ABSTRACT

Recent legislation has increased the type approval requirements in the domain of pedestrian protection. A non design restrictive solution for the bonnet area is the implementation of pop-up bonnet systems. Obviously, such systems need a sensing element detecting and classifying the impact object in order to make a fire/no-fire decision for the bonnet lifting actuators.

The working principle of IEE’s pedestrian protection sensor system not only allows the detection of pedestrian-type impacts, but also analyses crash event scenarios. Thus the same sensor is not only used for pedestrian protection, but can also contribute to passive safety by delivering information that can be used for enhanced occupant safety. In decision-making for the pop-up bonnet deployment, it is crucial to reliably distinguish between pedestrians and other objects like traffic signs, footballs or small animals, whereas in crash sensing, it is helpful to know as early as possible whether the collision object is a tree or a vehicle.

The pressure sensitive sensor is integrated into the vehicle front-end and detects parameters like \( T_0 \) (first contact), impact location, width of impacting object and impact dynamics. These data allow a more precise tuning of the restraint systems to specific crash events, the usage of less aggressive restraint systems due to the early \( T_0 \) signal, as well as the replacement of existing sensors (upfront, pole catchers, redundancy).

The sensors ability to deliver robust data in frontal crashes has been demonstrated in tests reflecting compliance, consumer and insurance testing requirements.

In order to provide even more information about crash situations and to offer optimised and cost-effective solutions for other applications, the goal is to develop a family of general impact sensors also covering the detection of rear-end collisions and side impacts.

INTRODUCTION

Regulations aiming at improved protection of pedestrians were first implemented in Europe and Japan in 2005. In November 2009, a UNECE GTR (Global Technical Regulation) with more stringent requirements was voted. The second phase of the European regulation, becoming effective in early 2013 [1], adopts this GTR.

The pedestrian protection regulation includes injury risk assessments for scenarios where a pedestrian head impacts onto the vehicle bonnet. Head impactors representing a child head and an adult head are propelled onto the vehicle bonnet with a speed of 35 km/h and the HIC (head injury criteria) values must comply with the regulation requirements. Compliance requires a certain amount of bonnet deflection, resulting in energy absorption and thus reducing the injury risk.

Vehicle types not having enough clearance between the bonnet and rigid engine bay components use so-called pop-up bonnet technology to guarantee regulation compliance. These vehicles have a sensor system in the front-end detecting an impact and discriminating between pedestrians and other collision objects. In case of a vehicle-pedestrian collision, the sensor signal triggers actuators lifting the bonnet by several centimetres and providing the necessary clearance.

IEE is currently investigating the potential of a PROTECTO™ pedestrian protection type sensor in the area of crash sensing.

FROM PEDESTRIAN PROTECTION TO OCCUPANCY SAFETY

Sensing Principle

The IEE bumper sensor is based on a flexible, foil-type pressure sensitive device which detects a frontal collision by providing four different impact related signals versus time: two switches react on specific force levels, and the impact width as well as the impact position is measured by means of a linear potentiometer. For that purpose a set of electrically conductive elements are printed on two flexible carrier foils which finally are laminated together by means of a double-sided adhesive film,
as schematically indicated in the cross-section view of Figure 1.

Figure 1. Schematics of a foil-type pressure sensor for pedestrian impact detection. Typical dimensions are: length \( l > 100 \) cm, width \( w = 2 \) cm, thickness \( d = 0.05 \) cm.

The adhesive layer contains a sequence of recess structures equally distributed over the complete length which allows establishing an electrical contact by deformation of both polymer foils in case of external pressure loads. The simultaneous parameter detection is accomplished by positioning the sensor somewhere between bumper skin and crossbeam (here: at the interface energy absorber – crossbeam, c.f. Figure 2). Hence, the integration can be handled quite flexibly. The major integration requirement is the presence of a mechanical support to build up the impact related reaction force which needs to be measured.

Sensor Integration

Figure 2 describes schematically a typical sensor integration concept based on detailed FE impact simulations which are performed in order to adjust sensor sensitivity and positioning within the bumper environment. In case of the presented example the contact sensor has been integrated in the energy absorber foam facing towards the crossbeam.

Figure 2. Sensor integration concept for a typical bumper configuration.

Simulation as Key Development Tool

Right from the start, the aim was to base the sensor development completely on simulation because of limited (and expensive) impact / crash test capabilities. Therefore, a virtual sensor development chain has been established which provides the following information:

- optimum sensor location in the bumper
- necessary bumper modifications to improve functionality / robustness
- impact data for calibrating the classification algorithm over the whole temperature range and the whole length of the bumper

Figure 3 describes the simulation based development concept to reduce lead time, test efforts and prototype needs.

Figure 3. Flow chart describing the virtual development chain of the crash sensor.

Based on the OEM specification requirements and CAD data of the carline, the simulation model will be created by applying appropriate (validated) material laws developed for highly non-linear deformation processes. A set of crash impact simulations (partly defined by the OEM and based on legal requirements) allows identifying the optimum sensor integration and provides also preliminary data for algorithm calibration. After finalizing the virtual optimization loop, prototype sensors will be built to perform verification tests (pendulum tests, sled tests, OEM crash tests). The obtained data is used for fine-tuning the algorithm settings. The final design / algorithm will be integrated in the vehicle to pass the official crash test sequence defined in the car type approval process.

Pedestrian Impact Detection and Crash Sensing

In the event of an impact (pedestrian, pole, other vehicle), the sensor delivers signals to the ECU being attached to the sensor. The ECU acquires and analyses the sensor data in order to provide a trigger signal to fire pop-up bonnet actuators in case of low speed collision events involving humans, or to provide an additional input to the
airbag control unit. By using a certain set of input signals, a classification algorithm determines the impacting object or evaluates the crash severity. In a pedestrian protection scenario, the algorithm discriminates so-called misuse objects from a vulnerable road user to actuate only in the latter case the associated pedestrian protection system in a timely manner.

**Pedestrian Detection** - During a collision event, the IEE bumper sensor delivers four different signals versus time such as impact width, impact position and the activation of two threshold levels of the impact force cells (low and high force switch). Figure 4 shows the acquired impact width data for different collision scenarios. Human-like impacts are experimentally simulated by crash-test dummies which have been hit in a lateral position or dedicated human-like leg-impactors (“lower limit” impactors). At $t = 20$ ms the linear potentiometer indicates the impact event. This signal triggers the collision time measuring process, i.e. the timer is set to $t_{col} = 0$ ms.

![Figure 4](image)

**Figure 4. Example of the impact width signal evolution measured during the collision with different objects or dummies.**

The impact width shows a typical increase in case of a human-like leg up to a level of $w = 30$ cm, which is reached about 6 ms after the impact detection. At $\Delta t_{col} = 15$ ms the second leg is also hit at a certain bumper distance offset with respect to the actual first impact location. About 25 ms after first contact detection, the collision process changes from the constitution into the restitution phase, therefore the impact width as well as the impact force started to decrease. Finally, the dummy looses the bumper contact about 35 ms after the first hit, which is monitored by the drop of the positioning signal of the linear potentiometer.

In parallel the impact location across the bumper is also measured (not shown) as well as the activation level of low force switch SWL and high force switch SWH which provide additional information about the strength of the impact. The plurality of data sets indicates an essential development problem, namely how to separate non-human impacts (misuse, e.g. animals, trash cans, traffic signs, etc.) from collision events with vulnerable road users for whom dedicated safety systems have to be activated. For a given object and a given bumper front-end the obtained data depend also on the impact location $Y$ across the bumper, the impact speed and environmental conditions (basically temperature).

**Crash Detection** - As described above, IEE originally developed a sensor element dedicated for pedestrian collision detection in order to trigger active protection systems (e.g. lifting mechanisms of the bonnet, additional air-bags, etc.). That sensor element shows fast response time on any low-energy (i.e. low-speed and low-mass) collision event with vulnerable road users or other objects which can be found on the road. During the collision event it continuously provides information about the impact. The field of application can be extended from such low-energy impacts (causing reversible bumper deformation or minor damages of the outer bumper skin) towards destructive high-energy crash events (e.g. car-to-pole accidents) in order to detect and to classify crashes in such a way that active passenger protection measures can be triggered in a timely manner. Crash tests showed that in comparison with standard crash sensing technology found in the vehicle front end, the new approach shows essential technical advantages:

- fast response time in case of impacts
- impact classification capabilities (strength, impact location / impact vector, type of collision object)
- ample mechanical robustness
- not affected by noise (i.e. vibrations due to rough road conditions)
- beneficial combination with pedestrian protection sensor thus reducing the number of needed sensor elements in the front-end

Indispensable is to categorize upper impact limits for human-like collision events in order to distinguish them from a crash.

**Potential for Improved Occupant Safety**

Automotive industry intends to establish more efficient passenger protection systems by means of improved active safety devices (e.g. multiple airbag solutions, more sophisticated restraint systems, adapted system deployment strategies, etc.) due to more restrictive safety regulation requirements and general market development trends. In general, such techniques can benefit from having more lead time for their activation in order to provide their full protection capability, and / or they need additional data to be deployed in a more dedicated
way according to the crash situation. In case of a frontal collision event it is therefore essential to identify as early as possible strong impacts, i.e. in best case to have a collision object classification very shortly after $T_0$ which is the time of first contact with the car bumper. It can be crucial to know as soon as possible if the collision object is a tree or rather a vehicle. This information can then be provided to the airbag control unit, and the additional information can support an earlier or more appropriate airbag deployment. Standard g-sensor technology shows limitations in detection efficiency due to mechanically more soft material and design constraints of modern car front-ends which are needed in order to fulfil the passive pedestrian protection requirements (injury mitigation). As a consequence, strong impacts are detected with some delay during the collision process, hence, not providing enough time to establish more complex counter measures for improved passenger protection.

**Outlook and Remaining Challenges**

Besides frontal crashes also side crash events as well as rear crash detection in view of whiplash protection can be additional fields of application.

Because of comparatively short distances between passenger and impacting object, it is obvious that fast side crash detection is indispensable to protect the passenger’s life. Timing is even more critical due to additional out-of position problems in case passenger’s head is resting against the B-pillar.

Whiplash protection in case of rear crashes requires fast impact detection to provide sufficient lead time to activate systems like active head-rest positioning. About 80% of all passenger injuries caused by rear crash accidents are whiplash injuries covering in total about 75% of all insurance costs to be paid in case of any passenger injury [2]. Therefore, development and test activities focusing on automatic headrest positioning devices (for front and rear seats) are in the focus of interest. Fast crash detection capabilities can provide a valuable input for such systems.

Although the sensor in its current form already shows the ability to cover a wide range of impacts (small stones to crash), future development is aimed at enhancing the detection range in the high-mass impact area even further.

**CONCLUSIONS**

The IEE bumper sensor is based on a flexible, foil-type pressure sensitive device which detects a frontal collision by measuring $T_0$ (first contact), impact location, width profile of impacting object and impact dynamics. The pressure sensitive sensor is integrated into the vehicle front-end and its working principle allows combining two different fields of sensor applications:

1. **Active Pedestrian Protection**
   Detecting accidents with vulnerable road users in order to trigger protective counter measures to save pedestrian’s lives (e.g. deployment of the car bonnet, windscreen airbags, etc.).

2. **Crash Detection**
   The identification and classification of crash events as early as possible in order to be able to trigger enhanced protective counter measures to save passenger’s lives.

**REFERENCES**
