Occupant Safety and Restraint Systems

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03.12.2018
Occupant Safety

Introduction

Protection in frontal impact

Protection in side impact

Protection in rollover events

Protection in rear impacts
Reasons for Restraint Systems

Seatbelt

- Rollover: keep occupant inside the car
- Frontal crash: early coupling of the occupant to vehicle deceleration

Airbag

- Frontal crash: protection of head and neck
- Side impact: protection of pelvis, abdomen, chest, and head
## Fatalities on the Road in EU15

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Percentage</th>
<th>No. Casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal Impact</td>
<td>28</td>
<td>11,760</td>
</tr>
<tr>
<td>Side Impact</td>
<td>25</td>
<td>10,500</td>
</tr>
<tr>
<td>Rear Impact</td>
<td>1</td>
<td>420</td>
</tr>
<tr>
<td>Rollover</td>
<td>4</td>
<td>1,680</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>20</td>
<td>8,400</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>16</td>
<td>6,720</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>2,520</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>100</strong></td>
<td><strong>42,000</strong></td>
</tr>
</tbody>
</table>

Car Structure

Stiff compartment
progressive crumble zone

Source: U. Seiffert, Fahrzeugsicherheit
Internal Safety: Restraint Systems

Seat belt, airbag, seat, side impact protection

Source: U. Seiffert, Fahrzeugsicherheit
Occupant Safety

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Car and Occupant Behaviour in Frontal Impact

Source: Zellmer et al. 1999
Speed $v$ and deceleration $a$ vs. distance at idealistic square shaped decelerations

- Occupant early coupling
- Occupant late coupling
- Vehicle

$\overline{d_r}$, early coupling

$\overline{d_r}$, late coupling

Displacement
Occupant Kinematics in a Frontal Crash

Pretensioner firing at about 10 ms

Source: U. Seiffert, Fahrzeugsicherheit
Restraint System Design for Frontal Impact

Belt System for early coupling of the occupant to the car

Airbag for protecting head and neck
History of the Seatbelt

First Seat Belt Patent
Gustave-Désiré Lebeau
May 11, 1903
History of the Seatbelt

Single lap belt on a live subject and during dynamic testing (40 km/h) 100 ms after impact.

History of the Seatbelt

Single diagonal belt on a live subject and during dynamic testing (40 km/h) 25 ms after impact.

History of the Seatbelt

Combined lap and chest restraint with two anchoring points on the floor and one in the door post (the three point belt). Restraint on a live subject and during dynamic testing (40 km/h) 100 ms after impact.

History of the Seatbelt

The 3-point seatbelt was first introduced as standard equipment by Volvo in 1959 for the Amazon 120 and the PV544
History of the Seatbelt

• Several improvements of the seat belt have taken place over the years. The first was the inertia reel (the belt retractor) during the 1960s followed by the retractor pretensioner and the buckle pretensioner during the 1980s.

• The first, and an important step into active and integrated safety was taken by Mercedes-Benz in 2002 with the belt pre-pretensioner (PRE-SAFE).
The Effect of the Belt System can be Classified into two Phases:

1) The belt pretensioning following the crash only by few milliseconds and creating the optimum pre-requisites for the restraint system.

2) The load limitation which keeps the force to the belt to a pre-defined level during the forward displacement of the occupant thus leading to an optimum utilization of the space available in the interior.
Pretensioning of the Belt System

Source: Zellmer et al., ESV 2005
Retractor Pretensioner

Source: Autoliv
Retractor R200RP- Working Principle

Pretensioner not activated

Gas Generator powder ignites
Pressure builds up within tube assembly
Balls are guided through tube around the pinion
Pinion subsequently drives the spindle
Webbing is retracted
Balls are collected in ball trap
Buckle Pretensioner

Source: Autoliv
Buckle Pretensioner

Locking principle

Balls deform the tube under load

Source: Autoliv
Requirements to Good Belt Pretensioning

Strong fixation of the occupant as early as possible.

Limitation of the shoulder force to 1.5kN – 2.5kN in order to avoid thorax injuries due to pretensioning.

Set-up of a suitable force on the retractor to minimize the film spool effect.

Fixation of the pelvis by second pretensioner at anchor plate.

Source: Zellmer et al., ESV 2005
Keep Shoulder Belt Forces Low in Crash

Probability of severe thoracic injuries (AIS3 or more severe) depending on the shoulder belt force and the occupant’s age

Retractor Load Limiting by Torsion Bar

Webbing load < 4kN: no webbing extraction

Webbing load > 4kN: webbing is extracted, plastically twisting of the torsion bar

Source: Autoliv
Restraint System Design for Frontal Impact

Belt System for early coupling of the occupant to the car

Airbag for protecting head and neck
Frontal Airbags
Airbag: How It Works

• Sensors (typically 1 central and 1 or 2 satellite) detect frontal crash
• Electrical signal, in excess of the monitoring current, is sent to the inflator initiator (squib)
• Inflator generates gas that begins to fill the cushion
• Pressure from inflating cushion breaks open “doors” on cover
• Cushion is inflated and in position to protect an occupant in typically 25-30 msec for Driver & Passenger Airbags, 10-15 mSec for Knee Airbags
Airbag: How It Works

- Gas is released through cushion vents to soften the impact of the occupant loading the cushion
- Occupant is protected from hitting the wheel, instrument panel, windshield and other interior geometry.
- Cushion is deflated
  - The majority of generated gas is typically vented from the cushion by 100 msec. This allows the driver to see and steer the vehicle if it is still moving.
Passenger Airbag Systems

Source: Autoliv
Restraint System for Frontal Impact of a State-of-the-Art Car

- buckle pretensioner
- anchor plate pretensioner
- retractor with load limiter 4kN
- dual stage airbag

Source: Renault
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What Happens in a Side Impact?

Start of impact

ECU

Electronic Control Unit

Head airbag

Thorax airbag

time in milliseconds

Source: Autoliv
Side Impact Regulation

<table>
<thead>
<tr>
<th>Side Barrier</th>
<th>Side Pole</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FMVSS 214</strong></td>
<td><strong>FMVSS 214</strong></td>
</tr>
<tr>
<td>ES-2 re</td>
<td>SiD IIIs / ES-2 re</td>
</tr>
<tr>
<td>54 km/h / 27°</td>
<td>0.32 km/h 75°</td>
</tr>
<tr>
<td>48 km/h</td>
<td>Rigid 254 mm Pole</td>
</tr>
<tr>
<td>MDB, 1368 kg</td>
<td>SiD IIIs / ES-2 re</td>
</tr>
<tr>
<td>SIV IIIs</td>
<td>0.32 km/h 75°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>UN R95</strong></th>
<th><strong>UN R135</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>ES-2</td>
<td>WS 50%</td>
</tr>
<tr>
<td>50 km/h 90°</td>
<td>32 km/h 75°</td>
</tr>
<tr>
<td>MDB EEVC, 950 kg</td>
<td>Rigid 254 mm Pole</td>
</tr>
</tbody>
</table>

Source: Cahrs
Thorax Side Airbag

Source: Autoliv
Inflatable Curtain

Source: Autoliv
State-of-the-Art Protection

Side Impact Protection in new Mercedes E-class (2009): 4 Airbags each Side

Source: Mercedes
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Rollover Protection

FMVSS 208
rollover test setup

Source: Prof. Norbert Schaub, Mercedes Benz Cars
Rollover Protection

New high-efficient silicon-based sensor and unique software program

Electronics

Pretensioner

Inflatable Curtain

7° 100 ms*

11° 130 ms*

* Worst Case

Source: Autoliv
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Rear Impact Protection

Fuel tank integrity test FMVSS & ECE
Rear Impact Protection

Cervical spine distortion injuries (CSD) - also known as whiplash injuries - in passenger car rear impact accidents, in particular at low speeds with a $\Delta v$ of 15 km/h or less, are becoming increasingly problematic.

![Annual socio-economic losses due to rear end collisions]

- **Germany**: 2,000 M Euro, 24 Euro/person
- **USA**: 10,000 M $, 24 $/person
- **Netherlands**: 150 M Euro, 9 Euro/person
- **Sweden**: 210 M Euro, 23 Euro/person

Source: Hell et all IIWPG/IRCBI Symposium, October 9, 2001
Standard Test Set Up
Benchmark of Seat Designs
Injury Mechanism in Rear End Collision

source: Felix Walz, modified

Phase 1
Translation and Extension

Phase 2
max Extension

Phase 3
Flexion Rebound
Occupant Safety

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Protection in frontal impact

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Occupant Safety: All Restraint Systems