RESEARCH UPDATE

Automotive restraint systems

In the past 20 years, newly produced automobiles have been equipped with occupant restraint systems, such as air bags, to reduce passenger injuries and fatalities in the event of a crash. An air bag is a passive restraint system—an automatic safety system that requires no action by the occupant. Government regulations, industrial participation, and social consciousness of safety have popularized the use of occupant restraints in vehicles worldwide. Using advanced technologies, additional restraints and enhanced functionalities are being implemented.

History

Automobiles entered the market more than 100 years ago. Since then, tremendous progress in reliability, usability, and safety of roadway vehicles has been made. However, the availability of passive safety systems was slow in coming, despite the initial conception in 1950s and experimental production in 1970s. It was not until the late 1980s that air bags became standard equipment, beginning in the United States. Over the last 20 years, the automotive safety industry has gone through considerable changes.

In recent years, passive restraint systems have been one of the fastest-growing sectors within the automotive industry. One reason for this growth is the inclusion of additional restraint devices on vehicles. For example, the average number of air-bag modules has increased from one to two per vehicle in the early 1990s to four to six per vehicle for the latest models, with more expected to come. Another reason for this growth is an increase in the complexity and sophistication of the safety systems' functional requirements. For example, to minimize out-of-position occupant injuries, a smart air-bag system needs to be equipped with occupant-sensing capabilities.

Particularly notable in the evolution of restraint systems has been the phenomenon of increasing use of electronics, which has occurred in parallel in the automotive world, as well as most technology fields. Increasingly, sensing, actuation, and control functions of air-bag systems are being implemented with electronic filters, conditioners, memory integrated circuits, microprocessors, and microcontrollers. Upcoming products implemented in electronics, such as rollover and other sensors, are being added into an integrated vehicular safety system.

Fundamental concept

In a collision, the vehicle deforms and crumbles rapidly after impact with an object, such as roadside obstacle or other vehicle. Typically, the structural deformation process takes only 0.1–0.2 second, compared to braking maneuvers, which take a few seconds. The deceleration experienced by the vehicle in a collision is at least one order of magnitude higher than normal driving and braking actions. As a result, the occupants inside a vehicle undergo a thrust in the direction of the impact. If there is no protection device in a frontal collision, the occupants will hit the interior (for example, the steering wheel or the dashboard), potentially resulting in injuries or fatalities depending on the severity of the impact. If seat belts are in place, they will exert a load on the occupants in a direction opposite to their movements. In a severe collision, the restraining force of seat belts alone will not sufficiently restrain the occupant, as the restraining forces are limited and concentrated along the narrow strips of belt fabrics. Unlike belts, air bags cushion the occupants in a manner that differ in two primary ways. First, the contact area between a bag and an occupant is larger, thus distributing the restraining load more evenly, and the total stopping force can be greater. Second, the bags have openings that allow the air to exit, thus dissipating the kinetic energy of the occupants more effectively.

The effectiveness of air bags depends on a timely deployment procedure, with all the components functioning properly. The major components in a frontal air-bag system are shown in **Fig. 1**. The sensors represent the brain and nerves of the system, which detect and decide whether and when to initiate the inflator. The inflator either generates or releases gas to deploy the bag. The bag is fully inflated before the occupant makes contact with the bag without inflicting unnecessary forces on the occupant. The vehicle interior sustains the collision with minimum penetration of structural deformation into the passenger compartment and offers supplementary support to the operation of air bags. Although the above description is for frontal systems, the fundamental concept applies to side air bags as well.

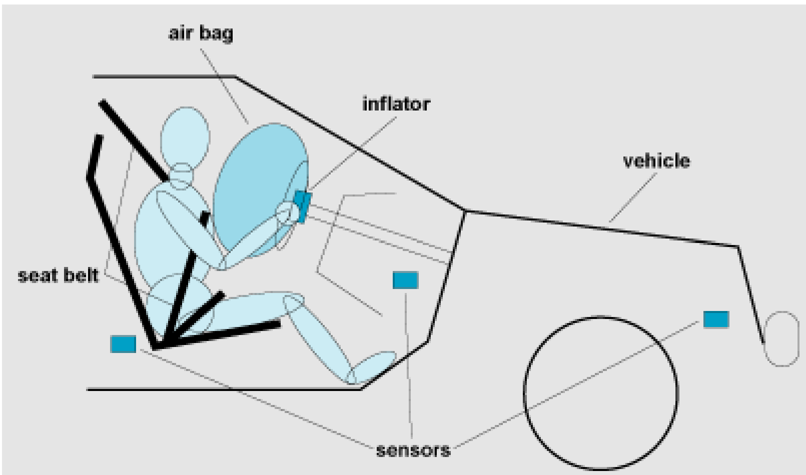

Fig. 1 Components of a frontal air-bag system.

Figure 1 shows a distributed sensing system, where multiple sensors are combined to detect a collision. An electronic control unit (ECU) often monitors the triggering of multiple sensors and controls the activation of the air bags. Over the last 10 years, the increasing capabilities of electronic sensors have enabled many vehicle platforms to adopt a single-point sensing concept, with one sensing module centrally located on a vehicle. However, the success of the single-point strategy requires that a variety of crash collisions yield sufficient and distinguishable signals to be sensed at a central location. Given the diverse characteristics of vehicle structures, not all vehicles are suited for the single-point placement strategy despite its enormous success across many vehicle types in the marketplace today. One countermeasure to overcome the deficiency of the single-point sensing arrangement is to add satellite sensors in select locations, such as the frontal corners of the vehicle for frontal air bags or side doors for side air bags.

Some concerns of air-bag safety have arisen in situations where passenger injuries or child fatalities have been caused by air-bag deployment. The countermeasures to avoid such problems include the depowering of air-bag modules or the disabling of air bags when it is warranted by vehicle interior conditions. The former can be achieved by a reduction of air-bag inflation force, if seat belts are worn by the occupants. The latter is realized by occupant sensing, which provides occupant status information to the ECU for final decisions. Smart restraints of current-generation vehicles are designed and equipped with these options.

Technology trends

Over the years, a transition in technology has occurred at several levels among the primary components of occupant restraint systems, including sensors, air-bag modules, and seat belts. In addition, product design and implementation methods have changed dramatically. The functional requirements of passive restraint systems have been elevated from a simple on-or-off deployment decision to a staged- or graded-control command, which provides a tailored choice for optimal protection in a smart system.

In the area of sensing technology, electronic sensors have become dominant and replaced first-generation mechanical and electromechanical devices. Electronic control units (ECU) have been equipped with sophisticated capabilities to allow reliable diagnosis and robust control. The ECU is coupled with a network of satellite and auxiliary sensors to acquire all the necessary information to make an appropriate crash-status decision. In addition, data from occupant sensors and seat-belt-buckle switches are fed into the ECU to provide occupant-seating conditions as a critical part of smart restraints. Through a sensor network distributed across the vehicle platform, intelligent decisions can be made for selective deployment of the proper restraints. Air-bag modules are moving quickly toward the use of dual- or multiple-stage inflators. These partitioned and staged inflators provide the benefits of minimizing loads on the occupants and offering the flexibility of meeting the protection requirements in various crash conditions. Seat belts have been engineered with versatile options such as pretensioning and load-limiting features.

Together, sensors, actuators, and protective devices constitute the foundation of smart air bags. An optimal protection sequence begins with the pretensioning of the seat belts to engage the occupant, followed by a seat-belt load-limiting feature to minimize the restraining load, and then an effective dissipation of occupant movements with an air-bag cushion inflated with an adjusted and controlled level of deployment power. All the restraining devices in the vehicle work in a smart and coordinated manner to manage the kinetic energy carried by occupants in a collision (**Fig. 2**).

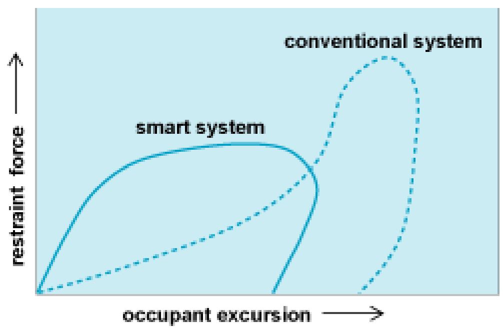

Fig. 2 Reduction of occupant excursion and restraining force by smart restraints.

Outlook

The air-bag industry has experienced tremendous growth in the last two decades, and is already maturing in several subsectors despite its relatively short history, compared with other sectors of the automotive industry. The concept of vehicular safety, however, is being rejuvenated with a variety of new developments. For example, global positioning systems are being integrated with wireless communication and crash-sensing systems into emergency notification and response services.

Parallel to the rapid progress in passive restraint systems, significant strides have been made in active safety systems. Passive safety systems are "reactive" with the purpose of mitigating accident consequences, while active safety systems are "preventive" and target the potential to avoid accidents. In active safety systems, the actions occur prior to the accident. One example is the mild level of braking exerted automatically in some advanced cruise control system when the vehicle-following distance falls below a threshold. Another example is the use of a steering-assist function to prevent road-departure accidents.

The introduction of active safety systems will provide the foundation for integrating selective components and capabilities into automotive safety systems. The focus of safety improvements will shift from collision mitigation to collision avoidance, although the two functions are not separable. The passive restraints, originating from the concept of a simple air-bag deployment, will evolve into a part of the smart-vehicle interior that accommodates all customer-appealing features inside a protective vehicle environment.

See also: Automobile; Automotive brake; Automotive steering; Microsensor

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Additional Readings

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