

Development of Side Curtain Airbags with Rollover Sensor

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ABSTRACT

Fatalities in rollover accidents have recently been increasing in the US. In particular, 60% of fatalities in SUVs are related to rollover accidents. In addition, 62% of occupants who die in rollover accidents involving all passenger vehicles are either partially or completely ejected from the vehicle. To help address this issue, a side curtain airbag system has been developed that enhances occupant safety in rollover accidents. When a rollover sensor detects the possibility of the vehicle rolling, the side curtain airbags are deployed, covering the greater part of the side windows and thus reducing the possibility of occupant ejection.

1. Introduction

1.1. Rollover Accidents

In the U.S., fatalities that occurred in rollover accidents are on the increase. The total number of fatalities that occurred in rollover accidents in 2002 for all passenger vehicles including light truck vehicles (LTV) such as sports utility vehicles (SUV), pickup trucks and vans, and passenger cars was 10 626, which is an increase of 4.9% compared to 2001. In regard to SUVs, the number of rollover accidents increased by 9.8% (Fig. 1).

The proportion of accidents involving bodily injuries occurring in rollover accidents was about 5% each in the case of passenger cars and vans, and about 10% and 13% for pickup trucks and SUV, respectively. The proportion of accidents involving fatalities occurring in rollover accidents was 24% for passenger cars, 33% for vans, 46% for pickup trucks, and 61% for SUV (Fig. 2)⁽¹⁾⁻⁽³⁾.

The fatalities that occurred during rollover accidents for all passenger vehicles were primarily caused by the occupants being ejected from the vehicle. While the wearing of seat belts is the most effective method of helping prevent occupants from being ejected from a vehicle, the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation, in 1988, also commenced research into ways of improving the side window glass, such as by using laminate glazing called Advanced Glazing, to help reduce the incidence of occupant ejection. However, rulemaking was abandoned in 2002 partly owing to design restrictions, and instead research and development pertaining to an overall evaluation of the ejection mitigation

performance of Advanced Glazing and side curtain airbags were commenced⁽⁴⁾⁻⁽⁶⁾.

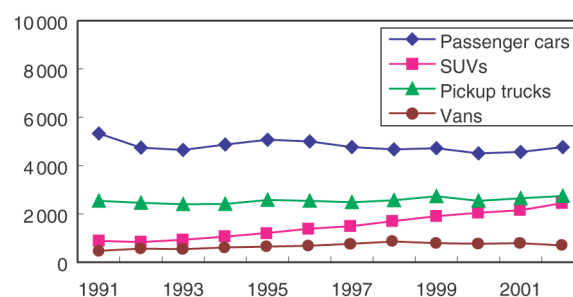


Fig. 1 Occupant fatalities in rollover accidents by year and type of vehicle

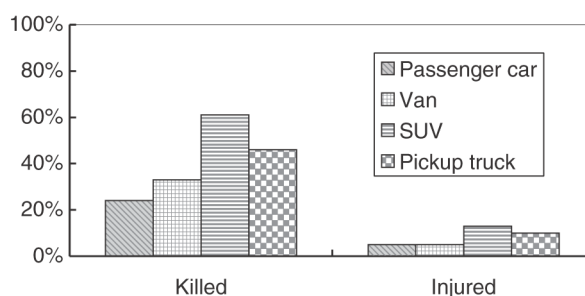


Fig. 2 Percentage of fatalities and injuries in rollover accidents by type of vehicle

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Table 1 Seat belt use and vehicle ejection in rollover fatalities

	Not ejected	Totally ejected	Partially ejected	Total
Belt used	14 272	771	1 382	16 425
Belt not used	22 089	49 017	9 328	80 434
Total	36 361	49 788	10 710	96 859

Source: FARS 1991-2001

1.2. Ejection from a Vehicle Due to a Rollover Accident

62% of occupants who die in a rollover accident for all passenger vehicles are either partially or completely ejected from the vehicle. In fatal rollover accidents for all passenger vehicles in which the occupant was not wearing a seat belt, 73% of the unbelted occupants were either partially or completely ejected from the vehicle. Also, 83% of occupants killed in rollover accidents for all passenger vehicles were not wearing a seat belt. On the other hand, in fatal rollover accidents for all passenger vehicles in which the occupant was wearing a seat belt, only 13% of the belted occupants were ejected from the vehicle (Table 1).

Reportedly, in most cases in which an occupant wearing a seat belt was ejected from the vehicle in a rollover accident, the occupant was ejected through the side window glass. Also, at least half of the occupants who were not wearing seat belts were ejected through the side window glass (Fig. 3).

Regarding the probability of injury in a rollover according to the Abbreviate Injury Scale (AIS) classification, when the occupant remained in the vehicle the occupant was either uninjured or sustained only minor injuries in 71% of the rollover accidents, and sustained serious injuries or worse in 13% of the rollover accidents. In contrast, when the

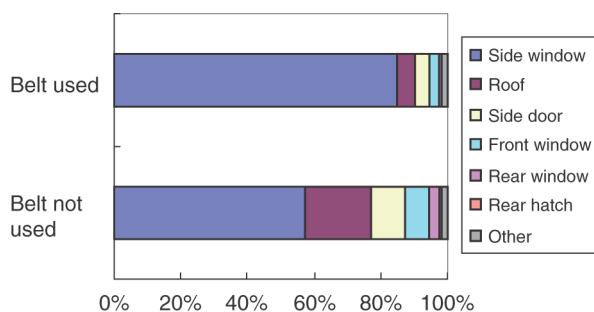


Fig. 3 Ejection path of occupant
Source: NASS CDS 1993-2001

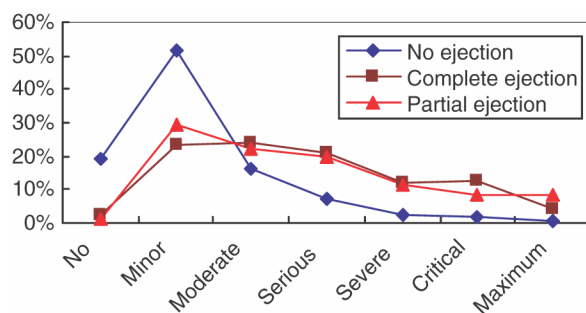


Fig. 4 Likelihood of injury in rollover by AIS Source: NASS/CDS 1988-2001

occupant was either partially or completely ejected, and the injury probability distribution was the same, the occupant was either uninjured or sustained only minor injuries in about 30% of the rollover accidents, and sustained serious injuries or worse in about 50% of the rollover accidents (Fig. 4).

2. Side Curtain Airbag System

2.1. Side Curtain Airbag

In the conventional side curtain airbag system, when the side impact sensor detects a collision of sufficient magnitude with the side of the vehicle, the side curtain airbag, housed in the roof rail on the inside of the vehicle, deploys to cover the side window as shown in Fig. 5, thus providing protection for the head of the occupants from external objects and the pillars. The system developed here possesses this side impact occupant protection function, and in addition detects the possibility of the vehicle rolling causing the side curtain airbags to deploy as well. In this way, it functions as a supplemental restraint system for the seatbelt, thus helping reduce the possibility of the occupant ejection from the side window of the vehicle and helping increase the possibility of the occupant remaining inside the vehicle.

2.2. Rollover Sensor

A rollover sensor was developed in order to detect the possibility of a rollover of the vehicle and cause the side curtain airbags to deploy. Like the front crash sensor and side impact sensor, the rollover sensor constitutes a sub-system of the airbag control system (Fig. 6).



Fig. 5 Deployed front airbags, side airbag and side curtain airbag

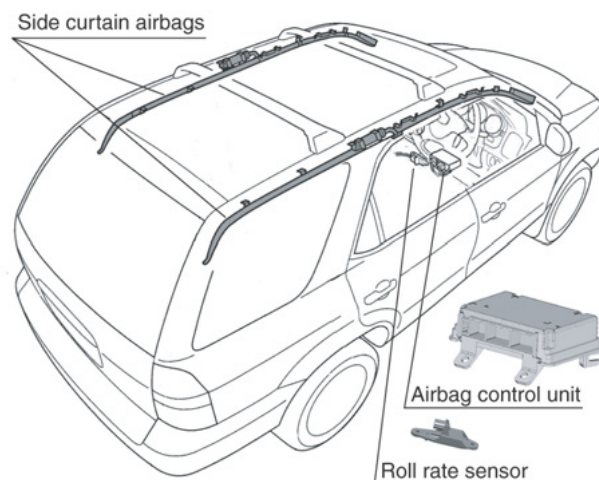


Fig. 6 Layout of side curtain airbags and rollover sensor system

2.2.1. Sensor system configuration

The rollover sensor system consists of an airbag control unit and a roll rate sensor.

The airbag control unit contains one horizontal direction accelerometer and one vertical direction accelerometer (sensors G_y and G_z), a microprocessor, an ignition control circuit, a circuit for communicating with the roll rate sensor, and a power supply circuit.

The roll rate sensor digitizes the analog voltage output from the gyro sensor by means of an analog-to-digital converter (ADC), and sends the resulting data serially to the airbag control unit.

(1) Accelerometer

Acceleration is measured using a Micro Electro-Mechanical System (MEMS) accelerometer made by silicon micro-fabrication, which has excellent impact resistance and reliability and is extremely compact. By utilizing semiconductor manufacturing technology, a fine structure consisting of the sensor element supported by springs is formed on the surface of a silicon chip by etching. The displacement of the sensor element due to acceleration is detected as a change in electrostatic capacitance. An analog signal processing circuit incorporated in the same semiconductor chip outputs a voltage proportional to the acceleration.

(2) Roll angular velocity meter

For measuring the roll angular velocity as well, a MEMS vibration gyro sensor was used, which, like the accelerometer, has excellent impact resistance and

reliability, and is extremely compact. This sensor uses the same principle of operation as that of the MEMS accelerometer, and detects the displacement of a resonator due to Coriolis force (Fig. 8). A pair of resonators are driven in opposite phases, and the differential output is used to remove the in-phase acceleration component, permitting accurate measurement of angular velocity even in the case of a large impact due to a collision, for example. The resonator drive circuit and signal processing circuit are also contained in the same chip, realizing a compact gyro sensor (Fig. 9)⁽⁷⁾.

(3) Microprocessor

The roll angular velocity and roll angle of the vehicle are computed from the signal output from the roll rate sensor. The analog voltage output from the accelerometer is converted into a digital signal by a built-in ADC.

These signals are processed by a pre-programmed rollover judgment algorithm, and a rollover judgment is made.

In order to raise the system reliability with respect to a breakdown of the roll rate sensor, two independent rollover judgment sections are used, namely a main judgment section that primarily uses the output from the roll rate sensor and a safe judgment section which uses the output from the accelerometer. Each of these sections sends a rollover judgment signal to the ignition control circuit.

(4) Ignition control circuit

When the rollover judgment signals are sent simultaneously from the main judgment section and the safe judgment section in the microprocessor to the ignition control circuit, current flows to the squib (ignition circuit) of the side curtain airbag inflator (gas generator), causing the airbag to deploy.

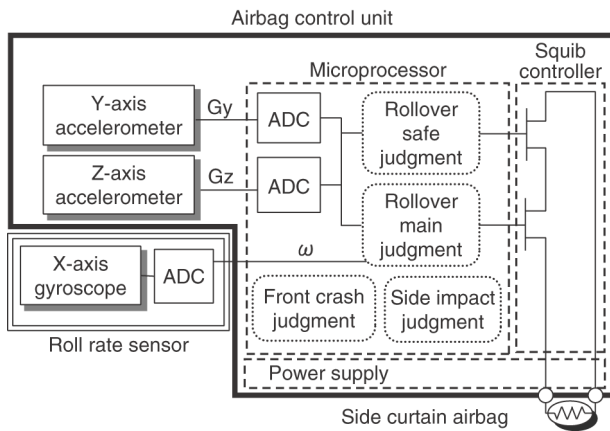


Fig. 7 System diagram of rollover sensor

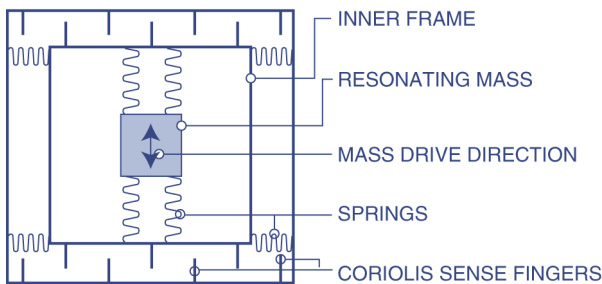


Fig. 8 Schematic of mechanical structure of gyro

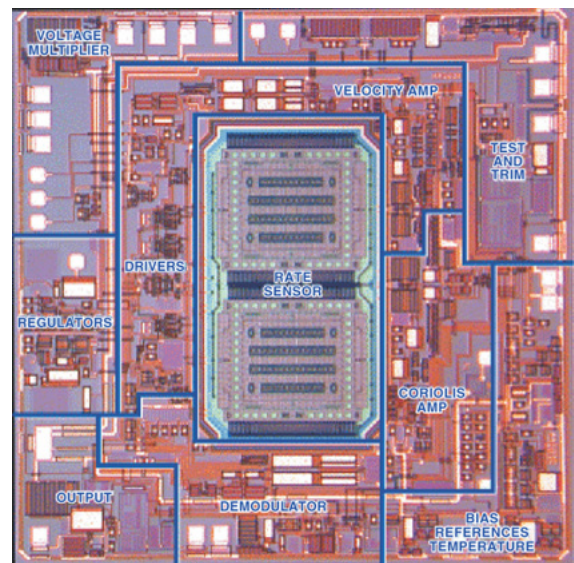


Fig. 9 Photograph of gyro die, highlighting integration of mechanical rate sensor and signal conditioning electronics

2.2.2. Rollover judgment algorithm

(1) Main judgment section algorithm

A rollover is primarily defined as the case where a vehicle tilts at least 90 degrees. When the center of gravity of the vehicle reaches the perpendicular line passing through the center of rotation, that is, the maximum stable angle, the vehicle will roll over under gravity.

Also, if the vehicle has sufficient angular velocity for it to reach the maximum stable angle, it will roll over even without the application of an external force. This dynamic rollover limit is the basis of vehicle rollover judgment.

When the vehicle is considered to be a rigid pendulum as shown in Fig. 10, the dynamic rollover judgment is expressed by Eq. (1). A rollover judgment is made according to whether or not the total rotational energy consisting of the sum of the potential energy $E(\theta)$ and the rotational kinetic energy $E(\omega)$ exceeds the minimum energy (MgR) necessary for reaching the maximum stable angle.

$$\begin{aligned} E(\theta) + E(\omega) &\geq MgR \\ E(\theta) &= MgR \sin(\theta + \theta_0) \\ E(\omega) &= 1/2 \cdot I\omega^2 \end{aligned} \quad (1)$$

θ_0 : Initial inclination of C.G.
 θ : Roll angle of vehicle
 g : Gravity acceleration
 R : Rotational radius
 I : Inertia moment of O-axis

Figure 11(a) shows the result of expressing Eq. (1) as a graph of ω versus θ . If the threshold is exceeded on the graph, it is judged that there is a high possibility of rollover occurring. Normally, a vehicle rolls over when a sustained external force is generated, causing the rotational energy to increase. For this reason, it is possible to make a rollover judgment more quickly by predicting the increase in

rotational energy due to an external force that may conceivably be applied in the future, from the change in angular velocity ($\Delta\omega$) and the deceleration. This is expressed mathematically by Eq. (2). Figure 11(b) shows a 3-dimensional diagrammatic representation of this equation. An actual vehicle differs from a pendulum in that it has a suspension mechanism. Consequently, this was taken into account in the determination of the threshold.

$$E(\omega) + E(\theta) \geq \text{Threshold} - E(\Delta\omega, G_y, G_z) \quad (2)$$

(2) Safe judgment section algorithm

The safe judgment section of the algorithm uses the values G_y and G_z .

When a rollover phenomenon occurs, abrupt motion occurs in the horizontal or vertical directions in addition to rotary motion, and compared to when the vehicle is running normally, a large acceleration is detected. This is utilized for making a safe judgment.

3. Conclusion

As a supplemental restraint system for the seatbelt, a side curtain airbag system with rollover sensor was developed in order to help increase the occupant safety in rollover accidents.

When the rollover sensor detects a situation that can conceivably lead to the occurrence of vehicle rollover, the side curtain air bags deploy, covering most of the side windows. As a result, the possibility of the occupant ejection from the vehicle is reduced and the possibility of the occupant remaining inside the vehicle is increased.

This system was installed on the 2004 model Acura MDX, and is scheduled to be installed progressively on future models.

Acknowledgments

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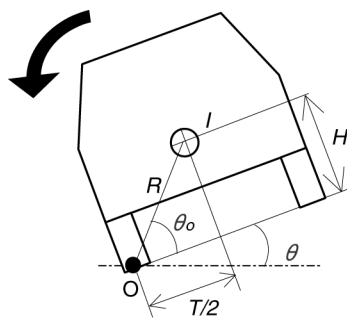


Fig. 10 Vehicle rigid model

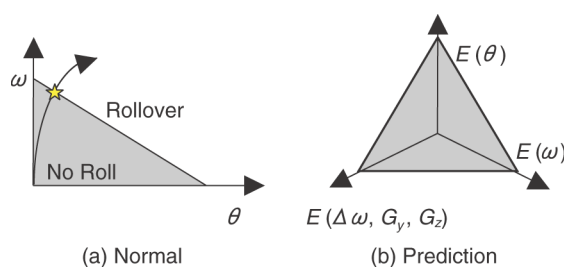
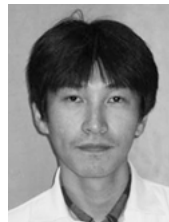


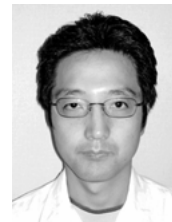
Fig. 11 Rollover main judgement threshold

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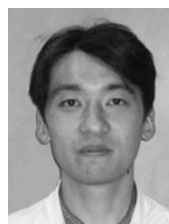
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