A New Pedestrian Head Injury Protection System with A Sensor in The Bumper and Lifting of The Bonnet’s Rear Part

Swaraj S Kore

ABSTRACT - Today’s cars are very densely packed under the bonnet. Certain stiff parts, such as the spring tower and the top of the engine, are very close to the bonnet. There is often not enough space for bonnet deformation by an impacting head. The consequence is often a severe or fatal head injury.

Therefore, a protection system has been developed to decrease the severity of head-to-bonnet impacts. The system is activated at the impact by a sensor located in the bumper, at speeds above 20 km/h. The sensor is able to discriminate objects with a different geometry (another car versus a leg), as well as with a different stiffness (a pole versus a leg). Two actuators lift the rear part of the bonnet approximately 100 mm. The actuators were tuned to have lifted the bonnet at 60-70 milliseconds after the leg-to-bumper impact, but before the head impact. The actuators/lifting elements were also tuned to stay up during the upper torso impact, but still be energy-absorbing to keep the head loading down if the head impact is on top of the lifting elements.

The system has been tested by a head form impacting the bonnet at various locations and speeds up to 50 km/h, as well as with a complete car front on a sled impacting a pedestrian dummy. The dummy tests were performed to check the timing of the system, but also to check that the lifting elements were strong enough to keep the bonnet in a lifted position during the upper torso impact until the head impacted the bonnet. The kinematics of the pedestrian dummy was compared to that of a validated pedestrian mathematical model. In head form tests in 40 km/h the system decreased the HIC values to acceptable levels (<1000) in all test points for the lifting bonnet, including the head form contact locations above where the bonnet was lifted. In the 50 km/h head form test above the bonnet’s stiffest point, a large reduction of the HIC value was achieved. It was reduced over 90 % to a value of 1213, with the active bonnet system compared to the standard bonnet.

***Index Terms*— Contact Sensor, impact speed, Pedestrian Protection, Traffic Accidents,**

I INTRODUCTION

It is observed that traffic related fatalities among pedestrians in 2009 were reported 4092 (NHTSA-2009).In the European Union around 7000 pedestrians are killed every year. This accounts for around 20 % of all traffic fatalities . In the world this number varies from 14 % in USA (NHTSA, 1995) to 47 % in Thailand.

Since the 1970's, extensive research has been carried out in the area of pedestrian protection to determine the causes of accidents and injuries, as well as means of reducing them. Many studies on injury mechanisms, tolerance levels, and influences of the vehicle design on impact responses, protection assessment techniques, and safety countermeasures have been carried out with pedestrian substitutes such as biological specimens, mechanical dummies and mathematical models. The impact speed and vehicle front structures including geometry and stiffness have been shown to be important injury-producing factors.

A majority of pedestrian fatalities are caused by head injuries. The major causes of severe head injuries are the bonnet, the scuttle and the A-pillars. Otte (1999) also reported that the windshield was a significant cause of head injuries. Modern cars have very stiff parts underneath the bonnet with gaps even less than 20mm. Therefore the deformation distance is too small to allow for the necessary energy absorption. Theoretically around 55 mm of stopping distance is needed at an impact speed of 40 km/h to be able to keep the HIC value below 1000 for an adult head form. Head form-to-bonnet impact tests were performed in Germany (Zellmer & Glaeser, 1994), and they showed that bonnets, which allowed for 70 mm of deflection or more, generally produced HIC values below 1000 for the adult head (Figure 1). The child head form needed only around 50 mm.

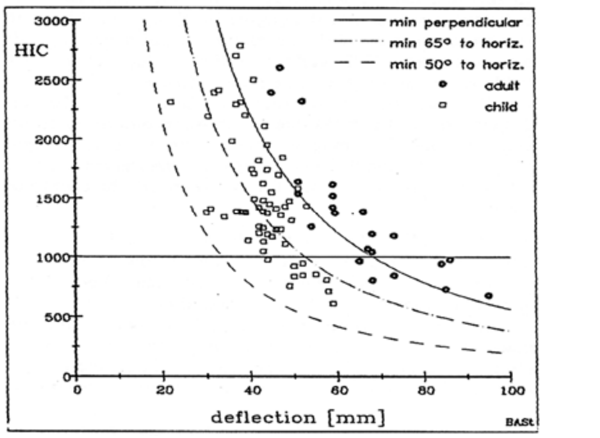

Fig 1 Bonnet head form tests performed at 40 km/h impact speed.

Swaraj S Kore (Email: swarajkore@rediffmail.com)
B.E.* Mechanical Engineering (Solapur University)
B.I.G.C.E Sholapur

Car impact speed also has a major influence on injury outcome. Pedestrians struck at impact speeds less than 25 km/h usually sustain only minor injuries. More than 95 % of all pedestrian accidents occur at impact speeds lower than 60 km/h. The average speed for severe injuries is around 40 km/h.

A typical head impact in a car-to-pedestrian collision at 40 km/h occurs at 140-150 ms after first leg contact with the bumper. The shoulder impacts the bonnet top typically at around 120-130 ms in the same kind of impact.

Liu and Yang (2001) reported that the head contact with the bonnet top in child pedestrian accidents occurs at about 60 ms for a 7 year old child at 40 km/h, and at about 90 ms for a 9 year old child at 30 km/h.

EEVC Working Groups 10 and 17 has proposed a test method for pedestrian impact tests EEVC, 1994 and 1998). The test method is a part of a proposed directive to be introduced in Europe. The test method consists of three component tests (Figure 2). The free-flying lower leg form is launched against the bumper at 40 km/h. The upper leg form is launched against the bonnet leading edge with a speed, angle and mass that depends on the car shape. The head form is launched against the bonnet at a speed of 40 km/h. The rear part of the bonnet (Wrap around Distance 1500-2100 mm) is impacted by an adult head form, while the front end of the bonnet is impacted by a child head form. The proposed criterion in the head form test is HIC with threshold of 1000.

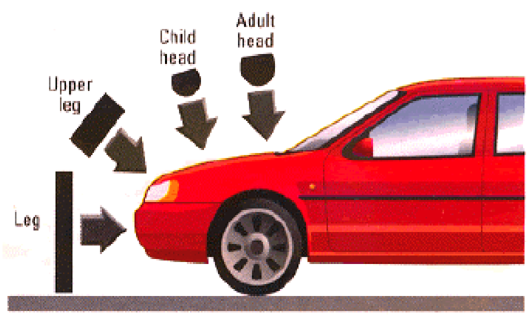

Fig 2 Test method

The bumper is divided in three areas, and the point considered to be the stiffest in each area is tested with the leg form. The bonnet leading edge is tested in the same way in 3 positions. The bonnet is divided in 6 areas, 3 areas in the front and 3 areas in the rear end of the bonnet. Two head form tests are performed in each area, so a total of 6 child and 6 adult head form tests are performed. If the car is very short the adult head form tests can be omitted.

Euro NCAP has performed crash-tests according to the test method on a large number of cars. 44 cars have been tested and this far no car has passed the proposed requirements. In the bonnet test the best car passed in 8 out of 12 test points. Research into injury mechanisms of pedestrians in vehicle accidents and counter-measures has been widely performed, but little improvement of the vehicle for pedestrian safety has been made. There is a large need to develop effective safety systems based on knowledge of pedestrian responses and injury mechanisms in vehicle accidents. Therefore, in this study a protection system has been developed to minimize the risk of head injuries in the head-to bonnet impacts.

The aim of this paper is to evaluate a new pedestrian protection system with a sensor in the bumper and two actuators for lifting of the bonnet's rear part. The sensor part of the system is tested with different impacting objects, to check the ability to differentiate between them. The active bonnet is tested with a head form impactor to check the possibility to decrease the head injury risk. A pedestrian adult dummy has also been developed to test the performance of the protection system in a more real life situation than the head form impact test.

II METHOD

The pedestrian protection system consists of two parts. The first part is the sensor system, which is placed in the bumper of the car to give an early indication that an impact is occurring. The second part of the protection system comprises two actuators for the lifting of the rear part of the bonnet. This creates a distance between the bonnet and the stiff parts beneath the bonnet. This distance needs to be large enough to absorb the energy of the impacting head.

A large European car was equipped with the head protection system. This car has been tested by Euro NCAP and it passed in 3 out of 6 of the child head form test points and in 2 out of 6 of the adult head form test points (Table 1).

Table I HIC values in Euro-NCAP head form tests (for the large European car selected in this study).

Point	HIC-Child	Point	HIC - Adult
1	1904	7	3257
2	729	8	7056
3	1145	9	1486
4	1398	10	877
5	913	11	1438
6	705	12	953

Crash tests were performed with both a leg form and with light poles against the bumper to learn about the differences of these impacts. The head protection system was tested with an adult free-flying head form at all stiff points of the bonnet, and also above one of the lifting points. Finally the complete head protection system was tested with a new developed pedestrian dummy. The validity of the dummy was evaluated by comparing its kinematics with a verified pedestrian mathematical model.

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III SENSOR SYSTEM

The task of the sensor is not only to sense the impact very fast, but also to detect whether the impacting object is a person or some other object. The sensor system consists of two different components. A "membrane switch"-type contact sensor covers the complete width of the bumper. It is placed in the foam just inside the plastic cover of the bumper. Two accelerometers are placed on the rear side of the bumper beam (Figure 3).

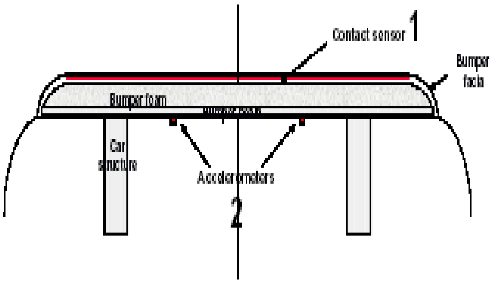

Fig 3 Position of sensors in bumper (1: contact sensor, 2: accelerometers).

The contact sensor strip is placed in a groove in the surface of the foam between two layers of a thin plastic material. The contact sensor is subdivided into elements, each 100 mm wide. Each element has a number of switches and gives a signal if one of the switches is closed. This gives information about the width of the impacting object. It is also a first indication to the system that an impact is occurring, a so called arming of the sensor system.

The accelerometers are placed 250 mm on each side of the centerline of the car in order to get a good signal regardless of where the impact is. The acceleration is integrated to a delta velocity. The maximum value during a chosen time period after first contact with the contact sensor is used. This value gives information about the stiffness of the impacting object, whether it is a leg or a pole for example.

IV SENSOR TESTS

Crash tests were performed with a complete car front on a sled. The car front impacted two different objects; a leg form and a light-pole. The crash tests were performed at different velocities, 20, 25 and 30 km/h.At 30 km/h and above the bumper started to deform plastically (in a nonreversible way) in the light-pole impacts. It is then easy to differentiate between the objects with the sensor system. The difficult task is to differentiate between the objects when the deformations are small. 20 km/h is the lower threshold for the sensor to activate the system. Injuries are often only minor at such a low impact speed. Therefore the work was focused on sensor testing between 20 and 30 km/h.

Head injury protection system (an active bonnet)

The protection system, an active bonnet, comprises two lifting elements which lifts the rear corners of the bonnet (Figure 4). The lifting elements consist of compressed metal bellows which are filled with gas from micro gas generators at the event of an impact. The benefits with the design are several.

1. The design does not need any sealing to keep the gas from leaking. The only opening in the bellow is where the gas generator is attached. Therefore it is easy to keep the pressure up a long time in the bellow. This is important since there can be large variations for when the head impacts occur, depending on the size of the person and the impact speed.
2. The bellow is insensitive to the angle of the impact. (Some lifting devices can absorb energy only if they get the impact at a perfect angle).
3. The dimensions of the actuator can be made small. The height of the device can be less than the lifting distance, which is not possible for a lifting device based on a piston.

Fig 4 Bonnet with protection system in activated (lifted) position**.**

V PEDESTRIAN & CAR MODEL

The Pedestrian and car model was created by using the MADYMO program to simulate a large passenger car front which has been used in sled impact tests. The stiffness characteristics of the car front model were defined in detailed bonnet parts. To achieve the correct stiffness properties of the car bonnet, the experimental results of Euro-NCAP tests made on the large passenger car were used. In the Euro-NCAP tests 12 different locations on the bonnet top were tested with both adult and child head forms. The bonnet top was then split by 13 ellipsoids, in which every ellipsoid was based on each impact location. Three other ellipsoids were added in the front of the car. The stiffness of those ellipsoids was derived directly from force curves for upper leg form tests. The upper leg form is thrown toward the bonnet leading edge in 7.4 m/s at an angle of 41.4 degrees. The other ellipsoids in the car model were a bumper and a windshield. The stiffness properties in those regions were chosen to be equal to the properties in published data.

The mathematical simulations were conducted to get knowledge about kinematics and responses of the pedestrian model, as well as head impact locations. In the simulations three different initial impact speeds (20, 30, and 40 km/h) and five different positions were chosen. In total fifteen runs

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were carried out. The results from mathematical modeling were used to evaluate the validity of the mechanical pedestrian dummy.

VI DUMMY TESTS

The complete system was tested with the pedestrian dummy. The focus of the dummy sled impact tests was on the kinematics of the head and on the head impact.

The large passenger car body is mounted on a sled. In each test, the sled is stopped after the impact by a braking system. The total 16 tests were conducted at the Autoliv Safety Centre in Sweden, at impact speeds of 20, 30, and 40 km/h.

A series of accelerometers and transducers were instrumented on the dummy and sled to measure accelerations of the head, thorax, pelvis, and leg, as well as displacement of the rib cage, and of the bonnet.

High-speed digital cameras (1000 frames per second) were set from different views to record the pedestrian kinematics during the impact. One camera was placed at the opposite side of the dummy face to get a whole view; the other was located in the same side to only focus on the head region of the dummy. An extra camera was placed above of the crash site to get top view in some of the tests.

VII RESULTS

Dummy tests and computer Modeling

The response of the pedestrian substitutes is compared between the sled tests and the computer simulations. Meanwhile, the influence of impact speed and characteristics of upper body of the crash dummy on the pedestrian responses is assessed in terms of a parametric study comprising different variables such as the linear acceleration and resultant impact speed of the head, impact location, and the trajectories of the C.G of the head. All of the concerns focus on the response of the head due to the high priority of improving the protection of the pedestrian's head. The main effects of these variables such as the linear acceleration and resultant impact speed of the head, impact location, and the trajectories of the C.G of the head. All of the concerns focus on the response of the head due to the high priority of improving the protection of the pedestrian's head. The main effects of these variables and parameters are examined and compared between dummy tests and mathematical simulations. The study is focusing on the tests in the centerline of the vehicle, since the geometry of the car model seems to be most correct in this position.

Kinematics - The kinematics of the dummy were captured from the high-speed films in all of the tests. An example of the sequence of events in a dummy test compared with corresponding mathematical simulation is shown in Figure 6. The initial impact speed is 30 km/h. The pedestrian is hit at the centerline of the vehicle. The construction of the upper body of the dummy used in this test is made up of a thorax from a US-SID with a comparatively flexible neck from a Euro-SID. This type of dummy showed a similar motion as the mathematical model, especially for the kinematics of the head.

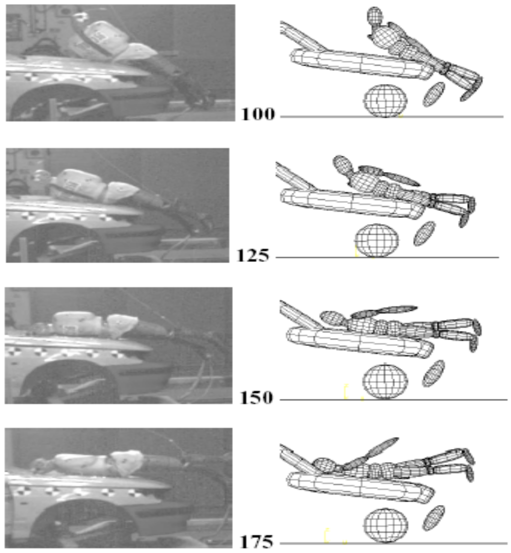

Fig 5 the comparison of the kinematics of the pedestrian dummy with a MADYMO model (at 30 km/h and at centre-line).

VIII CRASH TESTS OF COMPLETE SYSTEM

Figure 6 shows a crash test with the pedestrian dummy and a complete car front with the protection system installed. The bonnet lifting devices are activated at approximately 30 ms after the impact and the bonnet is fully raised at 70 ms, this test was run at 40 km/h. A prior test was run at 30 km/h. In both tests bonnet stayed up until the head impacted the bonnet.

Fig 6 Crash test in 40 km/h with a pedestrian dummy and an active bonnet

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IX DISCUSSION

The sensor tests showed that it is possible for the sensor system to separate a leg form from a pole. The level separating the output signals for the two objects could be used as a threshold for triggering the active bonnet system. The contact sensor gives the control unit the first indication that an impact is occurring. The contact sensor can be tuned not to trigger for very light objects. If the delta-v output signal is above the trigger level a no fire signal is sent. If the signal is below the trigger level a “fire” signal is sent to the two actuators lifting the bonnet.

The trigger level was found to be speed dependant, and therefore input to the control unit from the car speedometer is needed. Also, if the impact speed is below a certain level, for example 20 km/h, the active bonnet system is not activated in any case.

Tests were performed with poles up to 30 km/h and with a leg form impact up to 40 km/h. The bumper beam started to collapse in the more centrally positioned tests at 30 km/h. These tests showed a very big difference in sensor output values compared to the leg form tests. Tests performed with poles at higher velocities are believed to result in even greater bumper deformations, and therefore an even larger difference in sensor output values compared to the leg form. Therefore it was considered unnecessary at this point to perform tests at higher speeds with the poles, and instead focus at the speeds below which the bumper collapses. This means that above a certain impact speed, in this case 30 km/h, the protection system could be set at a trigger level with a greater margin to the sensor values with the leg form.

The bumper foam is believed to be sensitive to temperature differences. Therefore it is planned to test the bumper sensor with the leg form in dynamic tests in a climate chamber from cold to hot conditions.

The head form tests showed several benefits with the bellow lifting device design. The device proved to absorb impact energy very well. No stiff points are added to the bonnet. The device also proved to be able to stay up a long period of time. The pressure was almost constant up to 200 ms after activation. This is important since a short child hits the bonnet earlier than a tall adult. Also at higher impact velocities the person hits the bonnet earlier than at lower impact speeds. To make sure that the system works well, whatever the size of the pedestrian or impact speed, it is important to have a long stay-up time.

The head form test at 50 km/h resulted in a HIC value higher than 1000 (1213). The peak head form acceleration occurred in the very first part of the impact to the bonnet. In the later part of the bonnet compression, the acceleration was reduced to a lower level. This means that the high HIC value is not because of a bottoming out of the system. It is more likely to be a result of either the inertia of the bonnet, or the initial stiffness of deforming the bonnet in this point. By redesigning the bonnet to work together with the lifting device, it should be possible to reach a HIC value below 1000 also at an impact speed of 50 km/h.

The pedestrian dummy showed small differences in head impact position and timing compared to the mathematical model. This could be a result from the difference in position of the dummy where the dummy was rotated more towards the car in the mathematical simulation tests. It is planned to rerun the mathematical simulations with identical impact position. The mathematical and mechanical dummy tests showed a difference in head velocity prior to the head to bonnet impact. Reasons for this could be the design of the lumbar spine and the hip joint. In a further study, focus will be put on possible redesigning of the lumbar spine and the hip joint of the dummy. One important part of the study will also be the repeatability performance of the dummy. The repeatability was believed to be quite good, but actual repeatability tests under identical circumstances were not performed. Although the dummy showed good performance in the centerline tests, it showed larger differences to the mathematical dummy in the offset position tests on the car. This is probably not a result of poor dummy design. It is more likely a result of a difference between the car mathematical model and the real car geometrical design in these offset positions of the bumper. A redesign of the bumper curvature, seen from above, in the car model is needed to the next step of the study.

In the dummy tests with the active bonnet, the system proved to be able to keep the bonnet up during the torso impact until the head impacted the bonnet. This kind of performance test cannot be performed with the head impacted, and therefore a test with a full-size mechanical pedestrian dummy is necessary.

X CONCLUSION

The pedestrian protection system showed to perform well for an adult. The sensor system proved to be able to differentiate between impacts with a leg form and a pole. The active bonnet proved to be able to be activated quickly enough and to keep head form HIC values below 1000 at all points at 40 km/h impact speed. Also at an impact speed of 50 km/h, a large reduction of the HIC value was achieved.

In dummy tests the system also proved to perform well in more real-life conditions (the shoulder impacting the bonnet before the head).

The study needs to be continued to test the system with a child head form and child leg form. The sensor system also needs to be tested dynamically at different temperature conditions.

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