DEVELOPMENT OF POP-UP HOOD SYSTEM FOR PEDESTRIAN PROTECTION

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ABSTRACT

Pop-up hood systems have been developed as a pedestrian protection technology for vehicles that have a narrow space between the inside surface of the hood and the rigid parts in the engine compartment. The aim of these systems is to help reduce the head injury criterion (HIC) by lifting up the hood and creating a greater distance to the rigid parts in the engine compartment. However, various issues have yet to be resolved in the adoption of these systems. The first category of issues is sensing-related, such as the method of distinguishing between collisions with pedestrians and roadside objects, and ensuring stable detection regardless of the location of the collision at the front of the vehicle. The second category is actuator-related, particularly the method of keeping the hood held up while ensuring that the impact energy of the collision with the head is absorbed. This paper describes the development of a pressure chamber type sensing system and push-rod type actuator that were designed to address these issues.

INTRODUCTION

Pedestrian protection is a key aspect of helping to reduce traffic accident fatalities. In 2011, pedestrian accidents in Japan accounted for 36.6% of all fatal traffic accidents, the largest proportion of any accident type. The proportion of pedestrian accidents in Europe is also significant. In the United States, while the overall relative proportion is low, approximately 4,500 people were fatally injured in pedestrian accidents in 2011, roughly 2.5 times as many as in Japan. Both Japan and Europe introduced pedestrian protection regulations in 2005. In addition, new regulations based on the Global Technical Regulations (GTR) that were approved in 2008 are due to be adopted in Japan and Europe from 2013.

Fatal injuries in collisions between vehicles and pedestrians are often caused when the head of the pedestrian strikes either the vehicle or the ground. In addition, a collision with a vehicle often results in the head of the pedestrian striking the hood [1]. This makes the hood and the surrounding area particularly important areas for head protection. Various impact absorption structures have been developed and adopted for vehicles [2]. The aim of many of these technologies is to absorb sufficient impact energy through the body structure. One basic approach is to create a space between the inside surface of the hood and the rigid parts in the engine compartment. For this reason, hood heights have been increasing in recent years.

However, low hood styling is a requirement for sporty and other similar cars. For other vehicles as well, it may not be preferable to raise the hood height, even if rigid parts are positioned high in the engine compartment. To help meet these requirements, pop-up hood systems have been developed that forcibly lift up the hood after a collision with a pedestrian to create a larger space between the inside surface of the hood and the rigid parts in the engine compartment [3][4][5][6]. Pop-up hood systems consist of a bumper sensor that detects a collision with a pedestrian, an ECU that judges whether to operate the actuator, and an actuator that lifts the hood (Figure 1).

However, these systems have the following two main types of issues.

The first is distinguishing between collisions with pedestrians and collisions with roadside objects such as poles [7]. For example, a vehicle may collide with a roadside pole after departing from its

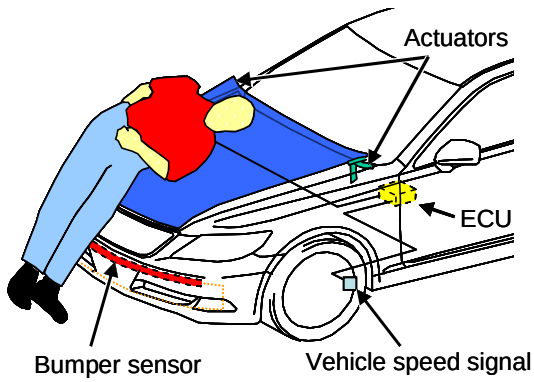

Figure 1. Pop-up hood system.

lane. In this case, the actuator should not lift the hood because system operation is not required. In contrast, however, the system should operate whenever the vehicle collides with a pedestrian. Similarly, stable detection is needed regardless of the location of the collision at the front of the vehicle. Various measures are being examined to address these issues. One proposal distinguishes between collision objects based on the characteristics of the shape of the signal inputted to the bumper after a collision with either a pedestrian or a roadside pole [8]. Another proposed method of distinguishing between collision objects focuses on differences in the bumper input width [9]. This paper describes a method that uses the concept of effective mass to address this issue.

The second issue is the impact energy absorption performance of the hood after it has been lifted by the actuator. The function of the actuator is to instantaneously lift up the hood and then hold it in the lifted position. After lifting, the hood should also absorb the impact energy from the head. However, the impact energy absorption performance of the hood held in the lifted position may not be sufficient. Proposed measures that are being studied to address this issue include the use of springs to hold the hood up and to absorb the impact energy [10] and the use of a collapsible mechanism [11]. This paper describes the development of a push-rod bending method.

DEVELOPMENT OF SENSING SYSTEM

Bumper Sensor Configuration

Sensing principle In pedestrian collisions, the legs of the pedestrian generally contact the bumper first before the upper body collapses onto the hood. In contrast, in a collision with a roadside pole, the pole collapses around the front of the vehicle because the bottom of the pole is fixed in the ground. From these characteristics, it can be assumed that the force in a pedestrian collision acts on the bumper for a longer period of time. In addition, the force acting on the bumper increases in accordance with the collision velocity, even with the same collision objects. Therefore, to distinguish between a pedestrian and a roadside pole, Equation (1) can be used to calculate the effective mass of the collision object from the force F and collision velocity v.

$$m = \frac{\int F dt}{v} \qquad (1).$$

Pressure sensor method The developed method uses a pressure chamber to obtain the force value used to detect the effective mass. The principle is as follows. The front surface of the bumper reinforcement contains an energy absorber, which helps to absorb the energy when the vehicle collides with the leg of a pedestrian. The example in Figure 2 shows that the force-stroke (F-S) curve of this energy absorber increases in a relatively linear manner. Therefore, a proportional relationship between the volumetric changes in the pressure chamber and the input force can be established by installing a pressure chamber that deforms at a lower force than the absorber, in a position parallel to the energy absorber. The pressure chamber uses these characteristics to measure a value equivalent to the force.

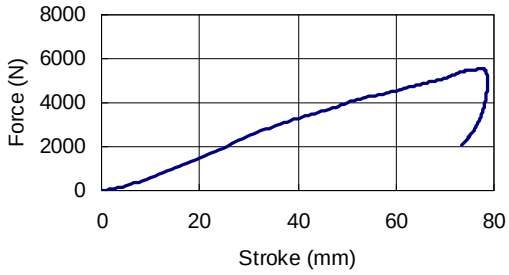

Figure 2. Example of absorber F-S curve.

Following the layout of the energy absorber, the pressure chamber is located across the vehicle from the left to the right. As a result, energy absorber characteristics can be obtained regardless of the lateral position of the collision. This reduces the effect of the bumper collision position on the sensing performance.

Equation (2) calculates the force F in accordance with pressure P.

$$F = K \frac{\triangle P}{P0 + \triangle P} \qquad (2).$$

where, K is the proportionality factor, P0 is the atmospheric pressure, and ΔP is the change in pressure.

The positional relationship of the pressure chamber and the energy absorber is as follows. The pressure chamber and energy absorber are located in front of the bumper reinforcement with the pressure chamber positioned above the energy absorber. This is because, in a pedestrian collision, the upper body of the pedestrian collapses onto the hood, making it more likely that force will be inputted to the top of the bumper.

Figure 3 shows the bumper sensor configuration. The pressure chamber is provided from one end of the bumper reinforcement to the other in front and across the top of the reinforcement. Two pressure sensors that detect changes in pressure are located at the left and right of the pressure chamber. These are called the main sensor and the safing sensor. In a

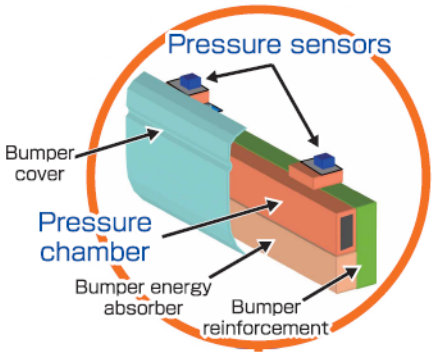

Figure 3. Bumper sensor configuration.

pedestrian collision, the pressure chamber deforms in accordance with the deformation in the energy absorber material below the pressure chamber. The changes in the pressure chamber when a collision occurs are detected by the two pressure sensors at the left and right. Both pressure sensors detect virtually identical changes in pressure.

Sensing Performance CAE Study

CAE study condition A CAE study was performed to verify whether the system is capable of distinguishing between pedestrians and roadside poles, and whether the system is capable of stable pedestrian detection, regardless of the collision position.

For the pedestrian models, the study used a six-year old child (6YO) with a small physique that was regarded as difficult to detect, and a small female model dummy (AF05) created as part of the Total Human Model for Safety (THUMS) project (version 1) jointly developed by Toyota Motor Corporation and Toyota Central R&D Labs. [12]. A roadside marker (RSM) was used for the pole model since a RSM is stiff and results in a large input force. For the collision velocities, a low input force of 25 km/h was selected for the pedestrian and a high input force of 55 km/h was selected for the RSM model. Two vehicle models were adopted for the calculations: a general sporty sedan (vehicle A) and a SUV type vehicle with a high bumper and ground clearance 100 mm higher than the sporty sedan (vehicle B). Table 1 shows the detailed study matrix including the collision objects, positions, velocities, and vehicles.

Table 1. CAE study matrix

CASE	Object	Position	Velocity	Vehicle
1	RSM	W=0	55km/h	Vehicle A
2	↑	W=400	↑	↑
3	6YO	W=0	25km/h	↑
4	↑	W=400	↑	↑
5	AF05	W=0	↑	↑
6	6YO	↑	↑	Vehicle B
7	AF05	↑	↑	↑

CAE study results Figure 4 shows the calculated effective mass results. In cases 1 and 2 (collision with RSM model), the effective mass differed clearly from cases 3 to 7 (collision with pedestrian models). The differences in the collision object can be distinguished in these cases. The results show that a pedestrian collision can be detected even with different collision positions, pedestrian physiques, and bumper heights.

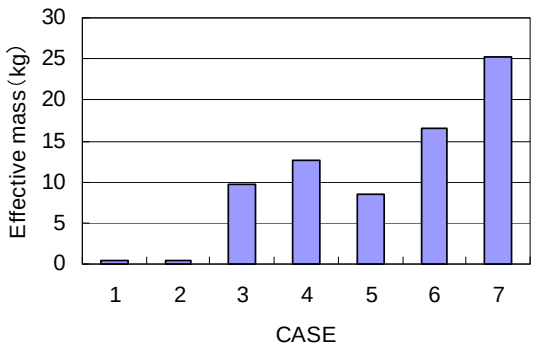

Figure 4. CAE study results.

Next, the study analyzed how the force inputted from the bumper cover acted on the pressure chamber and energy absorber. Figure 5 shows examples of bumper deformation at maximum pressure in cases 1 and 3. The figure shows the deformation 30 ms after the collision for the 6YO model and 10 ms after the collision for the RSM model. The results indicate that the pressure chamber was pushed firmly by the 6YO model, as intended by the developed system. In contrast, there was little pressure chamber deformation in the case of the RSM collision. Figures 6 and 7 show the input to the pressure chamber and the energy absorber below the pressure chamber in these collisions, respectively. In the case of the 6YO collision, the input to the chamber was large and continued for several tens of milliseconds. However, in the RSM collision, although chamber input was virtually zero, input to the energy absorber was large. As a result, the calculated effective mass of

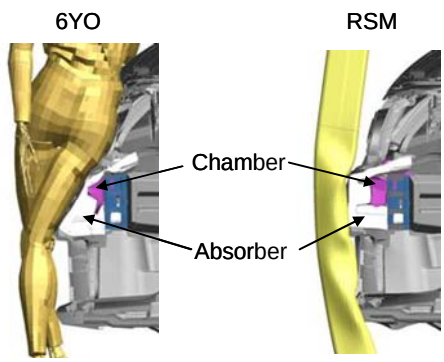

Figure 5. CAE results (Case 1 and 3).

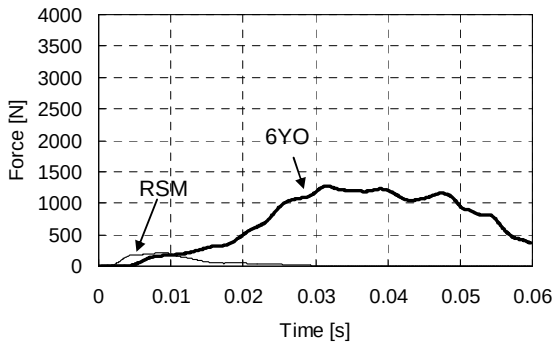

Figure 6. Chamber input force (Case 1 and 3).

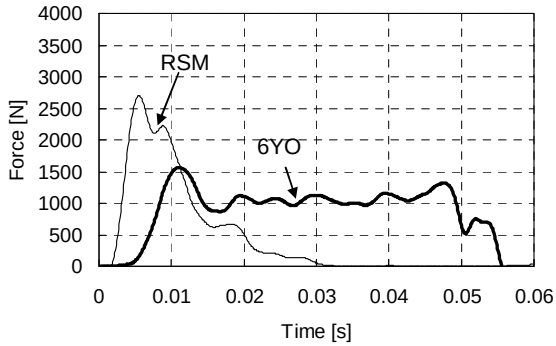

Figure 7. Absorber input force (Case 1 and 3).

the 6YO model was approximately 10 kg, compared to less than 1 kg for the RSM model. This shows that the system is capable of distinguishing between collision objects.

Discussion In the CAE study, the effective mass of the AF05 model was calculated to be 14% lower than that of the 6YO model in the case of vehicle A (Case 3 and 5). After looking at the calculation model, the knee joint of the AF05 model was found to be exactly at the same height as the pressure chamber (Figure 8).

The study assumed that the pushing force onto the pressure chamber was lower because the knee joint is narrower than the areas above and below, and because the knee joint bent after the collision. As a result, in the case of vehicle A, the AF05 model was the most hard-to-detect (HTD) case. However, detection was not affected since the calculated effective mass was approximately ten times higher than that of the RSM model.

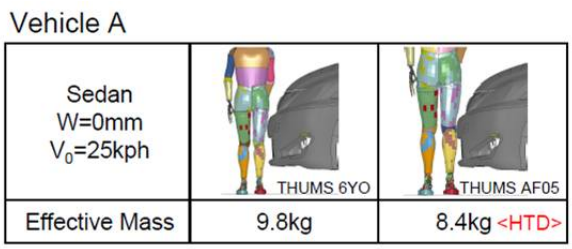

Figure 8. CAE models (Case 3 and 5).

Confirmation of Sensing Performance

The sensing performance was then confirmed using an actual vehicle. A pedestrian was simulated using a 6YO dummy developed by Toyota Central R&D Labs. [13]. The collision velocities and positions were as follows: 25 km/h at the vehicle center and 400 mm offset from the vehicle center, and 40 km/h at the vehicle center. The collision with the RSM was conducted at 40 km/h at the vehicle center and 400 mm offset from the vehicle center. Figure 9 shows the effective mass of the collisions with the 6YO pedestrian dummy and RSM detected by the pressure sensor system. For reference, the figure also shows the effective mass calculated from the force acting on the bumper reinforcement measured using a load cell.

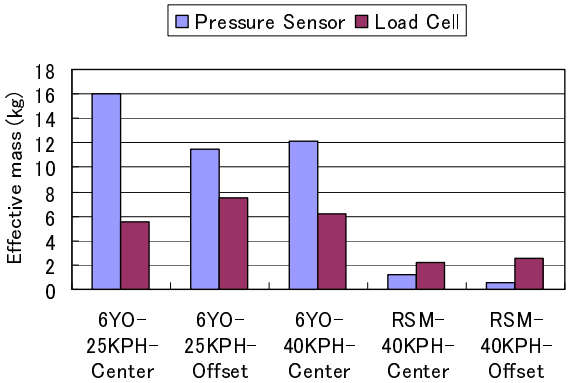

Figure 9. Sensing performance results.

The test results confirmed that the system could distinguish between a collision with a 6YO pedestrian dummy and a RSM. The results also confirmed that locating the pressure chamber at the top of the bumper reinforcement made it easier to distinguish the effective mass using the pressure sensor system than using load cell data.

DEVELOPMENT OF ACTUATOR METHOD

Actuator Configuration

Figure 10 shows the actuator configuration. The push-rod is pushed up using a micro gas generator

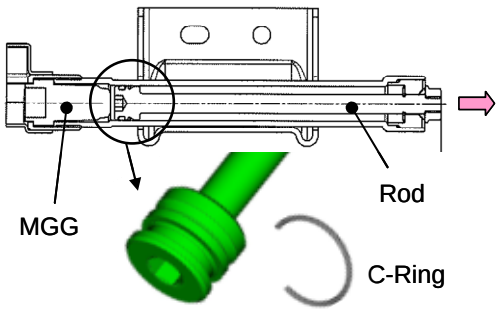

Figure 10. Actuator configuration.

(MGG). The rod lifts the hood by pushing up and deforming the hood hinge. After being pushed up, the rod holds its position by opening the C ring at the bottom of the rod.

The hood is pushed up by 70 mm to create enough space under the hood to help protect the head of a pedestrian in a collision (Figure 11).

When a pedestrian's head impacts the hood, the end of the rod is pushed by the bottom surface of the hood hinge, bending the rod toward the rear of the vehicle. As a result, the hood moves down, helping to absorb the impact of the head collision.

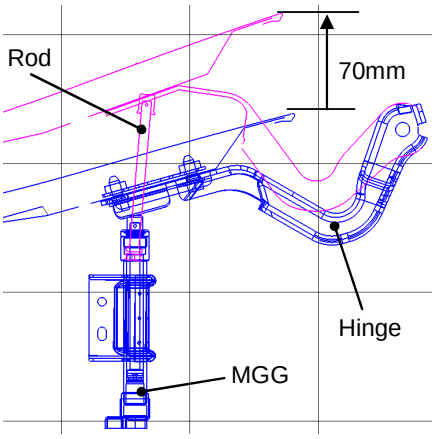

Figure 11. Actuator lift up height.

Impact Energy Absorption Performance Study

The impact energy absorption characteristics of this system after the hood is lifted by the actuator were studied in a head impactor test.

Head impact test condition An adult head impactor (4.5 kg) was used at an impact velocity of 40 km/h and an impact angle of 65°. Three impact positions were selected: directly above the actuator rod and 200 mm and 400 mm further toward the vehicle center.

Head impact test results Figure 12 shows the head injury criterion (HIC) in the impact tests at the three locations. In all cases, the HIC was less than 1,000. Particularly, in the test for the position directly above the actuator rod, the rod bent toward the rear of the vehicle, lowering the hood and absorbing the impact energy.

Discussion Although the rod bent backwards properly in the test directly above the actuator rod, the bend amount decreased as the impact position moved further away. The rod deformation in Figure 12 indicates that the rod remained virtually vertical in the impact test 400 mm away from the position directly above the actuator rod.

This is because the hood deforms in the area between the actuator rod and impact position. As a result, the absorbed energy increases gradually.

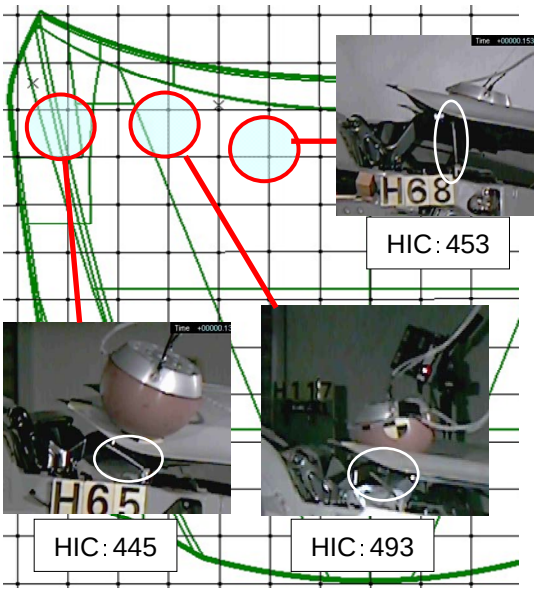

Figure 12. Head impact test results.

CONCLUSIONS

A pop-up hood system has been developed to help ensure pedestrian protection performance in vehicles that only have a narrow space under the hood.

The sensing method uses a pressure chamber and pressure sensor to determine the effective mass of the collision object. This allows the system to distinguish between collisions with pedestrians and collisions with roadside objects such as poles and the like. The system detects pedestrian collisions stably, regardless of differences in the collision position or the vehicle shape.

The actuator uses an MGG to push a rod upward and lift the hood. When a pedestrian's head impacts the hood, the rod bends to absorb the impact. This method achieves stable impact energy absorption, regardless of the impact position on the hood.

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REFERENCES

[1] ECE/TRANS/WP.29/2007/94, "Editorial correction to the proposal for a draft global technical regulation on pedestrian safety". 143rd

WP.29, 13-16 November 2007

[2] K. Ikeda, et al., “Development of Aluminum Hood Structure for Pedestrian Protection”. IBEC 20037070 Paper No. 2003-0102793, 2003

[3] K. Nagatomi, et al., “Development and Full-scale Dummy Tests of a Pop-up Hood System for Pedestrian Protection”. 19th ESV Paper No. 05-0113, 2005

[4] APROSYS Project Final report for the work on, “Pedestrian and Pedal Cyclist Accidents”. (SP3) AP-90-0003, 2012

[5] R. Fredriksson, “Priorities and Potential of Pedestrian Protection Accident data, Experimental tests and Numerical Simulations of Car-to-Pedestrian Impacts”. From the Department of Public Health Karolinska Institutet, Stockholm, Sweden, 2011

[6] Thatcham Research News, Special Edition 10/No.7, 2010

[7] K. B. Lee, et al., “The Study on Developing Active Hood Lift System for Decreasing Pedestrian Head Injury”. 20th ESV Paper No. 07-0198, 2007

[8] O. Scherf, “Development and Performance of Contact Sensors for Pedestrian Protection System”. 19th ESV Paper No. 05-0021, 2005

[9] H. Hofinger, et al., “A Holistic Approach to Pedestrian Protection and Crash Sensing”. 21st ESV Paper No. 09-0071, 2009

[10] C. Pinecki, et al., “Technical Solutions for Enhancing the Pedestrian Protection”. 20th ESV Paper No. 07-0307, 2007

[11] Y. Inomata, et al., “Development of the Pop-up Engine Hood for Pedestrian Head Protection”. 21st ESV Paper No. 09-0067, 2009

[12] R. Nishimura, et al., “Development of he Human FEM Model for Child Pedestrian”. Transactions of Society of Automotive Engineers of Japan, 20025504, 2002 Autumn

[13] N. Hayami, et al., “An Experimental Study of Child Pedestrian Injury (First Report)-Development of prototype 6-year-old pedestrian dummy-”. Transactions of Society of Automotive Engineers of Japan 34(3), 127-132, 2003