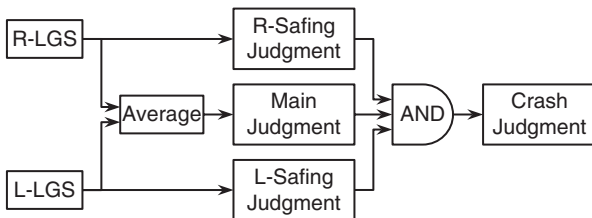


Fig. 4 Block diagram of two-sensor crash detection method

3.2. Safing Judgments Based on Unaveraged Signals

The same target performance as achieved by the previous method was set for the Safing Judgments. Discrimination between events during normal riding conditions and collisions that accompany the effect of the steered motion was required for the Safing Judgments.

By the way, normal riding conditions include running on rough roads. Figure 5 shows the waveforms measured when running on a specific rough road. The rough road included some potholes, and a deceleration peak of G_0 was recorded when the vehicle ran over the pothole.

To compare with those rough road running conditions, the collision where a passenger vehicle gave the impact to a motorcycle with the handle fully steered to the left was considered as an example of a situation where the steering motion occurred. The waveforms measured in such a collision are shown in Fig. 6. The scales of the vertical axes of Figs. 5 and 6 are the same.

There was a difference between the measured decelerations of the R-LGS and the L-LGS. The deceleration peak of the L-LGS was 2.2 times as big as G_1 , which was the deceleration peak of the R-LGS caused by the collision accompanying the left-steered state. The magnitude of G_1 was the same level as G_0 (shown in Fig. 5). Therefore it was

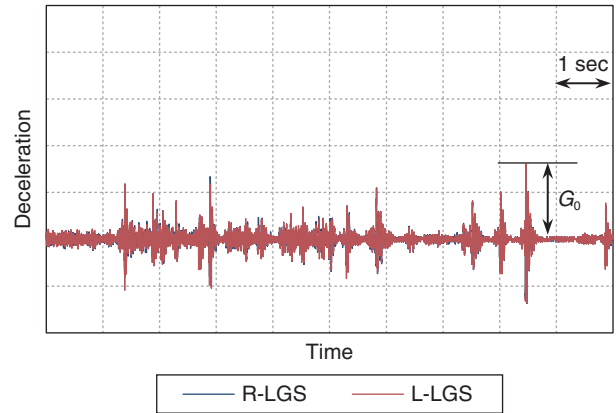


Fig. 5 Deceleration time history in rough road running

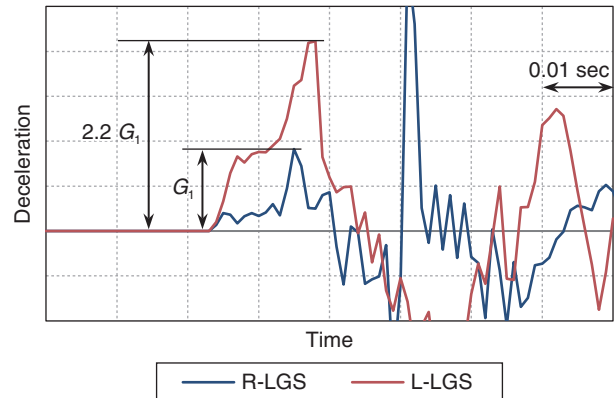


Fig. 6 Deceleration time history in steered collision

concluded that the Safing Judgment could not be conducted by just comparing the peak deceleration values.

3.3. Frequency Characteristics of Signals

Figure 7 shows the waveform in the vicinity of peak value of the waveform measured during rough road running, as shown in Fig. 5. The signals measured during rough road running show damped oscillation waveforms.

The spectrograms of measured deceleration values are shown in Fig. 8. The vertical axis of the figure indicates

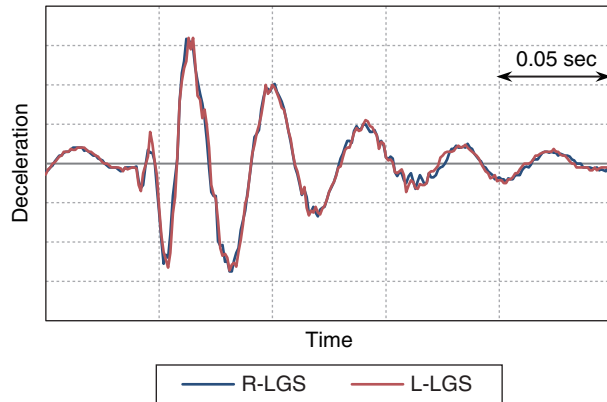


Fig. 7 Oscillation waveform of front suspensions

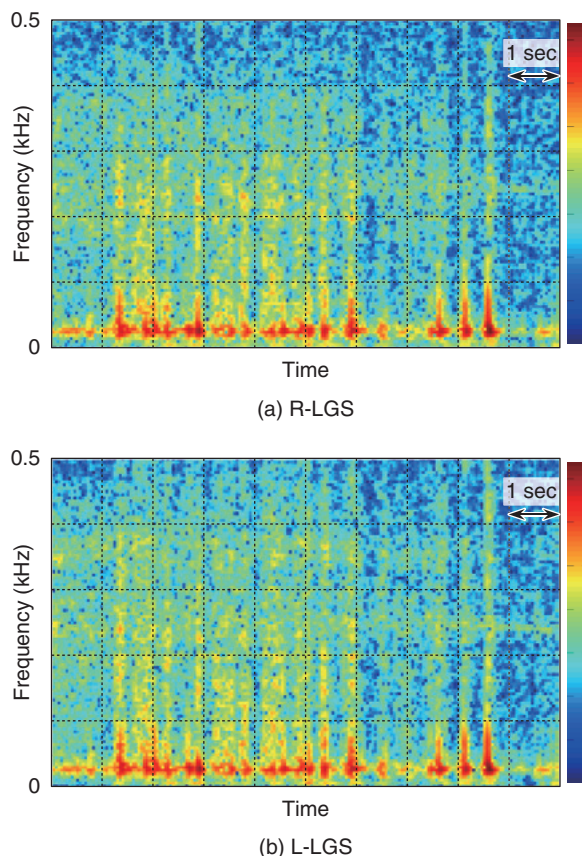


Fig. 8 Spectrogram of waveform of deceleration measured during rough road running

the frequency, the horizontal axis indicates the time of the measurement, and the colors of the pixels indicate the intensity of the signals.

During rough road running, random-seeming excitation forces are applied to the front wheel-suspension system with the uneven road surfaces. However, the spectrograms show high spectral density at around a fixed low frequency of 0.02 kHz. This frequency is almost equal to that of the natural frequency of the front wheel-suspension system. As the direction of the sensitivity of the accelerometer was perpendicular to the direction of the front suspension stroke, the acceleration along the axis of the suspension, which was caused by the suspension strokes absorbing the road unevenness, was not detected by the accelerometers. On the other hand, the front wheel-suspension system, which had a cantilever structure, was vibrated back and forth by the road unevenness in an orthogonal direction to the stroke of the front suspension. The oscillation cycle period during rough road running was determined by the inherent characteristics of the front wheel-suspension system, regardless of the attributes of the road unevenness.

We made the same frequency analysis on the waveforms of the decelerations measured in the steered collision (Fig. 9).

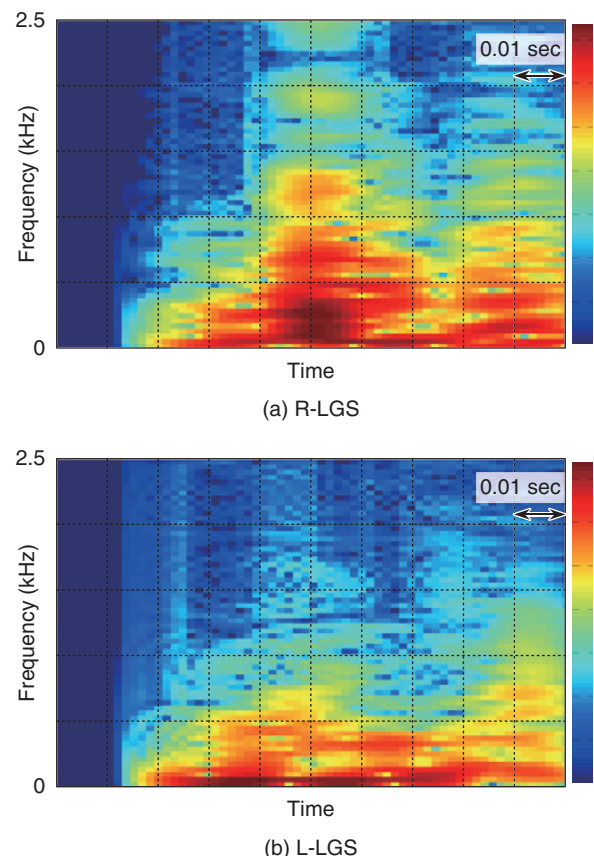


Fig. 9 Spectrogram of waveform of deceleration measured in steered collision

As the front fork was deformed beyond the extent of the elastic deformation during the steered collision, the detected waveform had no effect of the natural oscillation. As a result, the spectrum was dispersed over a wide area below 1.0 kHz.

3.4. Characteristics of Displacement-Deceleration Curve

Based on the spectral characteristics of the waveforms mentioned in section 3.3, we tried to establish a method to discriminate between a collision and rough road running. For this purpose, a theoretical analysis was conducted using approximated waveforms of the data.

To conduct the approximation of the waveform to present rough road running as part of normal riding conditions, all of the data should have been considered as the target data for the approximation. This was because the Safing Judgment process should stay OFF during any normal riding conditions. On the other hand, for the approximation of the waveform to present the actual impact in a steered collision, the deceleration that appeared in the initial part of the waveform was the only part to be approximated. This was because the ON-judgment was executed based on only the deceleration that was generated in the early stage of the impact.

The deceleration waveform measured when running on rough roads is approximated by Eq. (1) as a damped oscillation.

$$m\ddot{x} = -kx - c\dot{x} \quad (1)$$

Where

- m : Mass
- k : Spring constant
- c : Damping coefficient

Assuming initial position $x(0)$ as 0 and initial velocity $\dot{x}(0)$ as v_0 , the solutions are as follows:

$$x(t) = \frac{v_0}{\sqrt{1-\zeta^2}\omega_0} e^{-\zeta\omega_0 t} \sin(\sqrt{1-\zeta^2}\omega_0 t) \quad (2)$$

$$\dot{x}(t) = \frac{v_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_0 t} \cos(\sqrt{1-\zeta^2}\omega_0 t + \phi) \quad (3)$$

$$\ddot{x}(t) = -\frac{v_0\omega_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_0 t} \sin(\sqrt{1-\zeta^2}\omega_0 t + 2\phi) \quad (4)$$

Where

$$\zeta = \frac{c}{2\sqrt{mk}}$$

$$\omega_0 = \sqrt{\frac{k}{m}}$$

$$\phi = \tan^{-1}\left(\frac{\zeta}{\sqrt{1-\zeta^2}}\right)$$

We determined each parameter from the results of measurements in actual running tests, and obtained the approximate waveform shown in Fig. 10. The damping coefficient ζ was 0.08. Assuming $\phi \approx 0$ which is considered feasible as $\zeta \ll 1$, Eq. (5) can be obtained from Eq. (2) and Eq. (4).

$$\ddot{x}(t) \approx -\omega_0^2 x(t) \quad (5)$$

Thus, the waveform of the acceleration represents an oscillation almost reverse in phase to that of the displacement.

On the other hand, the initial part of the waveform in a steered collision is approximated by half-sine wave as described in Eq. (6).

$$\ddot{x}(t) = \begin{cases} 0 & (t < 0) \\ a_0 \sin \omega t & (0 \leq t \leq \pi/\omega) \end{cases} \quad (6)$$

The displacement is expressed by Eq. (7).

$$x(t) = \begin{cases} 0 & (t < 0) \\ a_0 (\omega t - \sin \omega t)/\omega^2 & (0 \leq t \leq \pi/\omega) \end{cases} \quad (7)$$

Figure 11 shows the approximated waveform of the R-LGS shown in Fig. 6, where the constants of a_0 and ω are assumed to be the same as those in the damped oscillation in Eq. (4).

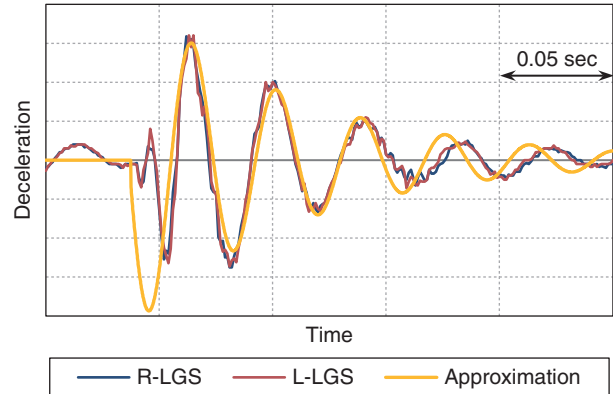


Fig. 10 Approximation of oscillation of front suspensions

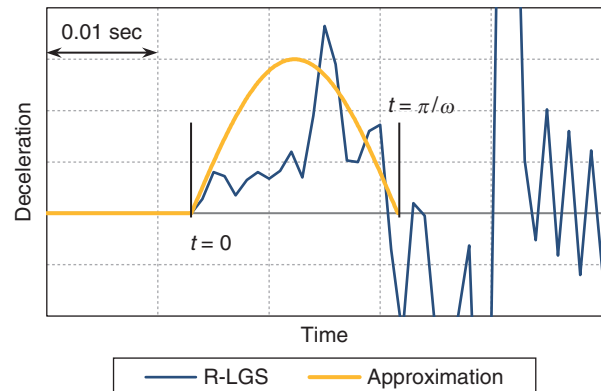


Fig. 11 Approximation of deceleration of steered collision

These approximated waveforms were transformed into the Displacement-Deceleration curves shown in Fig. 12. The vertical axis is defined for the deceleration and the horizontal axis is for the displacement. Curves of the damped oscillations are situated over the second and fourth quadrants as the displacement and the deceleration have opposite phases to each other. On the other hand, the half-sine wave is situated in the first quadrant as the displacement increases monotonically.

By utilizing these characteristics, it was possible to distinguish between rough road running and a steered collision with an appropriate judgment threshold line in the first quadrant of the Displacement-Deceleration plane.

3.5. Application to Crash Detection

Figure 13 shows a block diagram of the Safing Judgment applied to the two-sensor crash detection system.

The displacement (ΔS) was derived by short-term integration. The displacement (ΔS) of the damped oscillation, given by Eq. (4), is derived as follows;

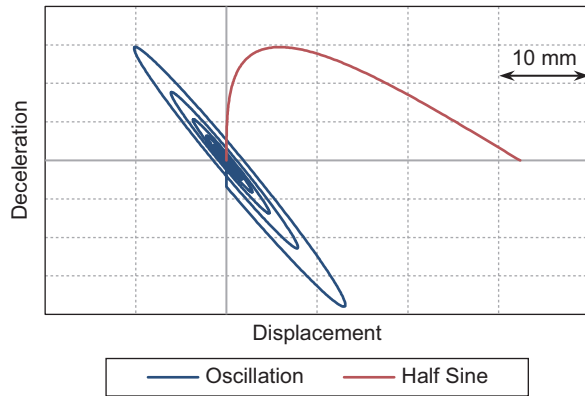


Fig. 12 Displacement-Deceleration curves of approximations

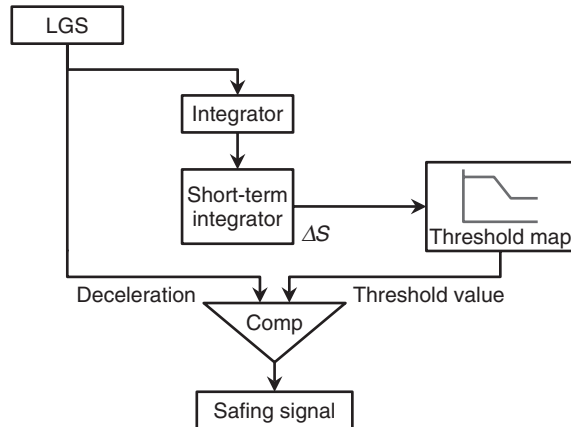


Fig. 13 Block diagram of Safing Judgment for two-sensor crash detection system

$$\begin{aligned} \Delta S(t) &= \int_{t-T_0}^t \dot{x}(t) dt \\ &= \frac{v_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_0 t} \sin \{ \sqrt{1-\zeta^2} \omega_0 t - \alpha(T_0) \} \end{aligned} \quad (8)$$

Where

ΔS : Displacement

T_0 : Interval of short-term integration

$$\sin \{ \alpha(T_0) \} = - \left| \cos \left(\frac{\omega}{2} T_0 \right) \right|$$

$$\cos \{ \alpha(T_0) \} = \left| \sin \left(\frac{\omega}{2} T_0 \right) \right|$$

The interval of the integration (T_0) was determined from the natural frequency and was defined so that the displacement was to be opposite in phase to the acceleration.

$$T_0 = \frac{\pi}{\sqrt{1-\zeta^2} \omega_0} \quad (9)$$

Figure 14 shows the Displacement-Deceleration curves of the actual data, which were measured during rough road running and a steered collision.

Plots on the first quadrant on the Displacement-Deceleration plane show that the status of the front wheel-suspension system is shifted to an area behind the normally located position and is decelerating as well. The ON area was set in this area and the threshold line was specified as shown in Fig. 14. Because it was translated that the impacts were applied to the extent at which the deformation of the front wheel-suspension system was lead to the plastic deformation range.

The waveforms when running on rough roads and when experiencing a steered collision are distinguishable on the Displacement-Deceleration plane even though their deceleration peaks reach the same levels.

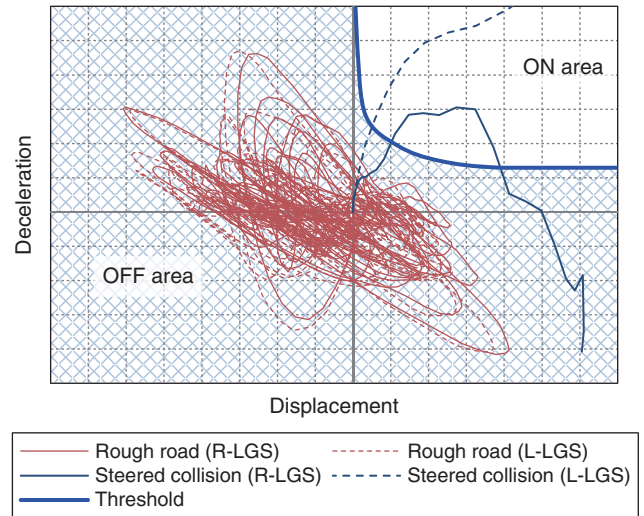


Fig. 14 Displacement-Deceleration curves and threshold of two-sensor Safing Judgment

Table 2 Evaluation result of two-sensor Safing Judgment

Configurations	Result				
	Main Judgment		Safing Judgment		
	Previous method	Two-sensor	Previous method	Two-sensor	
				R	L
Rough road	OFF	OFF	OFF	OFF	OFF
413-0.0/13.9*	ON	ON	ON	ON	ON
413-6.9/13.9*	ON	ON	ON	ON	ON
Steered collision	ON	ON	ON	ON	ON

*Impact configuration codes defined in ISO 13232

Table 3 Specifications of large scooter

Length	(mm)	2,185
Width	(mm)	750
Height	(mm)	1,180
Wheelbase	(mm)	1,545
Curb mass	(kg)	204
Engine displacement	(cm ³)	248

4. Verification

We compared the ON/OFF judgment results between the previous system and the two-sensor crash detection system by using the acceleration data measured in the same motorcycle discussed in section 3. As shown in Table 2, we obtained results equivalent to those obtained using the previous method in all configurations.

Furthermore, verification of the method was conducted using a large scooter as well. The major specifications of the scooter are shown in Table 3.

Unlike the large touring motorcycle, the large scooter did not have an upper triple clamp on its front fork and had a smaller front wheel. However, the waveforms measured during the rough road running tests showed damped oscillations (Fig. 15).

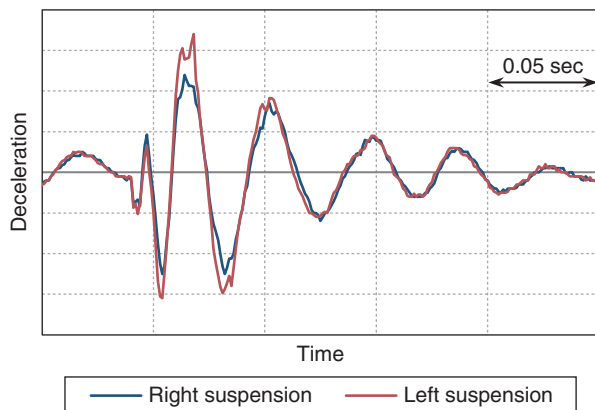


Fig. 15 Oscillation waveform of front suspension of large scooter during rough road running

The Displacement-Deceleration curves of the large scooter are shown in Fig. 16. They showed features similar to those in the large touring motorcycle, even though the parameters of natural oscillations in the large scooter were different from those in the large touring motorcycle because of the differences in the structures of the front wheel-suspension system.

These results verified that the new method was applicable to the large scooter type motorcycle as well.

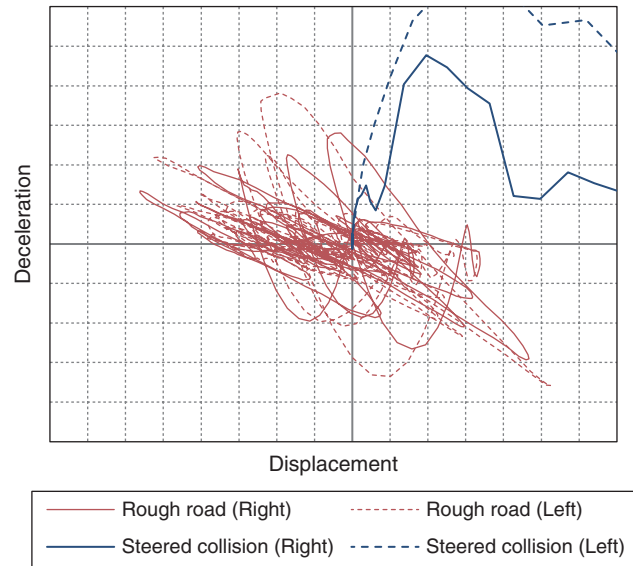


Fig. 16 Displacement-Deceleration curves measured in large scooter

5. Conclusions

A two-sensor crash detection method was successfully developed. The method utilized the characterized oscillation behavior that appeared in the motion of the front wheel-suspension system experienced when running on rough roads.

Following the development of the method, the validity of the method was then confirmed and a judgment performance equivalent to the previous method was verified.

In addition, based on data measured using large scooters it was confirmed that this method was also applicable to motorcycles with different front wheel-suspension system configurations.

References

- (1) Sporer, A., Langwieder, K., Polauke, J.: Development of a Safety Concept for Motorcycles - Results From Accident Analysis and Crash Tests, 11th International Technical Conference on Experimental Safety Vehicles, p.835-842, (1987)

- (2) Chinn, B. P., Okello, J. A., McDonough, P. J., Grose, G.: Development and Testing of a Purpose Built Motorcycle Airbag Restraint System, 15th International Technical Conference on the Enhanced Safety of Vehicles, p.1167-1188, (1996)
- (3) Iijima, S., Hosono, S., Ota, A., Yamamoto, T.: Exploratory Study of an Airbag Concept for a Large Touring Motorcycle, 16th International Technical Conference on the Enhanced Safety of Vehicles, p.2260-2278, (1998)
- (4) Kuroe, T., Iijima, S., Namiki, H.: Exploratory Study of an Airbag for a Large Scooter-Type Motorcycle, 5th International Motorcycle Conference 2004, (2004)
- (5) Kuroe, T., Namiki, H., Iijima, S.: Exploratory Study of an Airbag Concept for a Large Touring Motorcycle: Further Research Second Report, 19th International Technical Conference on the Enhanced Safety of Vehicles, Paper Number 05-0316, (2005)
- (6) Iijima, S.: Development of Airbag System for Motorcycle, Motor Ring, vol. 25, (2007)
- (7) ISO13232 2005(E): Motorcycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles -

■ Author ■



Yuki KOBAYASHI



Takumi MAKABE