A test procedure for airbags

ika Report 8328

Contents

1 Introduction

Airbags are a standard feature in most new vehicles today. A large number of vehicles already have different airbags: front airbags, side airbags, head airbags and knee airbags for driver and front-seat passenger. All of these systems use a number of acceleration sensors located at different positions on the vehicle bodywork. The deceleration occurring after an impact is detected by the systems, evaluated and if necessary the decision taken to trigger the individual airbags. A self-diagnosis system monitors the operativeness of the systems before and during journies. If malfunctions are recognized the system is deactivated, a message saved in the fault memory and the driver notified by an indicator light which comes on.

Although modern airbag systems undoubtedly improve the protection potential for vehicle opccupants considerably in interaction with the belt, very little is known about the effects of ageing on the reliability of these systems since airbags are not usually used during the life of a vehicle.

The "International Motor Vehicle Inspection Committee" (CITA) thus commissioned the "Institut für Kraftfahrwesen Aachen" (ika) to investigate the operativeness of older airbag systems.

In the context of this research project the extent to which the deployment threshold is reliably recognized by the electronics in older systems will be examined. The electronic components of the systems will be checked to allow a statement to be made on the deployment threshold of the different systems. For this purpose, the sensor system, wiring harness and control unit are mounted on a test sled in the crash test facilities at the ika. Tests will be also carried out at different impact speeds and decelerations. These tests should determine whether the deceleration threshold to trigger the airbag is recognized correctly. Furthermore, the airbag modules of the individual systems will be triggered and their correct inflation checked.

Before the actual tests can be carried out, the various systems will be analyzed and if necessary the electric characteristic of those components which are not connected (e.g. seat-belt tensioners) simulated so that numerous crash tests can be performed with the systems indepenent of the vehicle environment. The tests results show the mode of operation of the airbag systems, from which the reliability of the systems can be derived. A literature enquiry into the development, mode of operation and components of the airbag system precedes the study.

2 The airbag restraint system

2.1 Historical review of the development of airbag systems

The first concepts for an automatically inflating "air cushion" used as an impact protection for car passengers were discusssed in the sixties, approximately 10 years after corresponding patents had been granted (1952 for John HETRICK, USA, and 1953 for Walter LINDNER, D). John HETRICK's patent describes a general airbag system in which a self-opening airbag is automatically inflated following a sudden deceleration of the vehicle.

In the USA new ordinances (FMVSS 208) to improve vehicle safety were passed in the middle of the sixties against the background of increasing numbers of accidents, the so-called "Safety Act". A bundle of new ordinances were planned to improve safety in traffic. It was not until 1984, following long and controversial discussions, that an agreement could be reached on the introduction of a passive restraint system on September 1, 1989 for all new vehicles registered in the USA. These automatic restraint systems could be automatically closing seat belts or the airbag. However, only the airbag has been successful (as of model year 1990 for the driver and as of model year 94 for the front-seat passenger).

In order to be able to comply with the new ordinances (FMVSS 208) immediately after they come into force, airbag developments were also initiated and intensified by European automobile manufacturers; primarily by Mercedes-Benz. The basic development of "passive restraint systems" stepped up at Mercedes-Benz from 1967 onwards. The airbag patents turned out to be the only practical alternative offering scope for improvements.

This first development stage from 1967 to 1972 is referred to as "the principle functional proof". The airbags were initially inflated using compressed-gas canisters. However, the pressure canisters could only be accommodated in the instrument panel. Connection to the steering wheel proved problematic since it could only be sealed with great difficultly. In the next development phase experiments were carried out with liquefied gas and solid fuels. The solid propellant should supply the thermal energy needed to expand the liquid Frigen. Although the necessary inflation time of 1/30 second was reached this system was still too heavy. A neoprene-coated polyamide fabric was initially determined as a suitable material for the airbag. After 1970, research concentrated on an inflator filled with solid fuel to inflate the airbag. Together with development partners from the chemicals and automotive industries, this method of producing the gas was perfected for series production as of 1974. In December 1980 the first production vehicle with a driver airbag, a Mercedes Benz S Class, rolled off the assembly line. Seat belt tensioners were also offered for the driver and front-seat passenger. As of 1988 front-seat passengers in the S Class were also protected by an airbag [NN95a].

Since the beginning of the nineties, all automobile manufacturers have been offering airbags as a standard feature or optional extra, even in compact class cars [HAL96].

However, the world-wide use of the airbag system didn't proceed harmoniously since on the US-American market it is specified as the only restraint system (passive system) whereas in Europe it has been developed as an additional safety device (SRS: Supplemental Restraint System) to the seat belt system. These different developments have affected the size of the airbag and inflator. As a sole passenger protection system the airbags must be much bigger and must inflate earlier since the unprotected passenger collides faster with the instrument panel. Fig. 2-1 shows a summary of the various systems and airbag volumes.

	Driver	Front-seat passenger
Euro (Active, seat belts have to be worn)	approx. 35 l	approx. 65 l
US Fullsize (Passive, protective effect without seat belts)	approx. 70 l	approx. 120-170 l

Fig. 2-1: Different airbag volumes [SEI98]

The number of persons killed or injured in traffic has dropped continuously since 1970. Judging by the sample statistic for passive safety, safety has improved roughly 2,5-fold from 37 to approx. 90 accidents for each DM 1 million of the consequential costs of injury [LAG97]. Over the same time period the seat belt developed into a standard feature and has become an indisputable matter of course. Today, the 3-point automatic seat belt, seat belt tensioner and airbag constitute a carefully matched passenger protection system.

2.2 The mode of operation of the airbag system

The task of the airbag system is to minimise the risk of injury to the vehicle occupants following various types of impact. The airbag develops its protective effect depending on the direction from which the impact comes and the resulting vehicle deceleration. It reduces the kinetic energy of the forward moving vehicle occcupant, and thus their speed relative to the passenger compartment, with the aid of the gas escaping from the airbag which has been produced by the triggered pyrotechnic gas inflator, and thus prevents in combination with the seat belt system the head or chest hitting the steering wheel, instrument panel or the windscreen.

A complex sensor system and evaluation unit is required to control the system. The triggering unit, which is usually located in the centre of the vehicle, measures the deceleration recorded by one or several acceleration sensors during an impact and calculates physical parameters such as the deceleration, change in speed and path curves from these.

The airbag is triggered when a threshold value is exceeded which is determined by the collision conditions, the free forward movement path, the seat position and the passenger compartment.

A common rule for determing the moment of triggering is referred to as the "13 cm minus 30 milliseconds“-rule. This rule was used at the beginning of airbag developments. Put simply, this rule means that the required moment of triggering is calculated by subtracting 30 milliseconds from the time at which the occupant has moved 13 cm forwards [CHI00]. This rule is based on the following assumptions:

- the estimated distance between the fully inflated airbag and the chest or head of the passenger is 13 cm in the normal seat position at the beginning of the collision. For example, assuming the chest of the driver is 39 cm away from the steering wheel before a collision and the inflated airbag has an unfolded height of 26 cm, the occupant makes contact with the inflated airbag after a forward movement of 13 cm.
- 30 milliseconds are needed from the time at which the the inflator receives the triggering signal until full inflation of the airbag. These 30 milliseconds now have to be deducted from the time at which the occupant has moved forwards by13 cm.

These assumptions are simplifications because the distance and the calculated time depend on several factors. The different sized occupants sit behind the steering wheel in different positions so that the distance to the steering wheel differs. Different inflators need different times to fully inflate the airbag. The "13 cm minus 30 milliseconds"-rule is therefore only an initial approximation to determine the moment of triggering, though it should be noted that fleixble triggering times are needed for occupants of different heights and weights. It would appear that a more adaptable criterion is needed, "x - y miliseconds", with x and y adjusted to the repsecitve situation, instead of a fixed limit "13 cm – 30 milliseconds". Most driver airbag systems are triggered within 10-50 ms after a collision with a change in speed of 16 km/h or more [CHI00].

Fig. 2-2 shows the temporal course of a crash with airbag deployment. In the figure, a VW golf moves towards the crash wall at a speed of 56 kph. The two fastened occupants are moved forwards relative to the vehicle during the crash by the forces of inertia [SCH92].

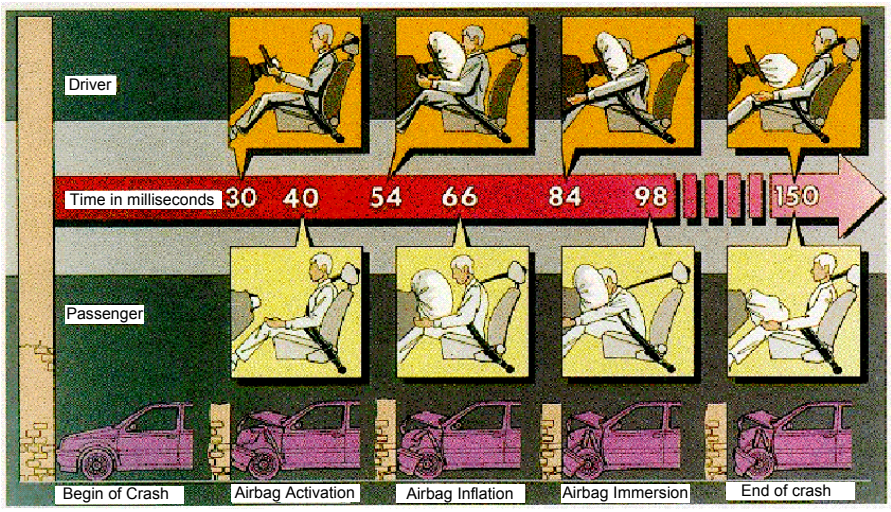


Fig. 2-2: Temporal course of a crash with air deployment [SCH92]

The following individual processes hereby take place:

- the bumper touches the crash wall at the time t=0
- after approximately 25 ms the electronic sensor activates the squib for the driver module
- after 30 ms the cover has already been torn off the driver module to allow the airbag to inflate
- after around 35 ms the squib is activated on the front passenger side (10 ms later than on the driver's side since the passenger-side airbag is much further forward)
- the driver airbag is fully inflated after around 55 ms and the driver dives in
- after around 65 ms the passenger-side airbag is also fully inflated and the front-seat passenger also falls into the airbag
- after around 85 ms the driver has reached maximum immersion in the bag and moves away from the steering wheel again
- the front-seat passenger reaches the foremost position after 100 ms and then starts to move back
- after 150 ms the accident is over, the passengers are back in their starting positions and both airbags are empty to a large extent.

The various airbags can be classified in different categories of airbag modules in accordance with the draft ruling of the European Community [NN95b]:

- Category A: Airbag system to protect the driver in the event of a front-end collision
- Category B: Airbag system to protect the front-seat passenger in the event of a front-end collision
- Category C: Airbag system to protect the passengers on the other seats in the event of a front-end collision
- Category D: Airbag system to protect the passengers in the event of a side collision

This research project deals with airbag systems in categories A and B.

2.3 The components of the airbag system

The airbag system together with the 3-point automatic safety belt and knee impact bolsters is part of an extensive passenger restraint system, Fig. 2-3.

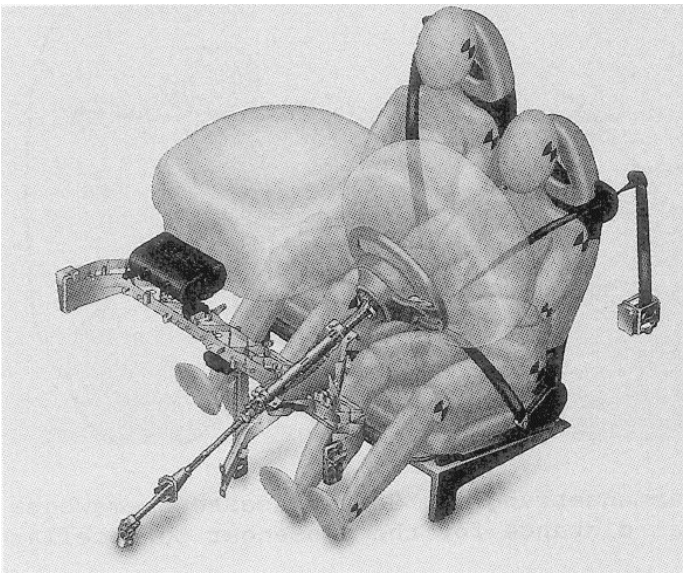


Fig. 2-3: Restraint system components [MAZ97]

The airbag system consists of the following components:

- Sensor system
- Control and diagnostic unit
- Wiring harness
- Airbag- module (airbag-steering wheel, airbag-shutter, inflator and inflator support, airbag, contact unit)

The mode of operation of airbag systems is characterised by the interplay of the components sensor system, triggering electronics, inflator and airbag. The individual components will be explained in the following sections.

2.3.1 The airbag steering wheel and the airbag cover

The vehicle's steering column, as the carrier of the steering wheel and airbag module, should move as little as possible in the event of an accident (low intrusion). Since the inflation of the airbag is constant relative to the steering wheel, any movement of the steering wheel inevitably leads to a movement of the airbag.

The steering wheel must provide sufficient installation space for the module components inflator support, inflator and airbag in the middle of the impact absorber. These components are covered by the steering wheel cover. The cover was initially manufactured of shatterproof plastic padded with PU foam. A belt (usually aramide fibre) with foamed-in polyester network was incorporated inside this. Later airbag covers were made of unreinforced thermoplastics. The latest covers offer better mechanical characteristics at low temperatures (<-20°C) than those on a PUR basis. The steering wheel cover has defined points of breakage through which the airbag can unfold [HAL96, MAT95, SEI98].

2.3.2 The inflator and inflator support

One of the two central components of the airbag module is the inflator with the inflator support. During the development of the airbag, attempts were initially made to carry the inflation gas needed for the airbag in gas canisters in the vehicle. Since this system was susceptible to leaks, particularly in the area of the rotating adapter on the steering wheel hub, an alternative concept had to be found to provide the airbag inflation gas. Storage of the gas directly in the steering wheel avoid this leak problem.

The inflator consists of a metal case inside of which there is a combustion chamber surrounded by a metallic tissue filter packing. In pyrotechnic inflators, this chamber contains 70-75 g of a solid fuel pressed into a tablet form. This consists of 60 % sodium azide (NaN_3), 20% potassium nitrate ($KN0_3$) and 20% silicon oxide ($Si0_2$).

When the inflator receives the triggering signal, the flow of current melts the triggering wire in the priming charge which is this ignited. This burn-off of the squib starts the exothermic oxidation of sodium azide with potassium nitrate. The gas mixture produced by this reaction passes through the filter unit, which separates out the solid particles and cools the gas down, into the airbag. This unfolds and breaks open the airbag cover at the defined points of breakage.

Nitrocellulose-based propellants are used as an alternative, whereby a smaller quantity of these is generally required. This propellant is an interesting alternative to sodium azide since it burns off completely and makes the inflator recyclable [SEI98].

By contrast, hybrid inflators work with a stored gas (example: argon or helium) which is heated to a certain temperature through the combustion of a relatively small amount of propellant (example: Arcide 4971) [WEH94]. There is a squib in the center of the combustion chamber (electric fuse with approx. 2 g of black gunpowder as a priming charge). The outlets of the combustion chamber are hermetically sealed by aluminium foil.

The inflation and unfolding procedure can be influenced by varying the parameters of the chemical composition of the propellant, the size of the squib, the exhaust vents and the porosity of the filter fabric. The pressure should build up slowly at the start of inflation and only reach its maximum on complete ejection of the airbag [KUR99, SEI98, WEH94].

Vehicles with driver and passenger-side airbags normally use three inflators (or one inflator for driver airbag and a tubular gas generator for the larger passenger airbag). One inflator is located in the steering wheel's airbag module and the other two belong to the passenger-side airbag module. The passenger-side airbag is often triggered with a delay 10-15 ms (larger forward movement space) after the driver airbag has been triggered. This significantly reduces the noise and the passenger compartment pressure gradient. The fuses for the airbag inflation (squibs) hereby work with a short impulse (50-200 ms) and a high current (5-20 A). The resistance is between 1 and 5 Ohm [HAL96, SEI98].

2.3.3 The airbag

Initial airbag developments used a fabric coated on the inside with polychloroprene. Most of today's airbags are uncoated. The fabric thickness has gradually been reduced from 940 dtex to 470 dtex [BRA93]. Fabrics with a thickness of 235 dtex are also used, thus benefiting the reduction in weight and a smaller volumetric size [SCA90].

Exhaust vents are used to allow the gas to escape. Gas-permeable fabric elements or openings could be found on the rear of all airbags which allowed a controlled deflation of the airbag. Altering the size of these fabric inserts or openings and their permeability allowed a vehicle-specific adjustment of the evacuation process and the cushioning of the passenger (energy absorption through flow losses during the expulsion of the gas) [KUR99].

Defined porosity filter fabrics are nowadays used on the sides of the airbag. This protects the passengers against possible escaping hot propellant particles and does take away with expensive reinforcing seams around the exhaust vents. Polyamide 6.6 fabric or PET is used as a material [SEI98]. A controlled opening is ensured by inflation control seam, restraints and the folding system. A number of 25-30 cm long restraints are sewn into the inside of most full-size driver airbags to achieve the cushion shape. The expansion in the direction of the passenger is thus restricted [OSA99].

The passenger-side airbag, which unlike the more lentiform driver airbag is wedge shaped, is designed analogous to the driver airbag and simply has a much larger volume of approx.120-170 l (US full size). The direction and speed of expansion during inflation can be varied in different ways [KUR99]. Apart from various ways of folding the airbag, inflation control seams are inserted during the production process when folding the airbag which allow this to be influenced. The various folding versions are referred to as buckle, roll and layer folding and differ in the stress on the airbag during inflation and in the possibility of a mechanical manufacture.

2.3.4 The contact unit

A contact unit is needed to transmit the trigger current and monitoring signals which also ensures an electric contact in all steering wheel positions. The transmissions in the driver airbag pass through a critical area (transfer from a cable fixed to the vehicle and a cable fixed to the steering wheel) within the airbag module. A failure of this transmission element blocks the airbag deployment. A double (redundant) sliding contact unit proved problematic since malfunctions occurred due to soiling and condensation. Today's systems use a coil spring, a cable loop or similar with a slip ring contact (together as a redundant system) to ensure the contact between the airbag module and control unit in all steering wheel positions and atmospheric conditions [KUR99].

2.3.5 The sensor system

An ideal acceleration sensor is assumed for the deceleration curve during a collision in sensor technology. This means that it works within a certain frequency range and records all rapid changes in acceleration without delay. This type of sensor has not been available up to now. Only the latest developments in the field of piezoelectricity and micromachine semiconductors have made such sensors any where near possible.

Different approaches were taken since ideal sensors were not available. The sensors shown in Fig. 2-4 were used in the early eighties when the first airbag systems were introduced.

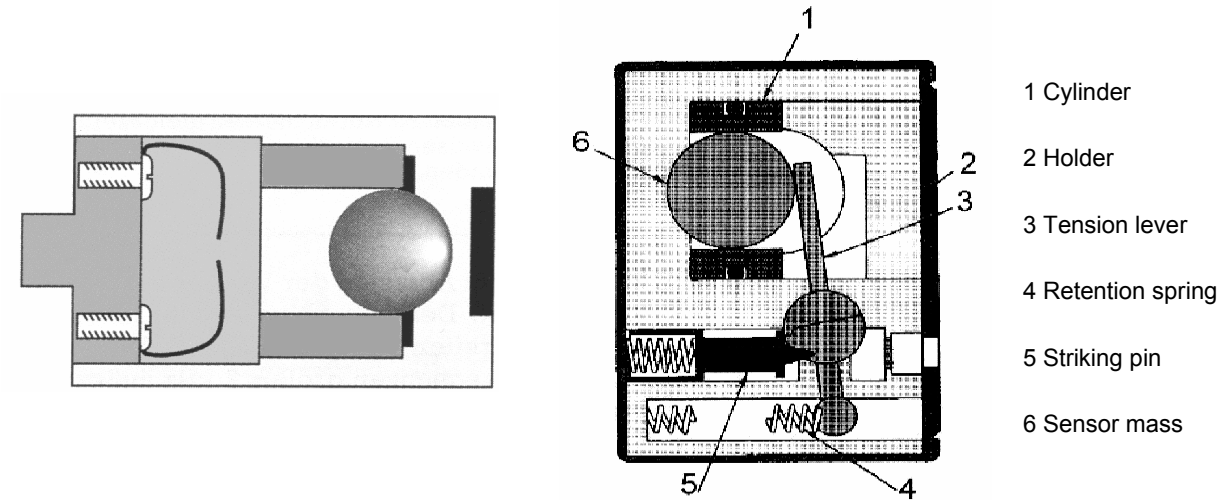


Fig. 2-4: Electromechanical ball/tube sensor (left) [DAH97] and mechanical ball sensor (right) [HAL96]

In the electromechanical sensor the iron ball is held by a permanent magnet. During a hard impact the ball breaks loose from the magnet and rolls along the tube in the direction of the contact. The air resistance causes a damping of the integration effect which has to be taken into account during the development of the vehicle. This sensor is characterised by its simplicity. It only reacts to acceleration in one direction and in the end consists of a simple switch which is closed in the event of an impact [DAH97].

The next illustrations show further electromechanical sensors. The disk sensor (Fig. 2-5) has an eccentric unbalanced mass. A deceleration causes the plate to turn against a coil spring and close a contact after a certain twisting angle, thus triggering the airbag.

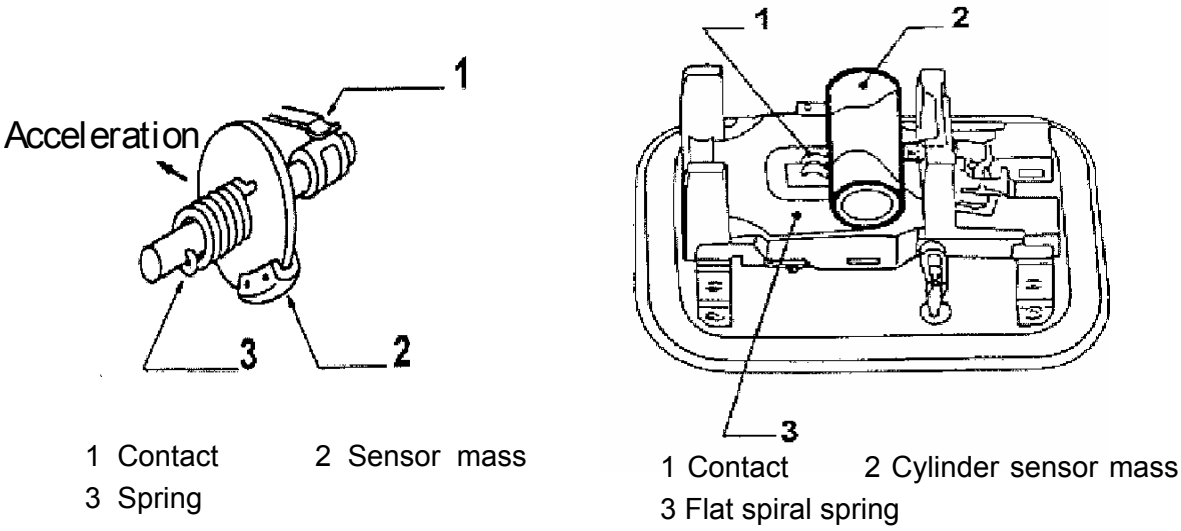
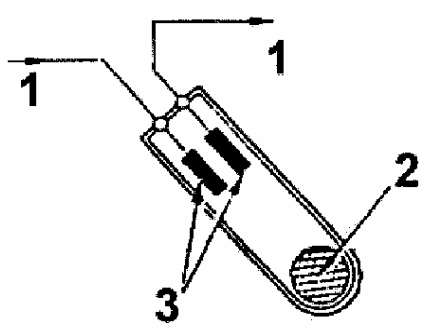


Fig. 2-5: Disk sensor (left) [HAL96] and cylinder sensor (right) [NN89]

In a cylinder sensor a flat spiral spring is wound around the cylindrical mass and unwinds in the event of a deceleration. At a sufficient deflection the contact closes and the airbag is triggered.

In the mercury sensor (Fig. 2-6) a mercury ball moves up an incline in a small glass tube to two contacts in the event of a deceleration. The airbag is triggered if it touches the contact.



1 Connecting lines
2 Mercury ball
3 Contacts

Fig. 2-6: Mercury sensor [HAL96]

Since the acceleration curve has to be considered for a safe decision on any airbag deployment and the system must be monitored to guarantee the function, the use of purely mechanical sensors proves difficult. Mechanical and electromechanical systems can only detect the transgression of a previously defined maximum acceleration, a diagnosis is complicated. A continuity check of the spring, for example, is possible to detect a broken spring.

The early designs thus led to a series of faulty triggerings. This in turn led to a double-track approach in which, for example, the ball sensor was combined with a wire strain gauge sensor (Fig. 2-7).

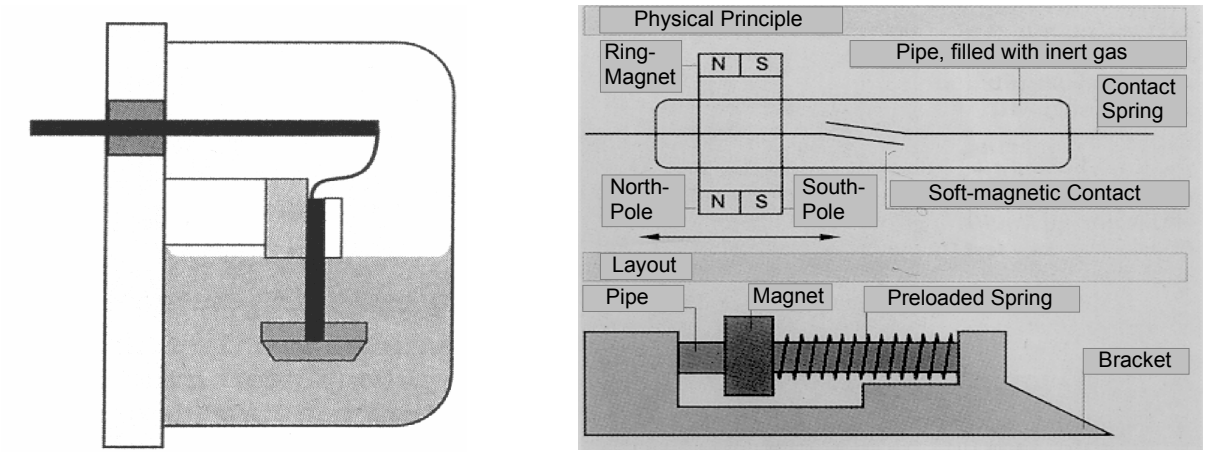


Fig. 2-7: g-level sensor (left) [DAH97] and magnetic reed contact sensor (right) [BRA93]

In this combination the roles of the sensors are divided up between a linear g-sensor and an electromechanical ball/tube-switch as the so-called safing sensor.

The safing sensor is used as a safety switch to prevent an unintentional triggering. Its switching thresholds are set so that no closure is possible in normal driving conditions. This sensor only switches early in the event of a crash and thus enables triggering. The g-level sensor in Fig. 2-7 is normally a wire strain gauge connected to the acceleration part by means of a spring. The viscosity of a liquid dampens the influences so that its behavior is smooth and linear. The safing sensor used by Mercedes-Benz, for example, is a magnetic reed contact sensor (Fig. 2-7), a mercury sensor was used in older systems (Fig. 2-6) [BRA93, SCH92]. In the electromechanical sensor shown in Fig. 2-7 a reed contact tube sits on a magnetic ring which is pressed against a spring by a deceleration and closes the reed contact.

A basic concept exists for the various combinations of sensors, shown in Fig. 2-8. A combination of a ball sensor and a wire strain gauge sensor is hereby assumed. It can be seen that both sensors have to switch simultaneously to trigger the squib.

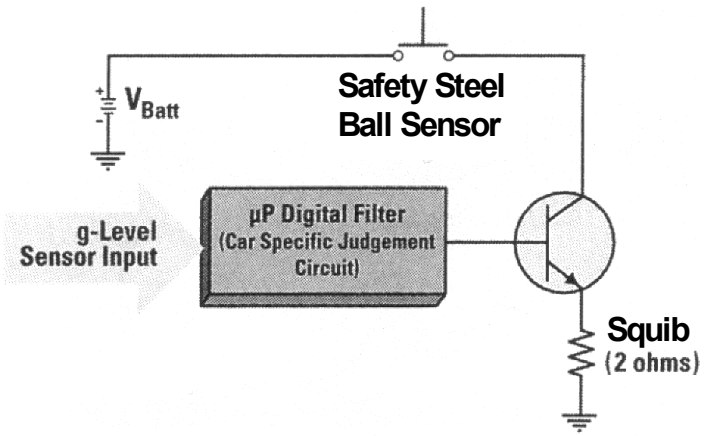


Fig. 2-8: Combination of a g-level sensor with a safety sensor [DAH97]

An impact normally starts with the actuation of the g-level sensor and its input into the lowpass filter or comparator circuit.

If the integrated g-level is large and lasts long enough the comparator switches to the trigger mode (fire state). Moreover, a sufficiently large collision or impact is required to tear the ball away from the magnet and close the contact at the end of the tube. This completes the two-stage test.

Two sensors are thus needed to meet the requirements of a double check. This can also be achieved with two identical sensors. The use of two different sensors has, however, become common practice. Fig. 2-9 shows from a different point of view why the two complementary sensors work well together. The linear g-sensor reacts very well to slow variations, though less so to high-frequency influences on account of the viscosity of the liquid. This corres-

ponds to the behavior of a lowpass filter. If the lowpass filter output exceeds the deployment threshold of the comparator one of the two criteria for triggering the squib is given.

The ball sensor on the other hand reacts to hard (hihg-frequency) changes and hardly at all to slow (low-frequency) changes. This corresponds to the sensitivity of a high-pass filter. Once the ball has broken free and is moving towards the contact it will not stop even if the acceleration decreases.

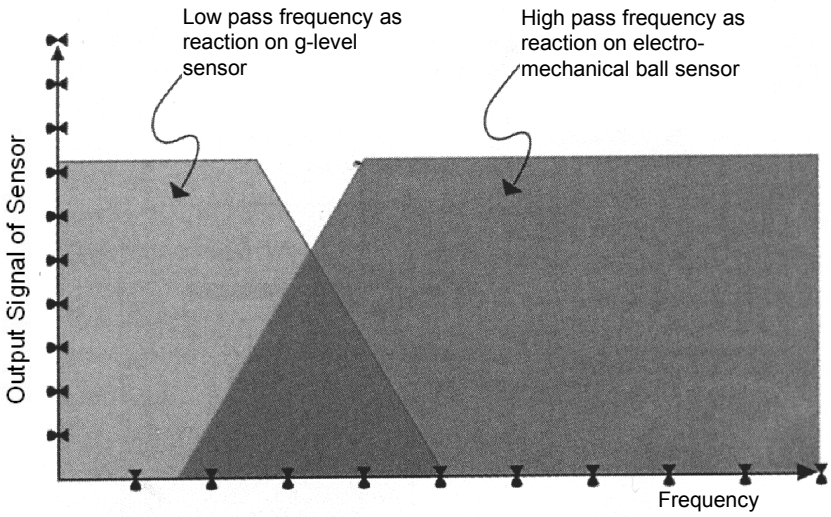


Fig. 2-9: Functional model for the behavior of both sensors [DAH97]

New semiconductor technologies brought developments much closer to the ideal sensor mentioned briefly above. The micromachine structure in silicon is shown in Fig. 2-10.

A free-moving, seismic mass hereby lies between two highly doped or metallized silicon layers. Two different sensors have been developed from this method, a piezoelectric and a capacitive variant. In the case of piezotechnology, the piezosensitive element itself rests in the supporting arms. In the capacitive version the seismic mass corresponds to the middle layer of a triplex condenser and is sensitive to accelerations. This signal is sent to the input of an amplifier designed to scan the variation. The capacitive version has a broad temperature range, is extreremly linear at frequencies greater than 2 kHz and surpasses the requirements of the piezoelectric variant [SCU97].

This type of sensor can be connected directly to a microprocessor via a circuit which conditions the signal. The sensor practically becomes a mini data acquisition system in which the microprocessor digitally filters data and uses evaluation functions and other algorithms which affect the digitized values of amplitude and frequency to decide when to trigger the squib. This new system works indepenent of a specific vehicle. The actions are accommodated depending on the application in a ROM [OSA99].

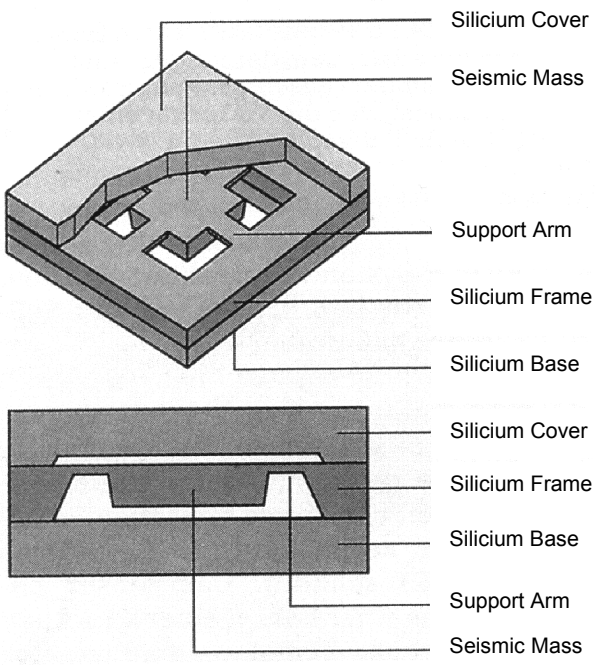


Fig. 2-10: Micromachine structure in silicon [DAH97]

In the vehicle the acceleration sensor is normally designed as a piezoresistive sensor, i.e. the controller monitors the sensor resistance and calculates the momentary acceleration from this. The sensor signal is cleaned of vehicle vibrations in a high-pass filter and forwarded to the control unit via an A/D-transducer. Piezoelectronic sensors offer a good diagnostic feature in the form of a continuity check [BRA93, HAL 96].

One can in principle differentiate between two types of sensor with respect to the positioning of the sensor and control unit (cf. Chap. 2.3.6):

- central airbag system
- decentralized airbag system

In a central airbag system the diagnostic and control unit as well as the acceleration sensor (electronic crash sensor) are combined in one housing and generally mounted centrally on the transmission tunnel, Fig. 2-11. This control unit is connected to the airbag, seat belt tensioners, warning light and electrical system via a plug board.

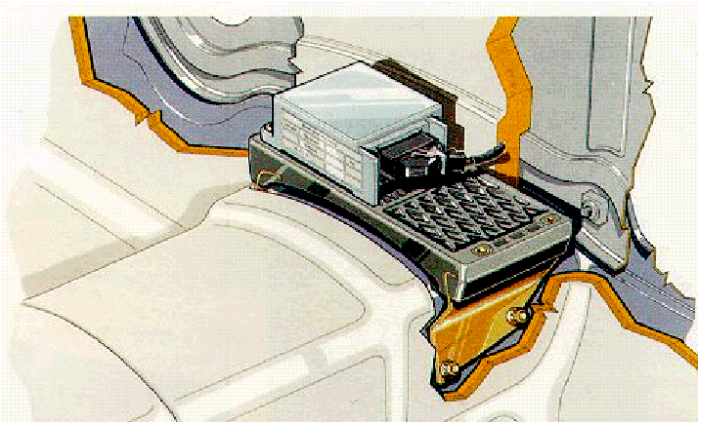


Fig. 2-11: Central triggering unit on the front tunnel [SCH92]

The decentralized airbag system has a number of individual components. The diagnostic and control unit contains a safety switch (safing sensor) in addition to the electronic control unit. The (generally mechanical) crash sensors are normally located on the left and right side members of the front end of the vehicle and are connected to the control unit via cable looms. The connections to the airbag module and warning light can be found at other unit interfaces.

Fig. 2-12 shows the possible positions of the sensors in the vehicle. The various positions of the sensors result from the historical development of the airbag systems :

- The first models (a) had only ball/tube sensors in the front and rear of the vehicle. Electronics were only used for the diagnosis. Faulty triggerings were a common feature of this variant and posed a problem.
- The next generation of models had two sensors to avoid faulty triggerings. The ball/tube sensor was re-defined as a safety sensor and always fitted in the fornt of the vehicle. A linear g-level sensor was mounted centrally in the vehicle as shown in Fig. 2-12b. The g-level sensor and the ECU were located in one module.
- In the next stage of developments, all sensors including diagnosis, evaluation circuits and triggering circuit were combined on a PCB, as shown in Fig. 2-12c . The g-level sensors were replaced by semiconductors based on micromachine technology which worked with a very broad frequency range and a high sensitivity. The ECU has processor algorithms which can be adapted to many different vehicles by simple exchanging the ROM. This configuration is used in most current models [DAH97, KUR99].

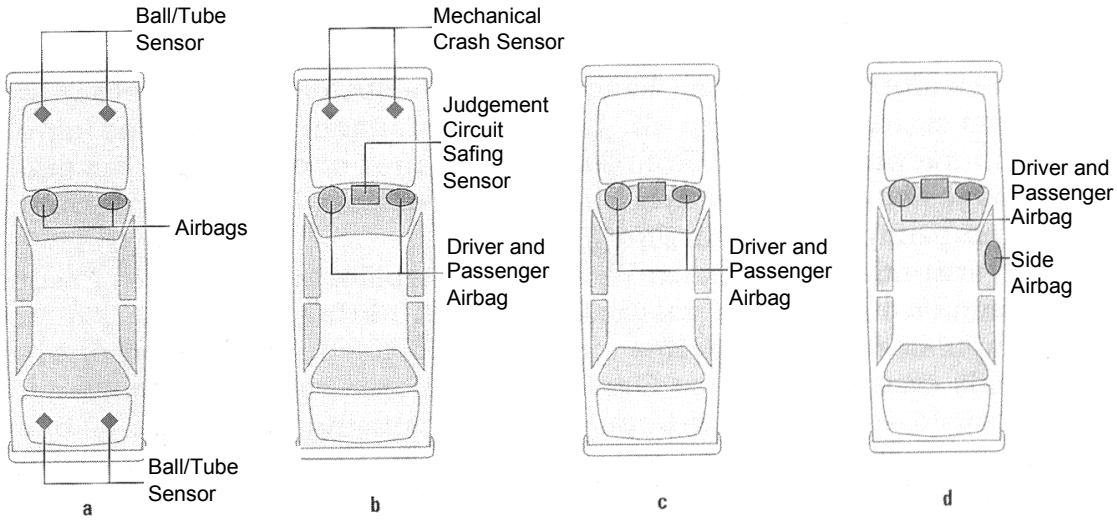


Fig. 2-12: Position of the sensors [DAH97]

The recently introduction of side airbags typically brought its own problems. Sensors in the doors normally supply narrower, faster output signals due to the low deformation of the side doors. These short signals are exposed to a variety of disturbances on their long path to the central processing unit. The disturbances cannot be filtered out because this would take too long. This is why there is a trend in developments towards fitting an additional control unit in the respective door, as shown in Fig. 2-12d.

More recent development work has invovled one central crash sensor CCS (Central Crash Sensor) and two additional sensors in the deformation zone of the front end, so-called upfront sensors (UFS). These enable an earlier statement on the severity of the crash as well as a statement on the crash configuration by comparing the UFS and CCS signals (e.g. central, offset, angled impact, driving under an obstacle) [LAN 99].

2.3.6 The control and diagnostic unit

The airbag control unit (also simply called ECU – Electronic Control Unit) plays a central role in the vehicle's safety concept. It is the interface between the sensor and the squib/airbag. The module's job is to monitor and analyse the sensor system. It decides when to trigger the airbag and specifies the moment of triggering depending on the evaluation of the acceleration curve according to individual vehicle specifications. The seat belt tensioner is also controlled by the ECU in the majority of systems. In addition it informs the driver by means of a lamp on the condition of the overal system.

In the event of a power failure due to an accident the central unit has sufficient own energy reserves to trigger the airbag. These are ensured by one or more condensers which are charged to 30 V – 40 V by means of a cascade connection. The capacity of the condensers

is enough to operate the evaluation and triggering electronics for 200-300 ms following an interruption to the power supply. They are charged during normal driving [SCA90, SCH92].

Legislation requires that airbag systems have a ready message and that their operatability is continuously monitored. The integrated diagnosis unit performs a functional test before a journey starts (*primary test*) and permanently monitors the function during the trip (*secondary test*).

> *"Once the triggering unit has been switched on the system runs through a self-test which simulates an acceleration of the sensor and checks whether the device is ready for triggering. The control lamp in the instrument cluster is activated. If the test cycle is completed without an error the control lamp goes out and thus indicates that the system is ready for use." [BRA93]*

Any errors are indicated by the control lamp and saved in the device's fault memory.

The system undergoes a secondary test during the trip. The power supply and ignition circuits including leads with plugs are permanently monitored. The diagnosis unit can differentiate between temporary and permanent errors. It switches the control lamp on if necessary to warn the driver and saves an fault message in the memory. The error code can later be read out in the workshop via an interface [HAL96].

The following features have to be taken into account when planning the crash recording system:

1) *Farsighted*

   As a fixed time is needed between the ignition pulse from the control unit until full inflation of the airbag, the control unit must be farsighted. At the time the airbag is triggered the vehicle's speed has only altered by a fraction of the possible overall value. The monitoring period is limited and the control unit must make a decision on the seriousness of the collision at a very early point in time.

2) *Differentiation*

   It is very important that the control unit is able to differentiate under the given circumstances whether the airbag needs to be triggered. Unnecesary airbag triggerings can constitute a serious risk of injury for passengers. A so-called misfiring of the airbag or an incorrect ignition time should be avoided by the logics of the control unit programming.

3) *Real-time*

   The collision must be recorded in real-time. This means that the airbag must be triggered immediately after the trigger pulse is received. The system cannot afford to record a crash data sequence and then analyse this data and react to a given situation. The short monitoring period for the crash data until the necessary ignition time is a further problem.

Fig. 2-13 shows an equivalent circuit diagram for an airbag control unit.

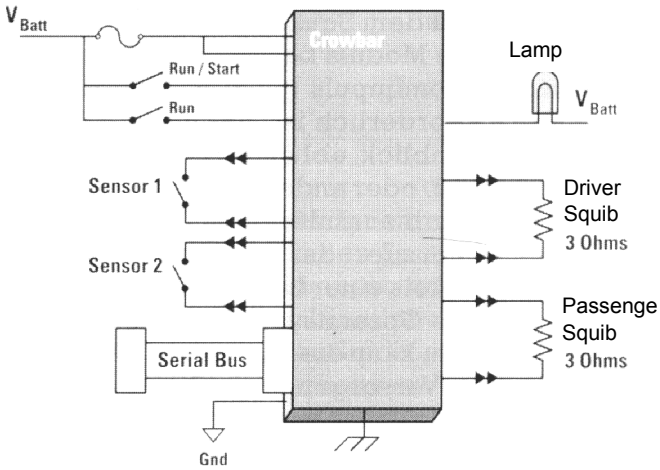


Fig. 2-13: Equivalent circuit diagram of an airbag control unit [DAH97]

One example for the general configuration of an Electronic Control Unit (ECU) is shown in Fig. 2-14. This is a largely redudant circuit in which either the electromechanical sensors and safety sensor or the g-level sensor in combination with the safety sensor triggers the squib.

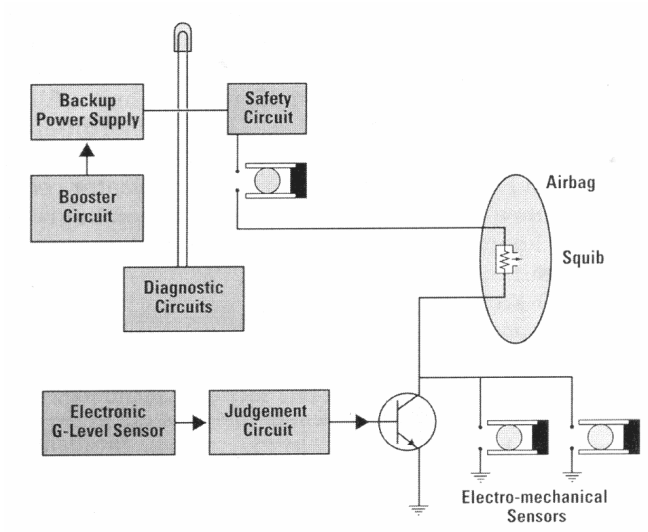


Fig. 2-14: Equivalent circuit diagram of an Electronic Control Unit (ECU) [DAH97]

The diagnosis circuit checks the system in the manner described above and warns the driver in the event of a fault by means of a warning lamp.

In some systems the so-called AC firing is used instead of a simple DC flow. This means that a high-frequency alternating current flows through the ignition wire. In these systems a capacitor is connected in series with the ignition wire which only represents a small resistance for the alternating current but a blockade for the direct current and thus safeguards the system against triggering by short-circuits in the wiring harness (e.g. when the harness is cut

during rescue work). The DC decoupling achieved in this way guarantees the short-circuit-proofness against the DC electrical system and static single or multiple faults [HAL96].

2.4 Airbag release threshold

Determining the release threshold is a central problem in designing airbag systems. It will therefore be taken up separately in this chapter.

When the ignition is turned on the release device goes through a test cycle in order to subsequently determine the current vehicle deceleration readings, e.g. in a 1 ms rhythm. Readings under 2 g as occur in normal driving are not taken into account. With greater deceleration the evaluation procedure is started in order to arrive at an accident evaluation. Between the passenger's injury severity and the deceleration signal measured there is, however, no simple mathematical connection. Unambiguous criteria must be set with the aid of which correct and timely release can occur. In doing so, solely noting maximum decelerations is by no means adequate for properly assessing a crash.

Basically, the measure for release of a front airbag is the collision-related change in speed Δv. This is computed by integrating the longitudinal vehicle deceleration after exceeding a threshold value beyond the maximum possible braking deceleration. For integration an acceleration-proportional electric signal is provided to the ECU.

With first-generation airbag control algorithms the release threshold was a fixed Δv reading, Fig. 2-15 [SCH92].

There are two characteristic threshold value curves, Fig. 2-16. The lower one (S1) is responsible for releasing the belt tightener, the higher one (S2) for releasing the airbag. With a medium-severity front collision where the additional protective effect of the airbag is not yet needed, only the belt tighteners are released. In case of a serious accident, the airbag systems are in addition ignited. By means of the option of varying evaluation parameters by software, the ability to adjust to different characteristic vehicle graphs while taking different crash types into account is provided for [BRA93].

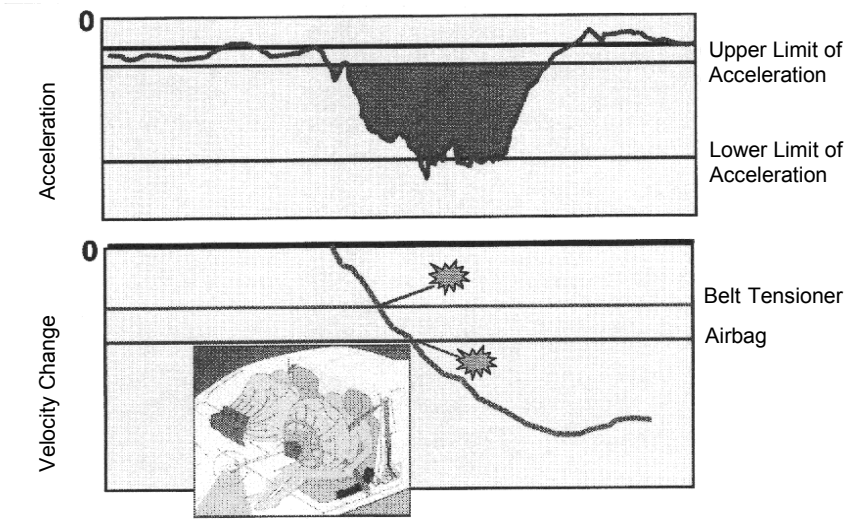


Fig. 2-15: Characteristic of acceleration and velocity change shown with corresponding activation thresholds for fixed Δv-activation thresholds [SCH92]

Subsequent generations are set off at variable Δv values [BRA93]. In doing so, there is essentially dependency on the gradient of the longitudinal deceleration measured. A steep rise in deceleration in principle lowers the Δv threshold value needed for airbag release. In the opposite direction, a slow deceleration rise increases the Δv threshold value. Correlation occurs according to the vehicle manufacturer's recorded values taking the interplay of safety belt and airbag into account in each passenger cell.

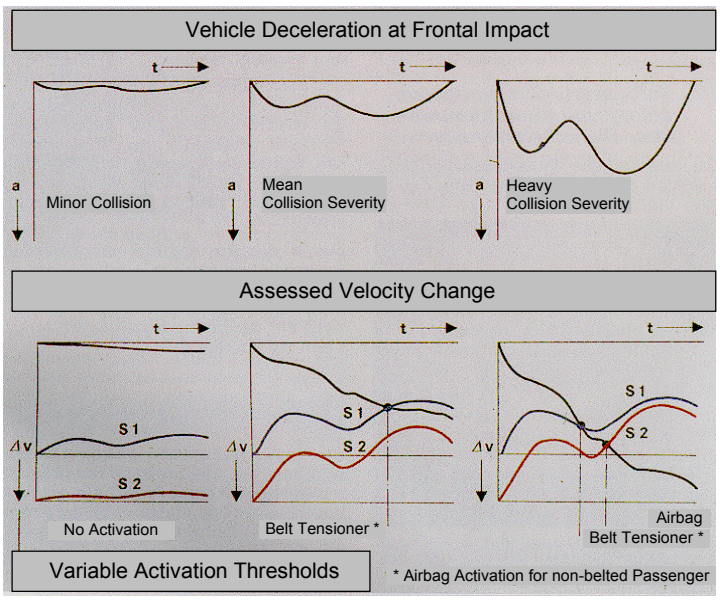


Fig. 2-16: Activation properties of the twin threshold system [BRA93]

The speed change measured by a sensor during a collision and the necessary ignition moment are depicted in Fig. 2-17. With the aid of the ignition moment the change in speed at the moment of release can be measured by intercepting the speed change curve. This

intercept shows the value of the change of speed at the moment when the ECU recognises the need of releasing the airbag.

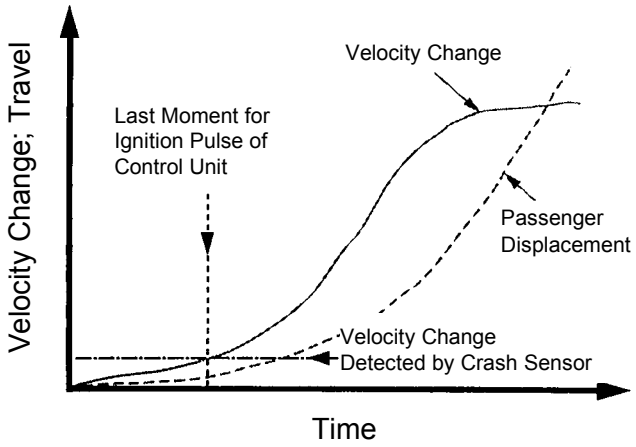


Fig. 2-17: Velocity change for a specific collision

In studying different collision severities, different ignition moments are obtained. These ignition moments can be reestablished in Fig. 2-18 as points on the different crash curves. All of these points show the value of the change in speed at the corresponding ignition moment. The illustration shows that with increasing collision severity the speed change graph rises more steeply and the airbag's ignition moment occurs sooner. This is necessary since in a serious accident the passenger experiences greater acceleration and thus the maximum displacement path is attained sooner.

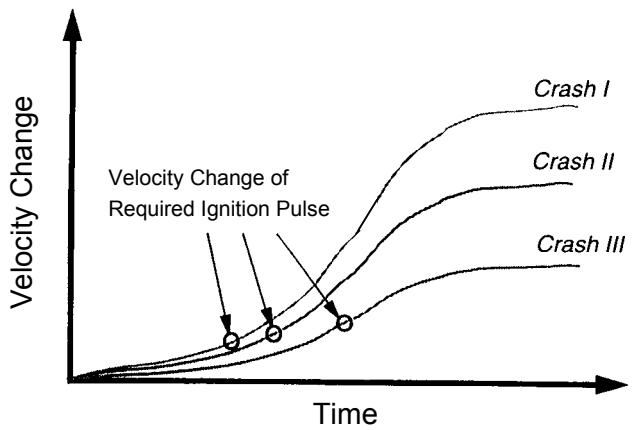


Fig. 2-18: Velocity change for various collisions

In the real-life accident situation, however, with different crash conditions and manufacture-related sensor tolerances airbag ignition cannot occur at a set value. Rather the airbag's release threshold is characterised by a value range. Fig. 2-19 illustrates this characteristic range of a crash sensor ignition impulse. The illustration shows that the change in speed leading to airbag release is a function of time. If the change in speed is below the lower limit of the ignition range then no airbag release results. On the other hand, if the change in speed lies above the ignition range limit then airbag release is guaranteed. The speed changes

located between the two limits characterise the “grey area” in which release of the restraint system is uncertain. This characteristic range represents the threshold range of the change of speed measured during a collision.

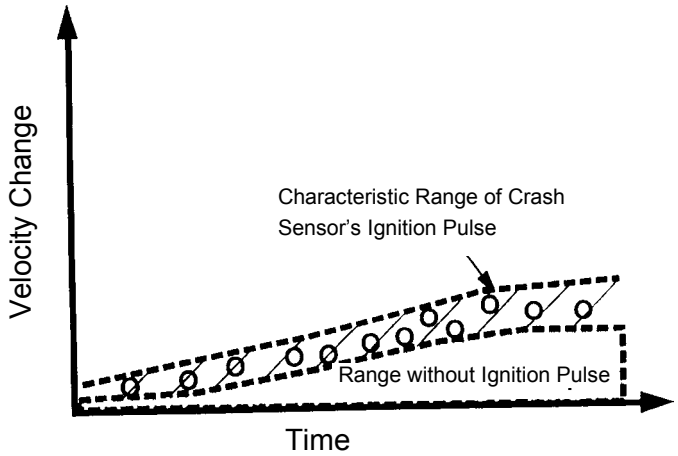
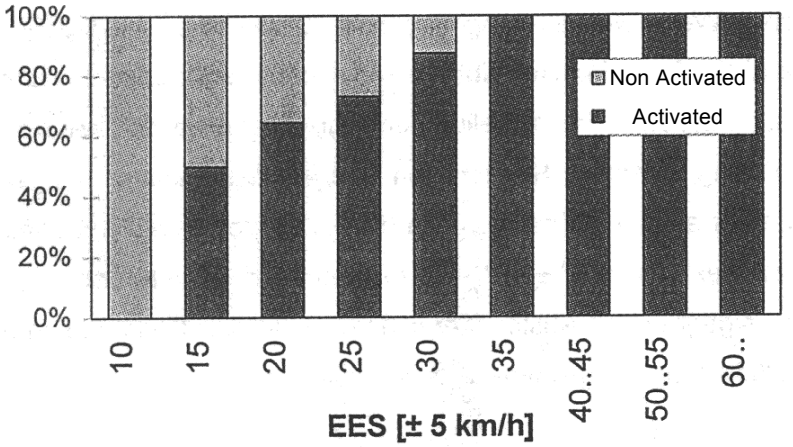


Fig. 2-19: Characteristic range of crash sensor’s ignition pulse

From a study made by the Allianz Centre for Technology with European vehicles, the typical release threshold fluctuates in a Δv range between 15 and 30 km/h (front collision against a rigid wall, 100% overlap) [LAG97]. Yet, since Δv can only be calculated with a complete accident re-enactment, it has been determined for airbag vehicles with the aid of the EES (energy equivalent speed) energy grid method which recognisably correlates very well with injury severity of the passengers. EES is here defined as the crash speed onto any solid obstacle where the same deformation impact can be achieved as in a real-life accident. It is also a measure of kinetic energy converted to deformation energy during the corresponding vehicle’s collision. It is indicated in Fig. 2-20 for all vehicles within an EES class whether the driver airbag was activated or not.

At EEC values around 10 km/h the airbag was not released on any vehicle, upwards of an EES of 35 ± 5 km/h, by contrast, all airbag systems were activated. It is striking that even in vehicles only involved in relatively slight accidents (EES between 15 km/h and 20 km/h) in at least half of the cases the airbags were already released [LAG97].



EES ± 5 km/h	10	15	20	25	30	35	40..45	50..55	60..
Number	2	30	31	26	24	16	14	7	6

Fig. 2-20: Driver airbag activation in dependece on EES [LAG97]

In view of the aspects described above, it seems to be meaningful for a study of the ECU's ignition impulse to limit experiments for this investigative work to a range of speed changes from 15 to 35 km/h.

2.5 Problem cases and malfunctioning of airbag systems

Since the middle of the 1990s at the latest there has been consensus between legislators, industry and consumer protection organisations that modern airbag systems have clearly increased the protection potential for vehicle passengers. The safety belt and the airbag together reduce in severe front collisions the danger of injury by some 80 to 90 % when compared with unprotected drivers. Front-seat passengers in airbag cars with belts fastened suffer 40 % less severe or lethal injuries than those who only had their belts fastened. This came out in a study of 330 airbag accidents conducted by the Institute for Vehicle Safety of the Consolidated Association of the German Insurance Industry (GDV).

However it is known at the same time that in practice problem cases with the airbag constantly occur [LAG97].

The problem cases can be divided up into two types:

- Release at a too low accident severity.
- Failure to release at high accident severity.

In an analysis of real-life accidents, cases are also seen where the airbag releases although this is clearly not required given the negligible severity of the accident. In such cases, unnecessary repairs are incurred and in less favourable situations (the out-of-position issue) unnecessary jeopardy to passengers can occur [LAG97]. Some examples of defective airbag action are listed under the following points.

- Spurious release without external force impact:

  In a vehicle of a 1997 model the side airbag opened out without any external impact at 150 km/h. The driver suffered slight bruises to his left arm. Such malfunctioning can cause an accident.

- Spurious release due to a blow to the underbody:

  Airbag release occurred in a vehicle of 1991 make at a driving speed of over 160 km/h. The vehicle drove over an exhaust lying on the roadway. Driver and front-seat passenger were slightly injured (abrasions, permanent hearing impairment). Repair costs amounted to about DM 11,000.

- Spurious release at a low accident severity level:

  This involved a minor front crash accident with an Opel Astra 1995 model. Airbag release would not have been required. The passenger-seat airbag released although the seat was not occupied.

- Failure to release at a high accident severity level:

  After skidding, a Mercedes-Benz with initial registration in 7/1999 drove under a lorry trailer. A strain of this magnitude was not recognised by the sensor system as a serious accident. The passengers sustained medium-grade injuries from their belts (effusion of blood, thoracic vertebra bruises, broken rib, head injuries) [KLA00].

Recall campaigns by automotive manufacturers indicate further problems which can lead to unintended release of the airbag:

- Saab is recalling 70,000 vehicles worldwide of the 9000 model (built in 1992-94) because with moisture and wetness a short circuit can release the airbag [MAY98].

- Volvo has recalled S40/V40 model vehicles and 8,300 model S80 vehicles to the workshop since the side airbags in certain vehicles ignited in the restraints instead of opening out sideways [MAY98].

- 20,000 vehicles of the 400 series of Volvo (1994 make with 2-litre motor) were recalled through Europe in order to move the position of the airbag sensor since spurious ignition of the airbag had occurred [MAY98].

- At Opel workshops worldwide, the airbag plugs were checked on 2.3 million vehicles of the Astra model since there had been accidents with major degrees of accident severity where the airbag did not release [MAY98].

- 280,000 BMW series 3 vehicles had to be taken to the workshop due to side airbags occasionally igniting without any reason [PYC99].

- Daimler-Chrysler is recalling 474,000 terrain vehicles of the Jeep-Cherokee type for inspection. This involved models built in 1997-1999 in which the airbag module had corroded due to contact with seawater [NN00].

- The car maker Renault is recalling about 140,000 small cars of the Twingo model due to problems with the airbag. There is a danger that the airbag is inadvertently released. The flaw is in the electric system which reacts over-sensitively to shocks [NN00].

- Ford is recalling about 9,000 vehicles of Focus model for workshop checks of the airbag ECU [NN00].

However, it also occurs that passengers suspect malfunctioning after an accident which they regarded as severe where the airbag did not release. In such cases, the lack of injuries or occurrence of only minor injuries to the persons in question indicate that additional protective effect from the airbag was actually not required in that particular case. For example, when a car rolls over or where grazing impact occurs on a protective side-railing at high speed on a motorway considerable vehicle damage can result. However, with such an impact the vehicles speed can be reduced with a comparatively low rate of deceleration so that the airbag release threshold is not attained [SCH92].

3 Structure of the experiment

The sled experiments needed to study the airbag systems are carried out at the ika crash facilities. The latter comprise an installation with a flywheel drive which accelerates the sled via connection to a pull-rope up to the required speed, Fig. 3-1.

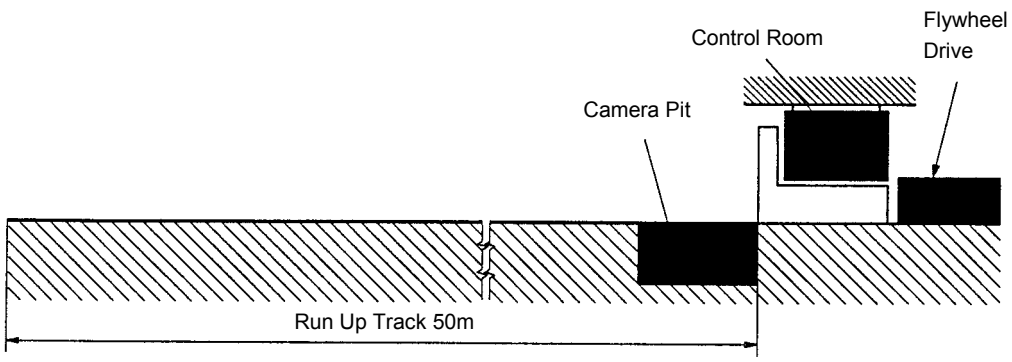


Fig. 3-1: Setup of ika crash-test facility

Transmission of the energy stored in the rotating flywheel occurs via the regulated opening and closing of a truck clutch connected to the rope via an enwrapped friction drum. The rope and the test object are guided through a track recessed into the floor. The connection of both of them can be cut mechanically at any point on the 50 m long runup stretch. Since the connection to the test object must be released at the latest 5 m prior to impact on the 120 t heavy concrete crash block, an acceleration stretch of 45 m is available. This length suffices in connection with propulsion in order to accelerate a passenger car up to a speed of 70 km/h.

In order to protect the measurement computer against shocks when the test object crashes, the control room is suspended from the ceiling of the hangar, detached from the crash block.

For reception of acceleration signals during impact, two crashproof measuring systems with 40 measurement channels are available, added to which are multi-axial acceleration sensors and laser beam barriers as well as an independent speed measurement system to determine the crash speed. Measurement data are picked up by WinCarat software and processed by DIAdem software. In the next subchapters the individual components of the crash facility will be explained.

3.1 The tensile sheet brake

For dynamic testing of airbag systems in regard to their release actions, a crash sled is used which with the aid of a deceleration device is brought to a standstill from a state of motion. The test deceleration is achieved by converting the motion energy of the crash sled into form-changing labour in that during the impact a folding-bending action is forced on

deformation steel. In order to achieve the required deceleration, the sled thrusts with the bending block into the tensile sheet brake furnished with deformation steel, Fig. 3-2.

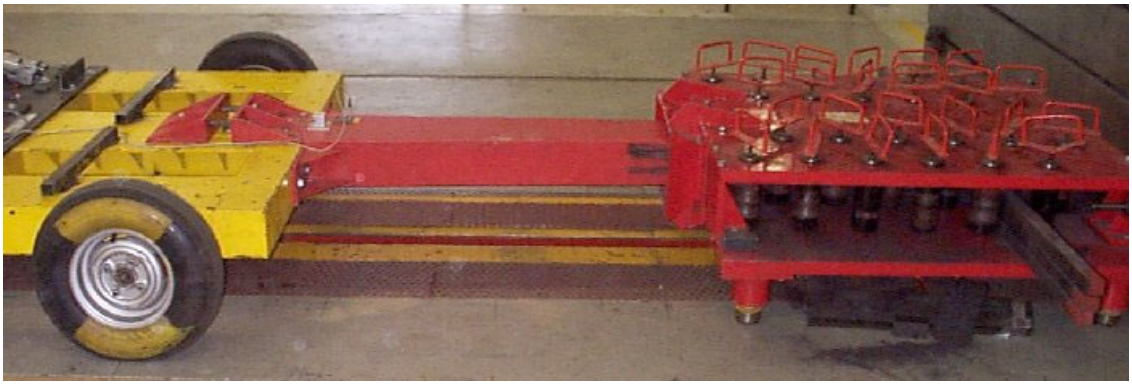


Fig. 3-2: Test sled with bending thorn and tensile sheet brake

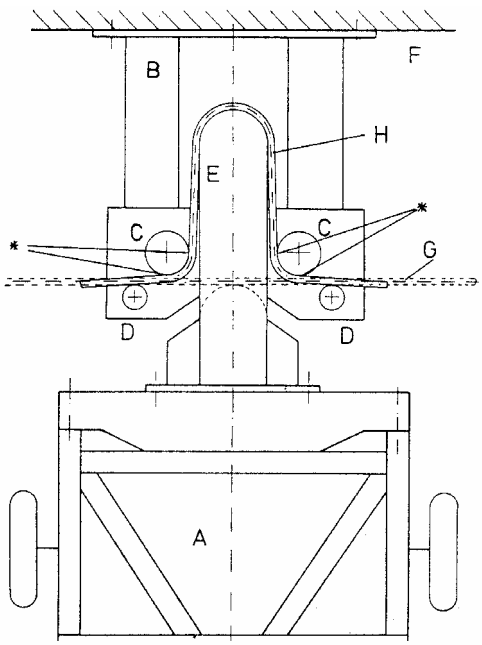
The tensile sheet brake is designed as a steel structure and has a total weight of 730 kg (Fig. 3-2, Fig. 3-3). It consists of one upper and one lower massive steel plate connected to each other front and back by two walls in such a way as to leave an intermediate space of 170 mm. The plates on the upper and lower side are drilled in a defined grid and when assembled together produce aligned clearance holes. Husks of high-strength steel are inserted into the 170 mm distance and centred above the drill holes.

Pins with handles on the upper side are stuck through the plate holes and the husks. With this arrangement, six lanes with four pin/husk combinations each (two inside and two outside) are created into which deformation rods can be inserted. The lower plate of the tensile sheet brake is supported with four adjustable legs on the floor. On the front side of the tensile sheet brake a small funnel is installed which assures centred insertion of the bending block.

Different decelerations are achieved by means of the geometric parameters of the deformation element and by the impact speed. By selection of deformation rods (cross-section) and outfitting of the lanes various different deceleration runs can be achieved for the sled. In choosing deformation steels care must be taken that only steel from the same supplier charge is used since the solidity readings can fluctuate greatly. In this way one can achieve comparable declaration readings at the same impact speeds and thus reproducible results as well.

Fig. 3-3: ika tensile sheet brake

The main magnitude of influence for the various deceleration runs is here constituted by the impact speed which significantly changes the tension values of the work material [SHE89].



A Impact Sled

B Support Case

C Bending Rolls

D Support Rolls

E Bending Thorn

F Impact Barrier

G Deformation Element before Test

H Deformation Element after Test

Fig. 3-4: Deciption of tensile sheet brake with bending thorn [SHE89]

The deformation rod is therefore subjected to strain and deformed in sled experiments (Fig. 3-5) of the type depicted in:

Bending and stretching

- simple bending in the area of the block tip
- propagated bending and stretching in the recessed area of the flat-rolled steel.

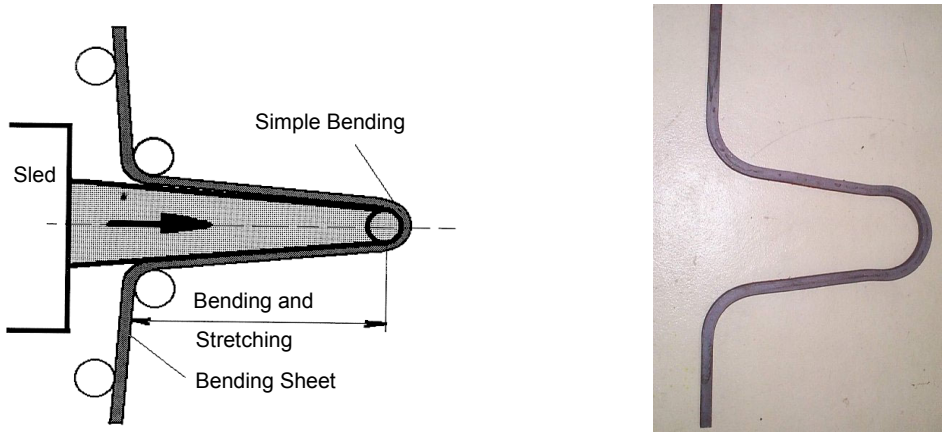


Fig. 3-5: Deformation in the tensile sheet brake and deformation element after the test [SHE89]

Selection of outfitting of the deceleration device of the tensile sheet brake with deformation rods is done on the basis of old experiments with this brake (experimental values) and on the basis of calculations and assumptions of the brake's design records.

3.2 The component sled

On the front (in drive direction) of the component sled a 156 kg heavy thorn has been mounted. This thorn (1) is 1300 mm long and 150 mm high. The front part is formed by a vertically upright massive semi-cylinder block with a radius of 100 mm, Fig. 3-6. The block's flanks consist of two vertical steel plates laid out in the shape of a V. Connection to the sled is made by vertically upright welded steel plates additionally reinforced by triangular plates. The block is connected to the sled with screws and additionally stretched over threaded rods.

As an experimental object a crash sled made of frame-iron design does service (2). Due to its very stable and rigid construction, the sled achieves a structural weight of 765 kg and allows for decelerations up to 50 g without damage. The crash sled is unsprung and roles on air-filled tyres. The component sled is fitted out with a large steel plate for mounting of the airbag components and with weights on the rear axle. The additional weights are meant to ensure that the sled when the blocks thrusts down into the tensile sheet brake maintains ground contact on the rear axle.

In addition, raising the weight is necessary for experiments according to ECE standards. The wheel strains shown in Fig. 3-7 are produced in this way.

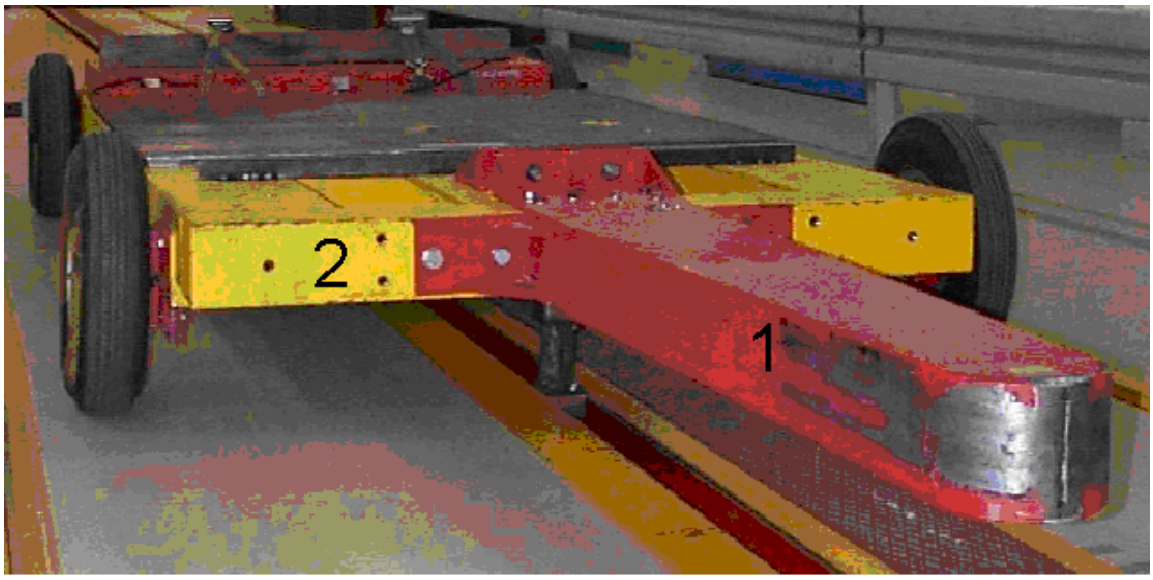
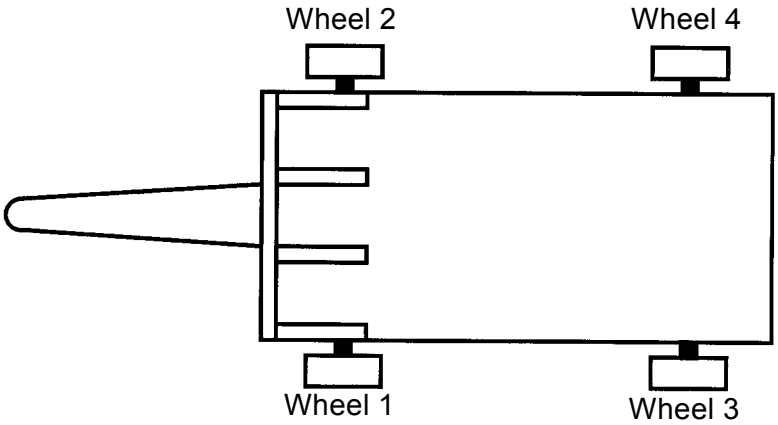


Fig. 3-6: ika component sled (2) with bending thorn (1)



Wheel 1: 475 kg	Front Axle: 835 kg	
Wheel 2: 360 kg		Total Mass: 1854 kg
Wheel 3: 449 Kg	Rear Axle: 1019 kg	
Wheel 4: 570 kg		

Fig. 3-7: Wheel loads component sled

The tensile sheet brake is set up in front of the crash block, centred and aligned in its height in such a way that the sled's block can enter between the upper and lower steel plates.

3.3 The acceleration sensors

For sled experiments resistant acceleration recorders designated as 322M/CM by the manufacturer MSC are used. The tri-axial sensors are designed for accelerations up to 1000 g. For experiments, however, only the x-component is relevant. The frequency limit is 3200 Hz. The sensors are supplied with a bridge voltage of 10 volts.

3.4 The optic measuring equipment for calculating speed

A prerequisite for reproducible experiments is compliance with the required impact speed. The calculation of that speed is accomplished by two systems independent of each other. For one, with the aid of beam barriers and the Tag-Heuer chronoprinter CP 705 (Fig. 3-8) the crash speed is determined. Two parallel-connected infrared beam barriers with transmitter transmit the sled block's entry signal to the Tag-Heuer evaluation unit which computes the impact speed with a precision of 1/10.000 km/h from the known path difference and the measured time difference and prints it out on the built-in thermal printer.

Fig. 3-8: Tag-Heuer chronoprinter CP 705

Secondly, the speed is determined with the aid of a laser beam barrier attached to the back of the experimental sled, Fig. 3-9. The laser beam barrier, where transmitter and receiver are housed together in one casing, offers the opportunity of scanning a reflection band.

The band has been prepared such that the emitted laser beam alternately imparts reflecting and non-reflecting strips which lie in a known distance to each other. From the length of the impulse and the distance the crash speed can then be determined.

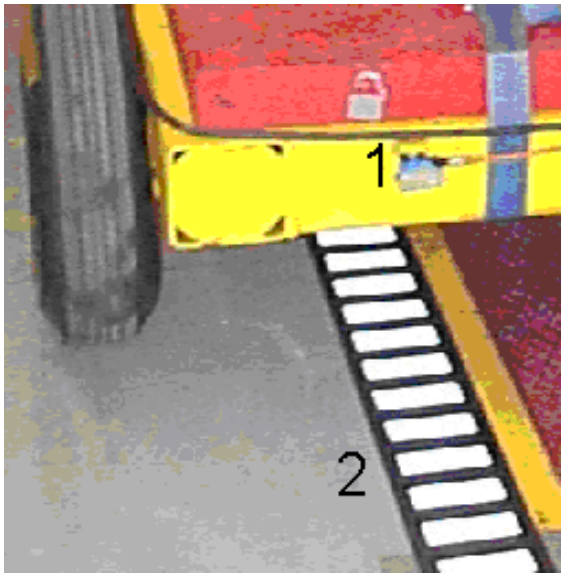


Fig. 3-9: Laser light barrier on sled and reflexion tape

3.5 The crash measurement technique

A model MDS32 (Fig. 3-10) data acquisition unit (DAU) is used for the sled tests carried out. It has 32 analog and 24 digital inputs. Memory capacity of 64 kB per channel makes it possible with a sensing rate of 10,000 Hz to attain a total recording time of 6.5 seconds. The input couplings are Lemo PHG.1B.307 type plugs connections.

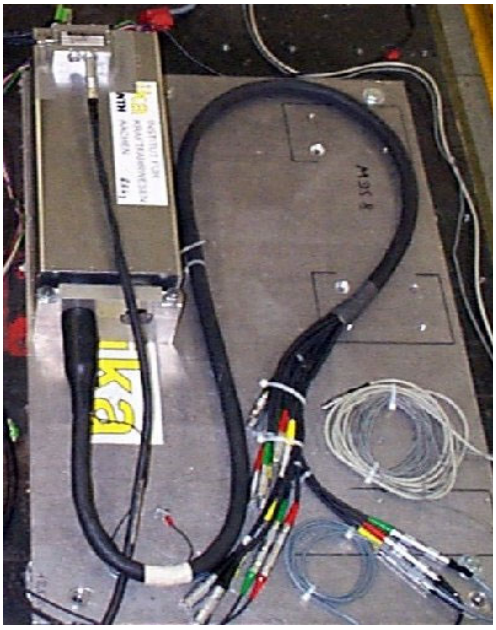


Fig. 3-10: MDS32 with adapter cable and CAN Bus adapter

A set digital input and two freely selectable analog channels are available for triggering. The latter set off triggering by exceeding or falling short of a selectable threshold value. The

DAU's supply voltage is 24 V. The data saved remain intact in the memory for five days without any power and can be read out more than once provided that the memory is not reset or overwritten. The connection between the DAU and the PC is accomplished with the aid of a bidirectional cable. All parameters to be set, readout of stored data and online transmission for viewing the signals are accomplished with a CAN bus interface via a common cable. Power supply for measurement runs through this as well.

3.6 The opto-coupler

With sled experiments for determination of the ignition moment an opto-coupler is connected between the airbag unit and the DAU. The purpose of this arrangement is to achieve, for safety reasons, non-reactive de-insulation between the receiver and transmitter units.

Opto-couplers are electronic components that have both an opto-electric transmitter and the receiver housed in the same casing. Light serves here as the transmission element. With opto-electric signal transmission the signal to be transmitted is fed to a voltage source which transmits this information as a modulated optical ray. Reconversion of the optic signal then takes place in a receiver, Fig. 3-11.

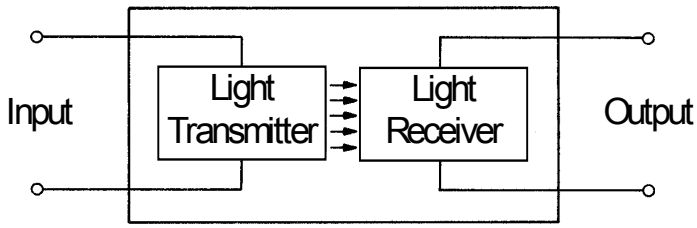


Fig. 3-11: Function principle of an opto-coupler [BEU84]

For viewing the maximum voltage and current values, originally the idea was to directly pick up the airbag unit's ignition signal and record it with the aid of the measuring technique. For currents (5-20 A) and voltages (30-40 V) generated during airbag ignition, however, the measurement technique used is not suitable in the long run. Therefore, viewing of the maximum voltage and current values was dispensed with. For evaluation of the trigger characteristics and to prove reliability, ignition measurement with the opto-coupler is a safe method. The proof that the ignition current for airbag ignition is sufficient is reliably produced by ignition of the real-life airbag by the control equipment. As high-speed pictures of the crash experiments showed, the opto-coupler signal tallied with the airbag module's moment of ignition.

3.7 The measurement computer

For operation of the measurement technique, a crash system PC was fitted out with a ISA CAN bus card. This card is a CAN-AC2 from Softing. With WinCarat software data exchange takes placed with the DAU via this interface. The PC communicates with the CAN card via a so-called “dual poled RAM” (DPRAM). This DPRAM has 64 kB.

3.8 Data recording and configuration setting with WinCarat II version 3.03

WinCarat serves both to set the experimental configuration and communication between PC and measurement technique as well as for management of all tests. The basis is formed by MS-ACCESS software in which various databases are kept. Besides management of sensors, the experimental database constitutes the core of the software. In it the experiment is initially configured in regard to the sensors used, measurement points, recording times and all other technical measurement data. In doing so, for instance, the sensor database is accessed in order to retrieve calibration data and maximum measurement ranges.

If the experiment has been completely set, then the DAU is programmed on the basis of this information and put in standby mode. After data have been recorded, the latter may likewise be read out with WinCarat and stored on the hard drive.

3.9 Data evaluation and analysis with DIAdem version 6.0

For evaluation and analysis of measurement data numerous individual steps are required such as filtering or calculation of speed and displacement path of the passengers from the acceleration signal. For such data evaluation the DIAdem programme from the firm of Gfs in Aachen is used. DIAdem is a software package that was expanded in its latest version by functions for analysis of vehicle safety data.

4 Description of the airbag system tested

A total of 14 airbag systems of different manufacture and vehicle models is tested. Two systems come from Mercedes-Benz S-Classes, another one from a Mercedes-Benz 300E. The Mercedes-Benz systems are in part 16 years old. Systems from an Opel Vectra have an average age of 6-7 years, three from a Ford Escort and one additional one from a Ford Mondeo. Originally, all tested systems are supposed to be more than 8 years old. Since purchasing such airbags is either impossible or only possible at disproportionately high cost, systems that were just below the required age limit are included in the study.

It is furthermore decided to test systems representing current state-of-the-art. For this purpose, the airbags of a Ford Ka, a Fiat Multipla and a VW Lupo 3L TDI are chosen. In comparison with older systems from relatively large vehicles, the newer systems are part of compact class vehicles something which makes a comparison between the systems interesting. Unfortunately, for these three technically up-to-date systems the airbag modules are not available for ignition experiments. The eight different types of airbags are first described in the following chapters.

4.1 The Mercedes-Benz 300E airbag system

The Mercedes 300E airbag system studied is taken from a 1986 model 300E. This involves a system with a driver airbag. The airbag module is not available since the airbag system has already released in a real-life crash. The airbag system consists of the components described in Fig. 4-1.

1. Voltage Converter
2. Capacitor (Energy Reserve)
3. Airbag-Control Unit
4. Harness
5. Control Lamp

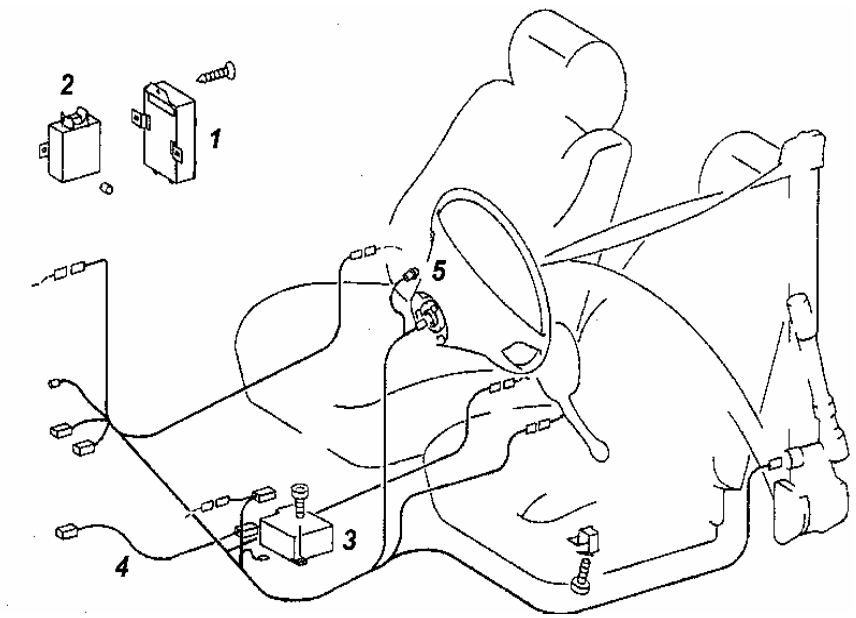


Fig. 4-1: Airbag system MB 300E [NN87]

Fig. 4-2 shows the airbag ECU (1) from Bosch and the attached components, condenser (2) and voltage converter (3).

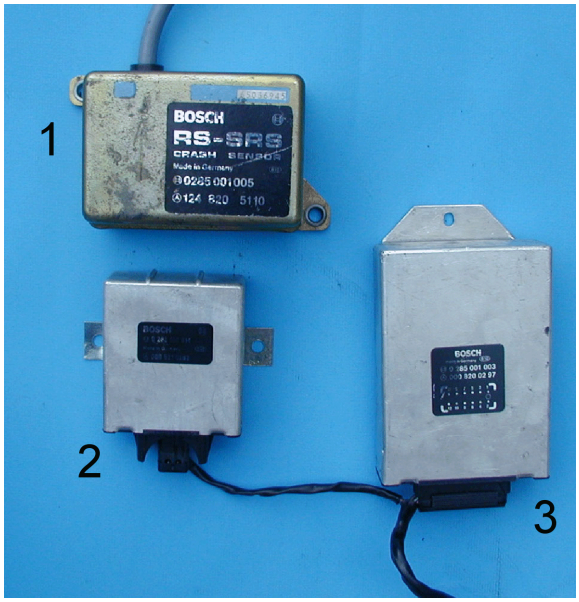


Fig. 4-2: Components airbag system MB 300E

The electrical circuit of the restraint system from an 300E (W124) is shown in Fig. 4-3.

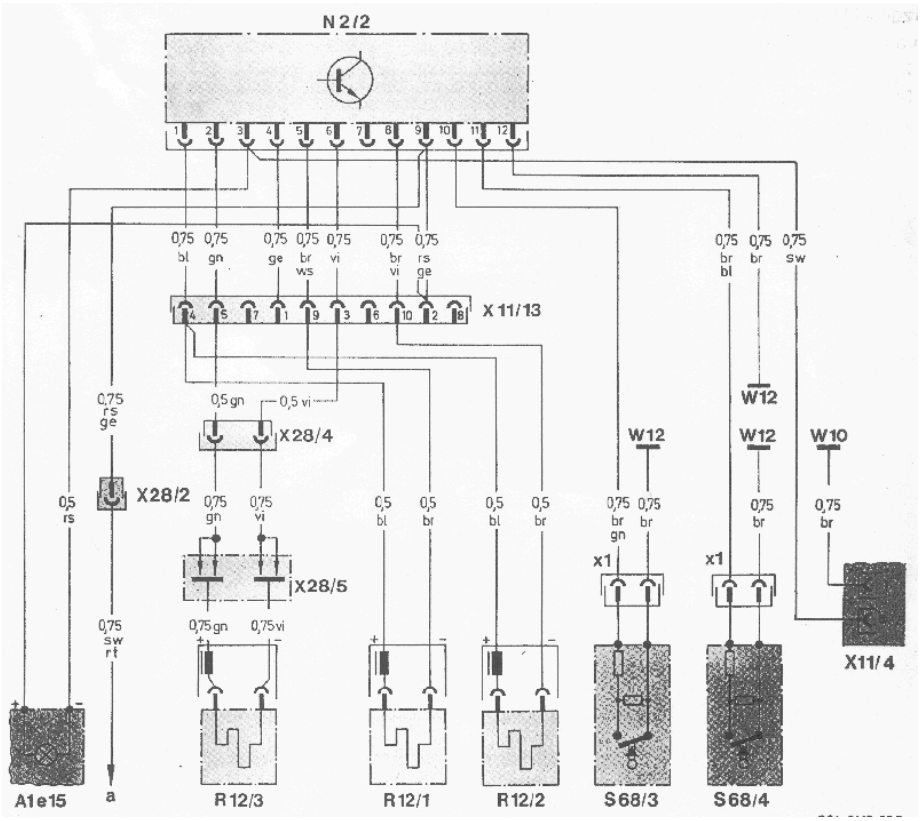


Fig. 4-3: Electrical circuit of the MB 300E [NN87]

This circuit serves as a basis for completing appropriate connection and with which numerous crash experiments can be conducted with the airbag system outside of the vehicle.

The cable harness is connected with a source of voltage according to the wiring diagram. A crashproof rechargeable battery block with DC current of 12 volts is connected as a source of power. When the couplings are removed on the R12/1 and R12/2 belt-tightener ignition donuts and on the R 12/3 airbag ignition donut, the plugs on R12/1, R12/2 and R12/3 are jumped and in that way normally short-circuited. By means of corresponding plugs and modifications to the couplings this is prevented. With the aid of a extra plug the ECU ignition signal can be viewed with and without the steering wheel wiping contact. The ignition signal is picked up at a corresponding point and transmitted on with the aid of an opto-coupler (Chapter 2.6) to the measurement technique. The airbag in this system must not be replaced with an ohmic resistor.

After appropriate connection and checking of the ignition circuit the airbag system warning light lights up. This is the case if the system has already released in the past. This error cannot be deleted in the ECU so that the control light always lights up during crash experiments. However, this does not impair the system's release characteristics according to the manufacturer.

4.2 The Mercedes-Benz S-Class airbag system

Two further systems were taken from Mercedes-Benz S-Class vehicles built in April and August 1984 (hereinafter referred to as system 1 and system 2). Being more than 16 years old, four years after the first installation of an airbag safety system, they are the oldest to be studied. The vehicles had total mileage of over 230,000 km. The airbag units were de-installed complete with the full-size airbag module which had never released. The systems are additionally fitted out with belt-tighteners.

These systems are on the outside hardly different from the 300E. Fig. 4-4 shows the airbag ECUs (1) and the connected components, the condenser (2) and the voltage converter (3).

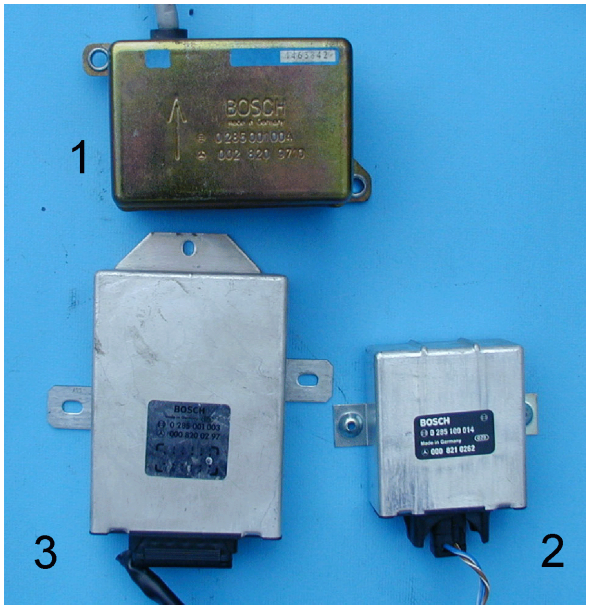


Fig. 4-4: Components airbag system MB S-Class

The wiring diagram of these systems is depicted in Fig. 4-5. Connection to the measuring system is similar to the one already described for the 300E system.

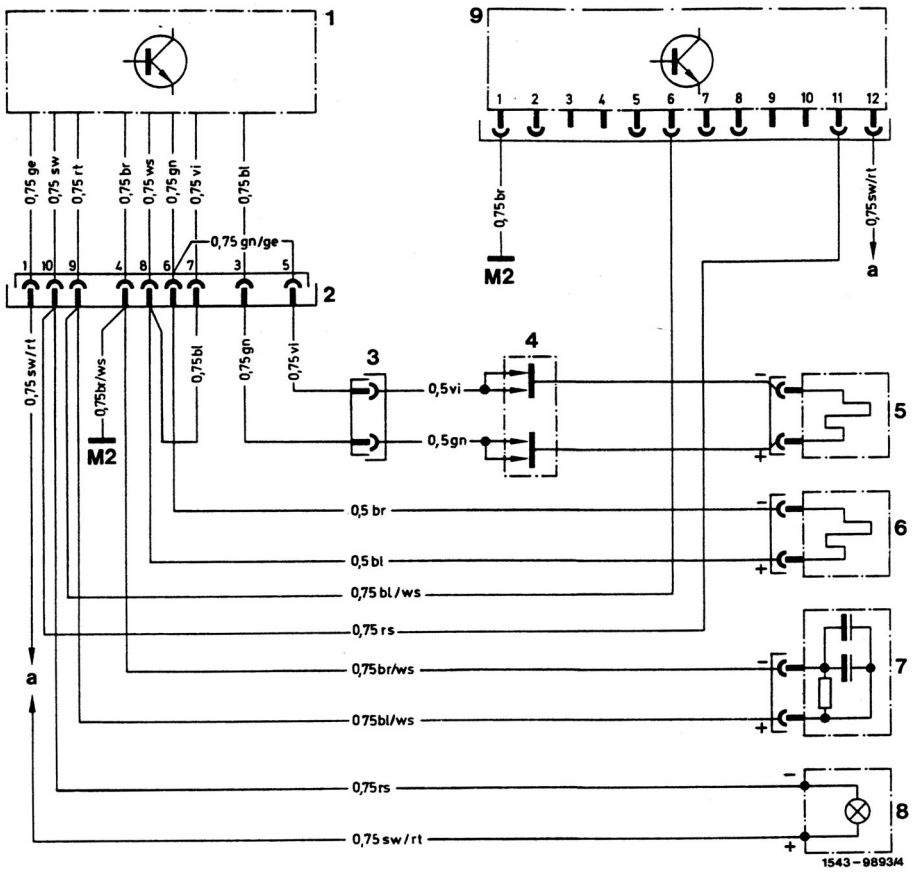


Fig. 4-5: Electrical circuit MB W126

4.3 The Opel Vectra airbag system

The four Opel systems (Fig. 4-7) were removed from Vectra models. Driver and front-seat passenger airbags can be connected to the ECU. Condenser and voltage converter are, in contrast to the Mercedes-Benz systems directly integrated into the central ECU. They were produced by Siemens. The airbag is tested along with it is a full-size airbag module.

Fig. 4-6 provides a survey of the model designation, year of make and the numbers used for the experiments. The O1 and O4 systems as well as O2 ands O3 are of the same construction according to the designation number.

Number	Vehicle	Model Year	Identification
O1	Opel Vectra	Sep 94	90 462 072 JM
O2	Opel Vectra	22/95	90 506 466 LK
O3	Opel Vectra	Okt 95	90 506 466 LK
O4	Opel Vectra	21/94	90 462 072 JM

Fig. 4-6: Overview Opel systems

Fig. 4-7: Opel control units

In Fig. 4-8 the pin allocation of the ECU is listed, knowledge of which is needed in order to wire the cable harness properly. Since these are ECUs of the more recent generation, they are subjected in operation to constant auto-testing. For that reason, it is necessary to replace the airbags which are not always connected during the tests by resistors.

Pin-Number	Function
Pin 1	Driver Squib, Top
Pin 2	Driver Squib, Bottom
Pin 3	K-Wire (Diagnosis)
Pin 4	-
Pin 5	Passenger Squib, Bottom
Pin 6	Passenger Squib, Top
Pin 7	Terminal 15 (Positive Pol)
Pin 8	Internal Test Purpose
Pin 9	Failure Warning Light
Pin 10	Terminal31 (Ground)
Pin 14, 15 Pin 18, 19 Pin 22, 23 Pin 24, 25	Short Circuit Breaker

Fig. 4-8: Pin configuration Opel control unit

On the recommendation of the manufacturer, the driver ignition donut (pin 1 and pin 2) is reproduced with 3.0 Ohm, those of the front-seat passenger (pin 5 and pin 6) with 2.2 Ohm. The ignition signal is picked up in parallel on the resistors and sent to the opto-coupler where an active current transmits a signal and forwards ignition to data measurement recording.

4.4 The Ford Mondeo airbag system

In Fig. 4-9 a picture of the Ford Mondeo ECU can be seen. The control electronic system carries on constant monitoring of the squib during operation. It is therefore necessary to simulate the missing ignition donut with a resistor (2.2 Ohm). For the test, the corresponding Euro-airbag is available with a inflated volume of about 30 litres.

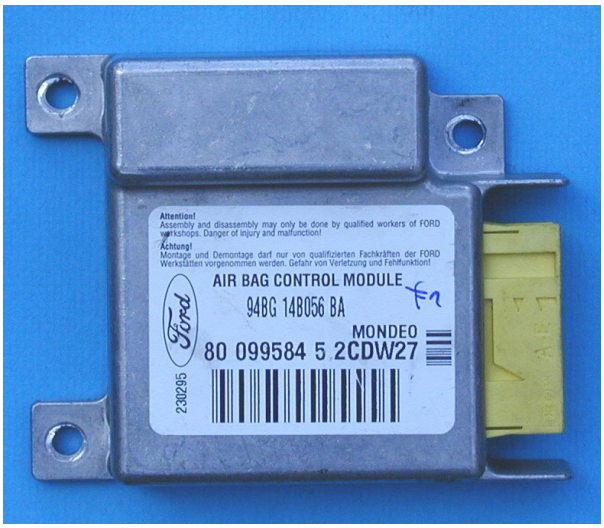


Fig. 4-9: Control unit Ford Mondeo

Fig. 4-10 shows the principle installation position of a Ford airbag system with driver and passenger airbag. One can recognise the centrally placed ECU (2) without any peripheral sensors which is installed vertically to the direction in which the vehicle is travelling.

1. Airbag-Mounting Frame
2. Airbag Module
3. Indicator Light
4. Clock Spring
5. Cover
6. Airbag
7. Gas Generator
8. Container
9. 16-Pin Diagnosis Connector

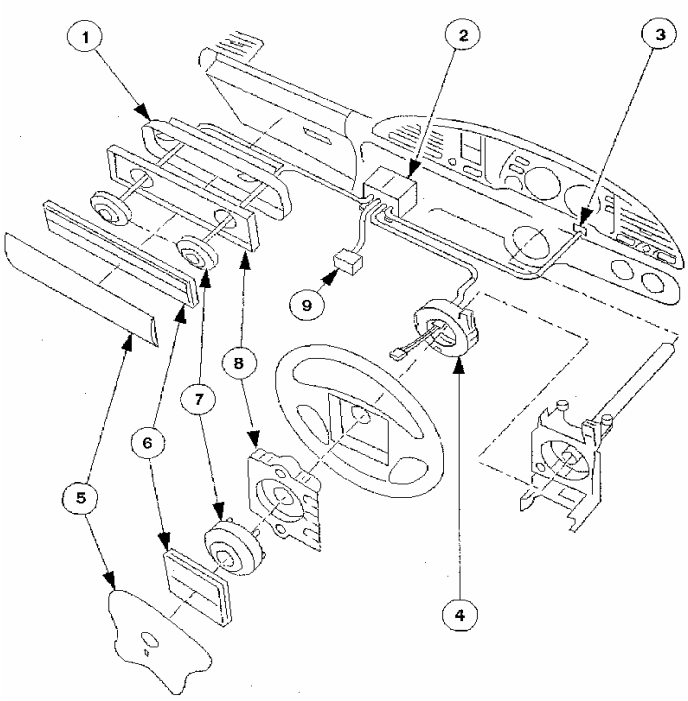


Fig. 4-10: Airbag system Ford Mondeo [NN97]

The model designation of the ECU is listed in Fig. 4-11.

F1	Ford Mondeo	`94	94 BG 14 B056 BA

Fig. 4-11: Identification number Ford Mondeo control unit

4.5 The Ford Escort airbag system

In addition three Ford Escort airbag systems are tested. For these systems as well the Ford Euro-airbag is available. The following table (Fig. 4-12) lists (from left to right) the model designation, year of make and the numbers used in the experiment for the individual devices. With the exception of the most up-to-date system, all of them have only a driver airbag.

Number	Vehicle	Model Year	Identification
F2	Ford Escort	`94	94 AG 14B056 B1A
F3	Ford Escort	`94	94 AG 14B056 B1A
F4	Ford Escort 95.5	`95	95 AG 14B056 CD

Fig. 4-12: Overview Ford Escort systems

A picture of the 94 AG model ECU (left) and the 95 AG one are depicted in Fig. 4-13.

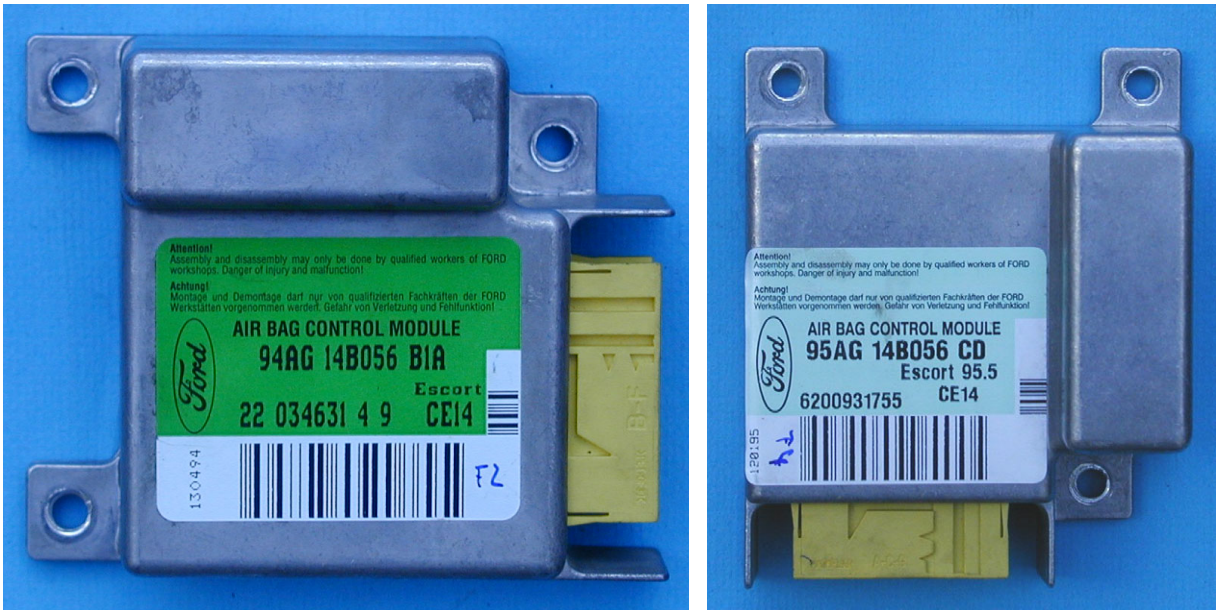


Fig. 4-13: Control Units Ford Escort

The systems are connected to the measurement system like the Mondeo unit. With system F4 driver and front-seat passenger airbags are simulated by ohmic resistors (2.2 Ohm) on the airbag plugs.

4.6 The Ford Ka airbag system

The airbag system of the Ford Ka studied comes from a vehicle produced in May of 1996. This is a system with a driver and a passenger airbag. The airbag system consists of the components described in Fig. 4-14.

The airbag ECU registers permanent and intermittently occurring errors. Both types of error are displayed by permanent lighting-up of the airbag control light. The control light only turns off if the error has been corrected and the error code with the Ford diagnostic equipment has been deleted from the airbag module's memory.

Via the cable string the airbag module and from there the airbags and the airbag warning light are supplied with voltage from the vehicles electric system. The buffer spring has been designed for transmission of signals between the airbag module and the driver airbag. The driver airbag has a gas generator and an airbag with an inflated volume of 30 litres. The front-seat passenger airbag has two gas generators and an airbag with an inflated volume of 60 litres. The airbags are woven from a single piece and are silicium coated to protect with from heat [NN97].

1. Airbag Mounting Frame
2. Airbag Module
3. Indicator Light
4. Clock Spring
5. Cover
6. Airbag
7. Gas Generator
8. Container
9. 16-Pin Diagnostic Connector

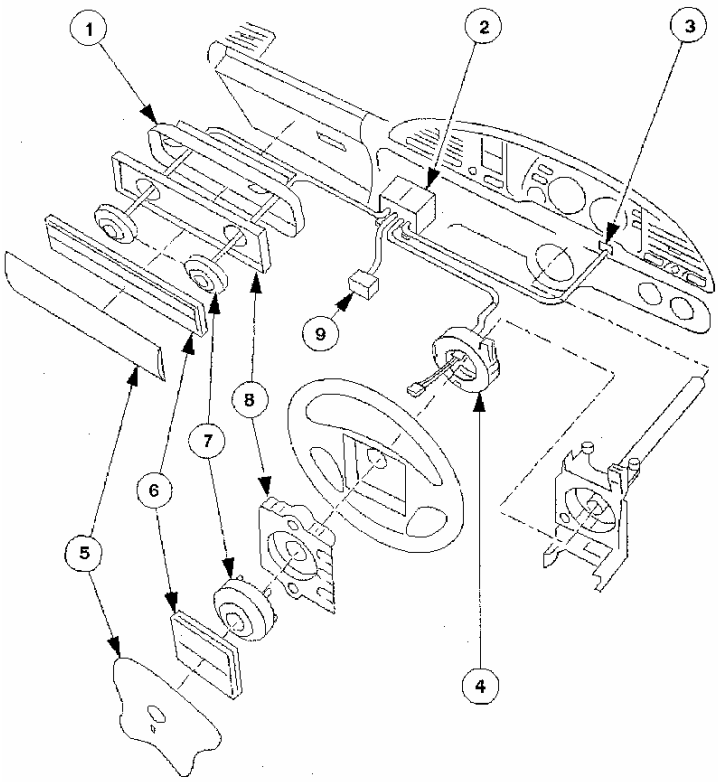


Fig. 4-14: Airbag System Ford Ka [NN97]

The electrical wiring diagram of the restraint system in a Ford Ka is depicted in Fig. 4-15.

This wiring diagram served as the basis of achieving suitable connection with which numerous crash tests can be carried out with the airbag system outside of the vehicle. The cable harness is connected according to the wiring diagram with a source of voltage (rechargeable battery block).

The driver and front-seat passenger garbags are simulated by means of ohmic resistors (2.2 Ohm) on the airbag plugs.

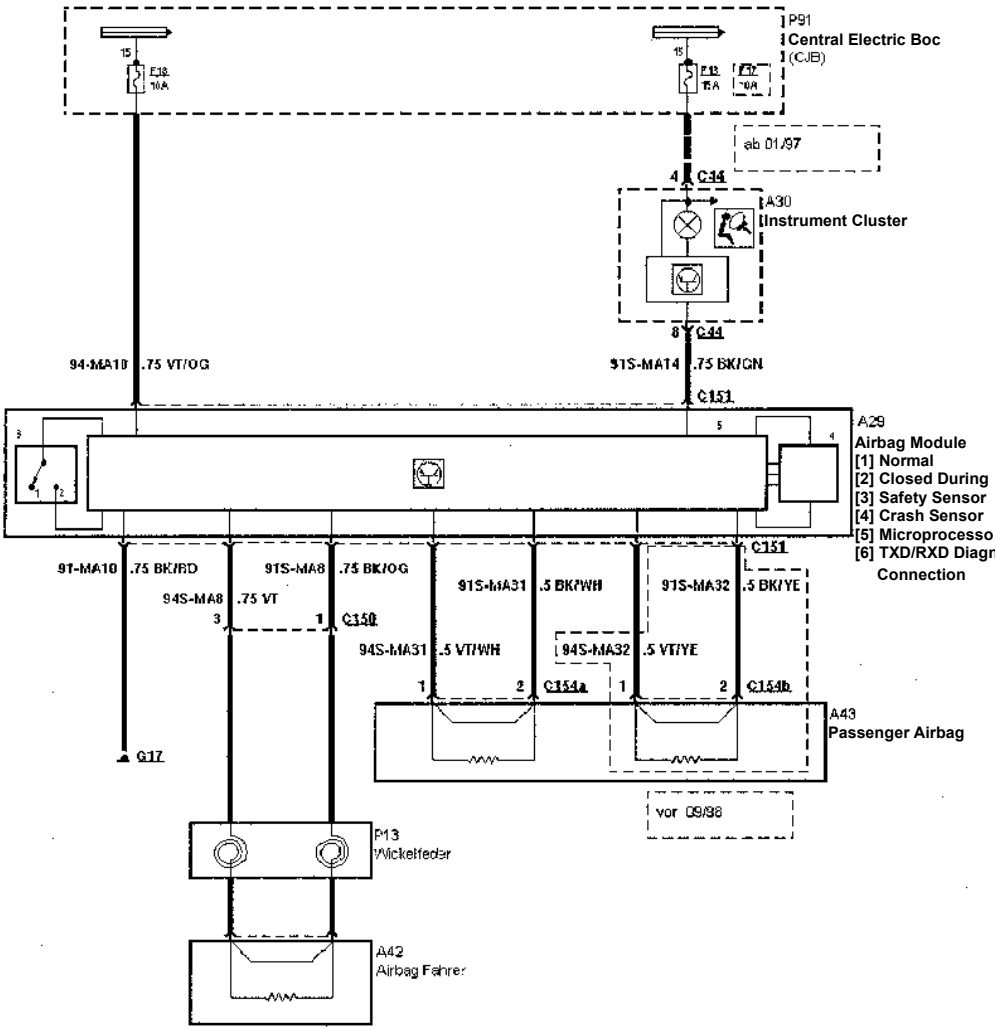
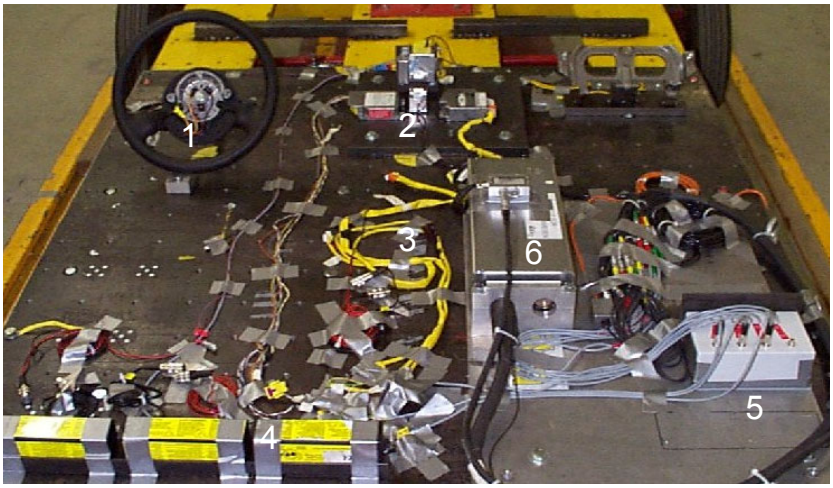


Fig. 4-15: Electrical circuit Ford Ka [NN97]

After a crash experiment, an error is displayed by permanent light-up of the airbag control light. This error is entered in the ECU after the airbag releases. The control light only goes off if the error is corrected and the error code has been deleted from the airbag module memory with the Ford diagnostic device. According to consultations with the manufacturer Autoliv the error message can be ignored since airbag release is guaranteed despite the error message. Resetting the error display would furthermore only be possible once with this system.

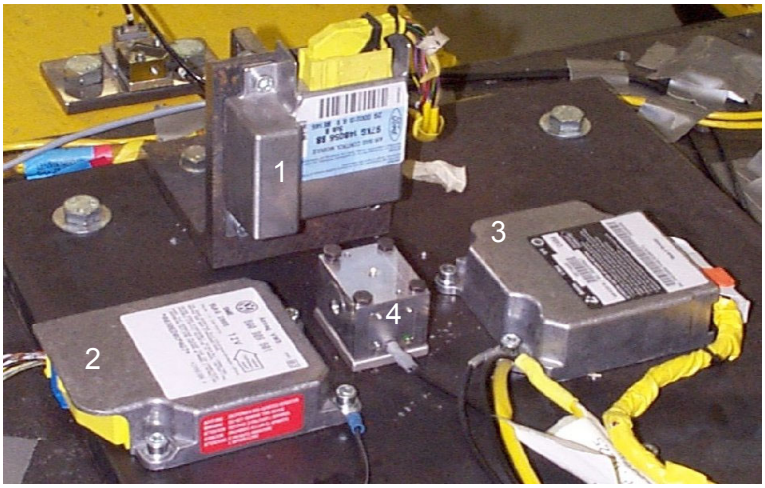
In Fig. 4-16 the correspondingly wired airbag system is shown with which several crash experiments can be carried out. Additionally, the Fiat Multipla and VW Lupo systems (explained later) are shown.



1 Ford Ka Steering Wheel
2 Control Units
3 Cable Harness
4 Power Supply
5 Optocoupler
6 Measuring Equipment

Fig. 4-16: Airbag systems of Ford Ka, VW Lupo and Fiat Multipla with measuring equipment and power supply

Fig. 4-17 shows the airbag ECU in a Ford Ka. The VW Lupo and Fiat Multipla ECUs are likewise depicted. The manufacture of the Ford system is Autoliv. With the Ford, the vertical position of the ECU must be heeded when mounting it on the test sleds. The tri-axial acceleration sensor which is supposed to take measurements in parallel to the sensors is likewise shown in this illustration.



1 Control Unit Ford Ka
2 Control Unit VW Lupo
3 Control Unit Fiat Multipla
4 Acceleration Sensor

Fig. 4-17: Control units of Ford Ka, VW Lupo and Fiat Multipla plus acceleration sensor

4.7 The VW Lupo 3L TDI airbag system

The airbag system of the VW Lupo 3L TDI studied comes from a vehicle produced in December 1999. This is a system with a driver and passenger airbag. The airbag system consists, as Fig. 4-18 shows, of the components:

1. Airbag Unit Driver Side
2. Airbag Indicator Light
3. Airbag Unit Passenger Side
4. Diagnosis Connector
5. Airbag Control Unit

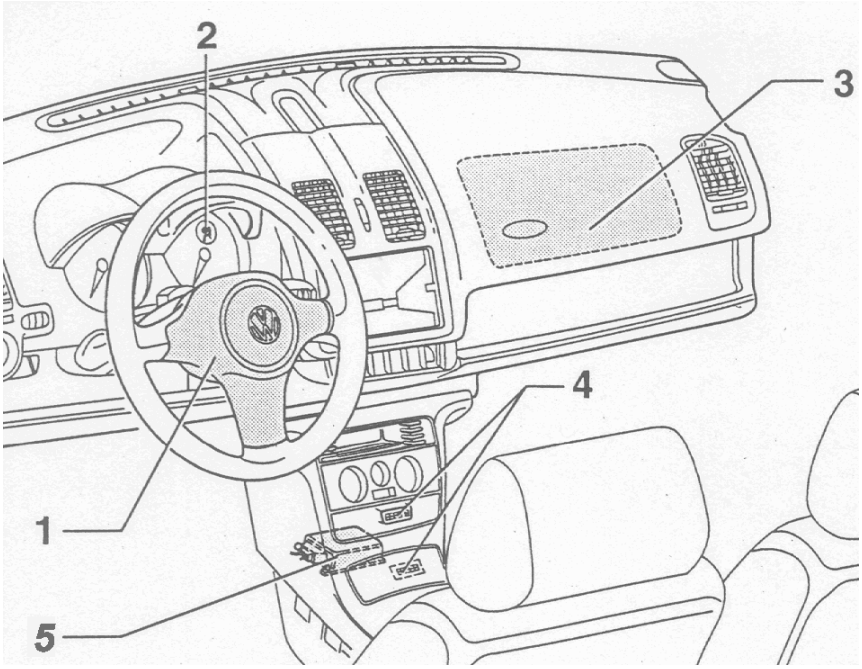


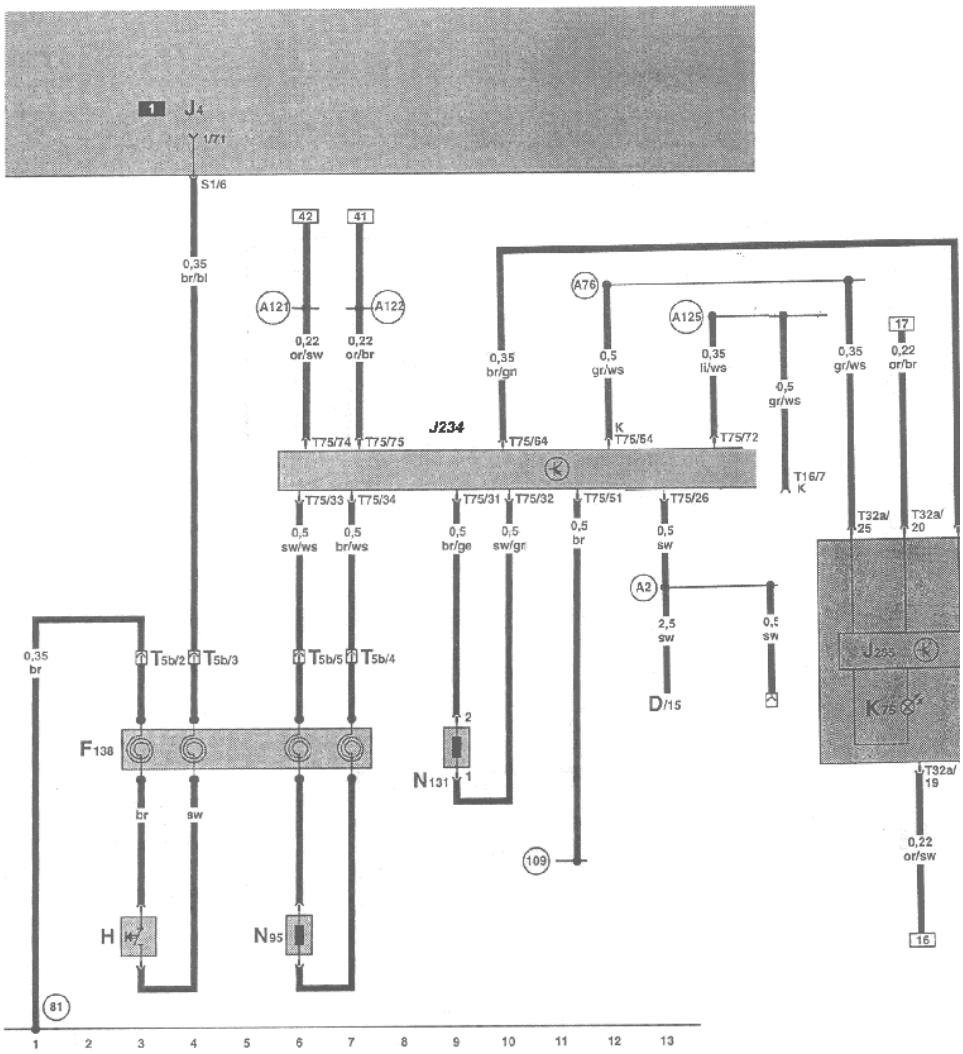
Fig. 4-18: Airbag components VW Lupo 3L TDI [NN99a]

The electrical wiring diagram of the restraint system of the VW Lupo 3L TDI is depicted in Fig. 4-19.

The resistors with which the airbag donuts can be reproduced must yield the following readings (plug contact resistors as well as including the cable harness):

- driver airbag 2.3 Ohm up to 4.8 Ohm
- all other ignition donuts 1.7 Ohm up to 4.8 Ohm

For simulation of the airbag ignition donuts 3.3 Ohm resistors were chosen here. The connections of the CAN interface are left open. As mass neutral point a bolt point on the ECU casing is used to which the pin mass, pin (51) is tied.



N95	Airbag Igniter Driver Side	A121	Connection High-Bus
N131	Airbag Igniter Passenger Side	109	Battery Ground
J234	Airbag Control Unit	A76	Diagnosis Connector

Fig. 4-19: Electrical circuit VW Lupo 3L TDI [NN99a]

The system has a CAN bus and permanently checks to see that the entire system is error-free. It is therefore necessary to exactly reproduce the airbag system's connections in order to maintain the same conditions as existed in the vehicle. Fig. 4-20 shows the electrical wiring diagram of the VW Lupo ECU and a substitute circuit for the error warning light.

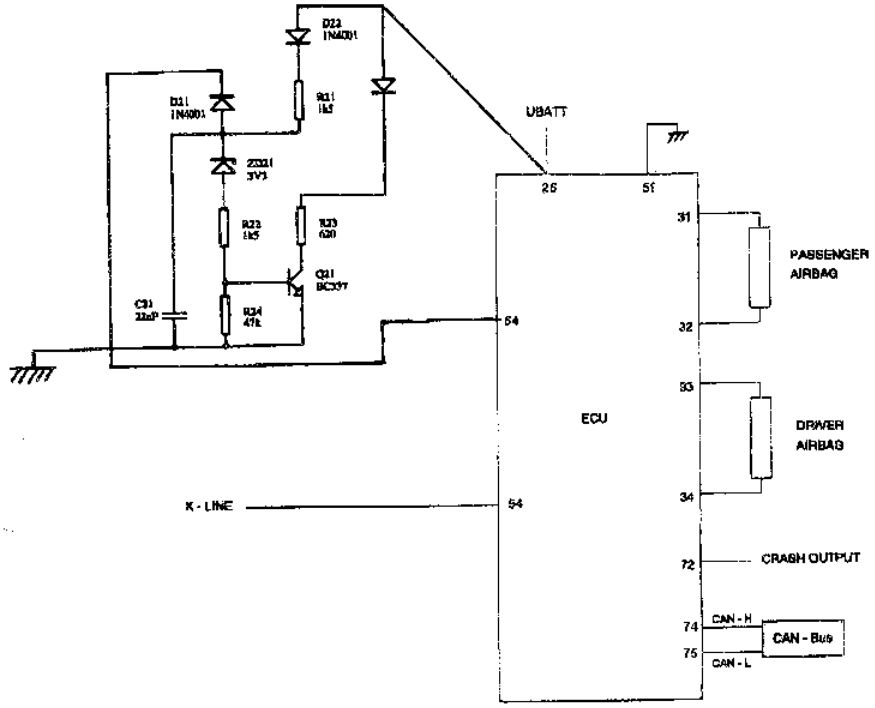


Fig. 4-20: Electrical wiring diagram of VW Lupo ECU and substitution diagram of indicator light [BAU00]

The error warning light must be replaced by a corresponding circuit. Substitute wiring of the error warning light and its implementation are depicted in Fig. 4-21.

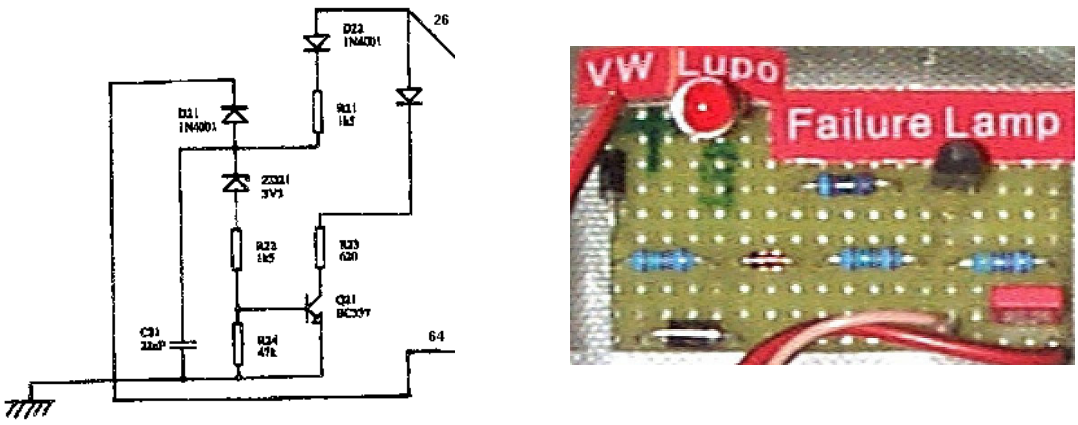


Fig. 4-21: Substitution wiring of the error warning light (left) and implementation (right)

With a completely connected peripheral connections and turning on of the voltage (in the range of 11-16 volt) to the ECU, in trouble-free operation the warning light must light up for several seconds and then turn off permanently. Should the device detect an error then the light is turned on again. In most cases the possibility then obtains to delete the error with a workshop tester. After a crash experiment, an error is displayed by permanent lighting-up of the airbag control light. This error is entered in the ECU after the airbag released. According

to consultation with the manufacturer Siemens the error message can be ignored since despite the error message with proper peripheral connections release of the airbag is guaranteed. The only condition is that after each release of the ignition impulse the ECU must be kept free of voltage for at least 4 seconds. Resetting the error message would with this system only be possible once anyway. Wire connection of the VW system and the VW ECU have already been depicted in Fig. 4-16 and Fig. 4-17.

4.8 The Fiat Multipla airbag system

The airbag system of the Fiat Multipla studied comes from a vehicle produced in December 1999. This is a system with a driver and front-seat passenger airbag as well as side airbags. But in the crash experiments only the ignition impulses to the driver and passenger airbags are taken into account. The airbag system consists, as shown in Fig. 4-22, of the components:

1. Airbag Fixture with Spiral Cable
2. Control Unit Airbag
3. Airbag Unit Passenger Side
4. Airbag Unit Passenger Side
5. Switch for Passenger Airbag

The driver airbag is located in the steering wheel on a pivot plate so that the horn can be blown. The driver airbag has a gas generator and an airbag with an inflated volume of 42 litres. The front-seat passenger airbag has two gas generators and an airbag with an inflated volume of 120 litres. The passenger airbag protects the passengers in the middle seat and in the outer right seat.

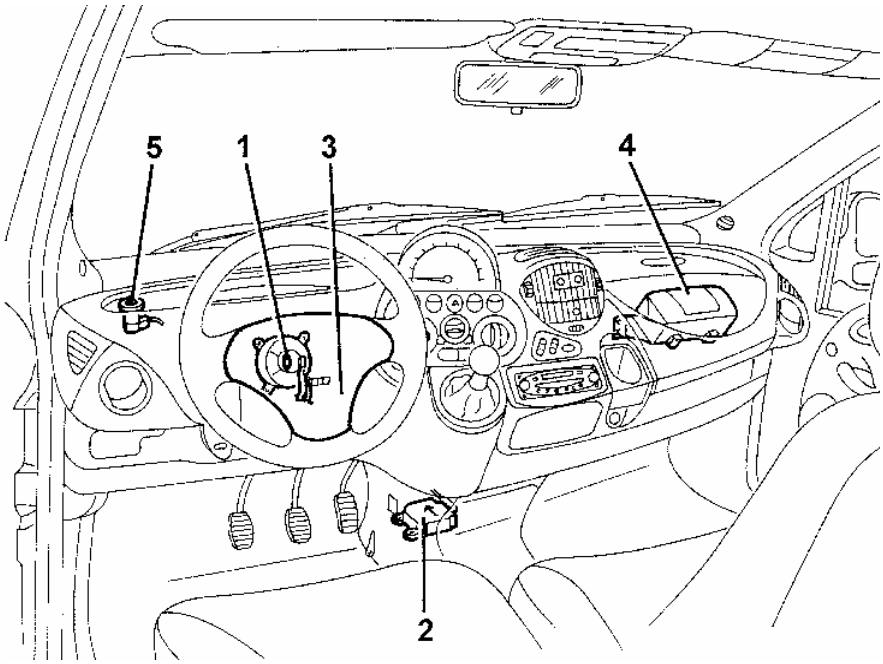
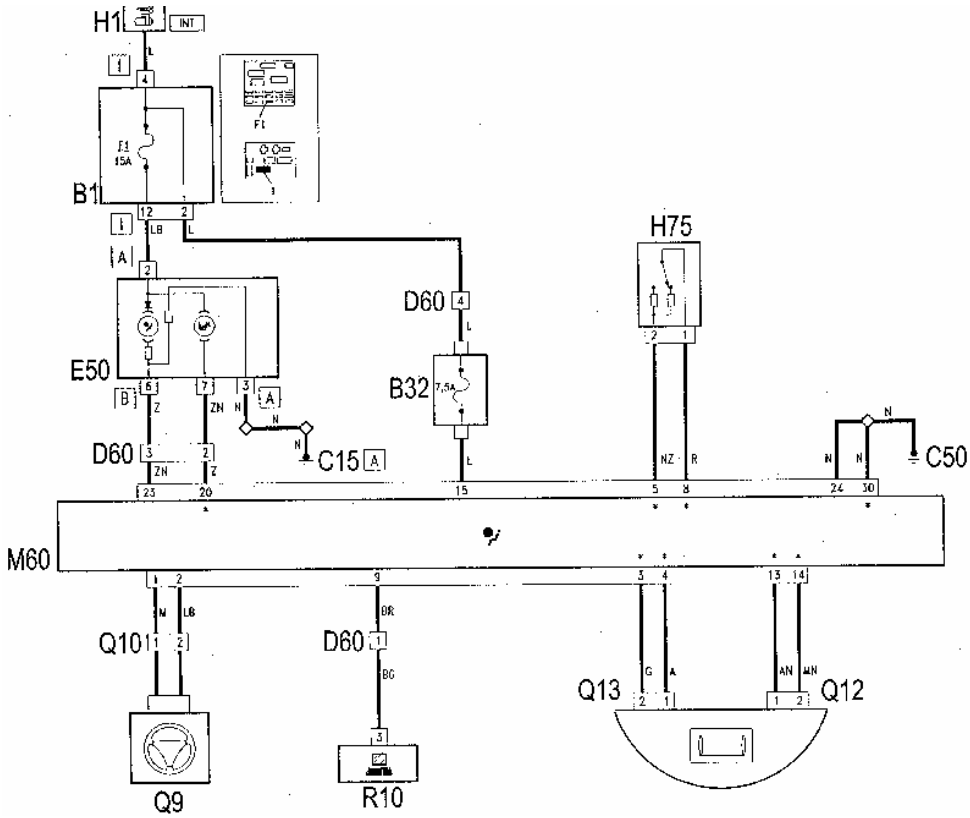


Fig. 4-22: Airbag components of Fiat Multipla [NN99b]

The electric wiring diagram of the restraint system of a Fiat Multipla for the driver and passenger airbags is shown in Fig. 4-23. The ECU in this wiring diagram requires a 30-pole plug (ECU without side airbag propulsion). The available system however has a 50-pole plug (ECU with side airbag propulsion). The plugs are here connected in such a way that they overlap in the common area. This means that the allocation of pins 1 through 15 are identical, pins 16 through 30 of the 30-pole plug correspond to 26 through 40 of the 50-pole plug. The following components are connected to the Fiat Multipla ECU:

- Driver airbag as well as connections for the two gas generators of the passenger airbag
- Side airbag of the driver and passenger airbag
- Acceleration sensor for the side airbags of the driver and passenger sides
- Switch for deactivating the passenger airbag
- Red error warning light (LED)
- Yellow airbag-off light which indicates that the passenger airbag has been deactivated



Q09	Airbag Driver Side	H75	Passenger Airbag Shutoff Switch
Q12/13	Airbag Passenger Side	C50	Ground Connector
M60	Airbag Control Unit	R10	Diagnosis Connector

Fig. 4-23: Electric wiring diagram Fiat Multipla (w/o Sidebags) [NN99b]

The system constantly checks to see that all connections to the airbag components are error-free. It is therefore necessary to exactly reproduce the airbag system connections in order to

obtain the same conditions as obtain in the vehicle. Fig. 4-24 shows the electrical wiring diagram of the Fiat Multipla's ECU. The error warning light and the passenger airbag-off light must be replaced by equivalent circuits. The choice of the light diode is without any bearing in this case. The substitute connections for the error warning light and the passenger airbag-off light and their connection are depicted in Fig. 4-25.

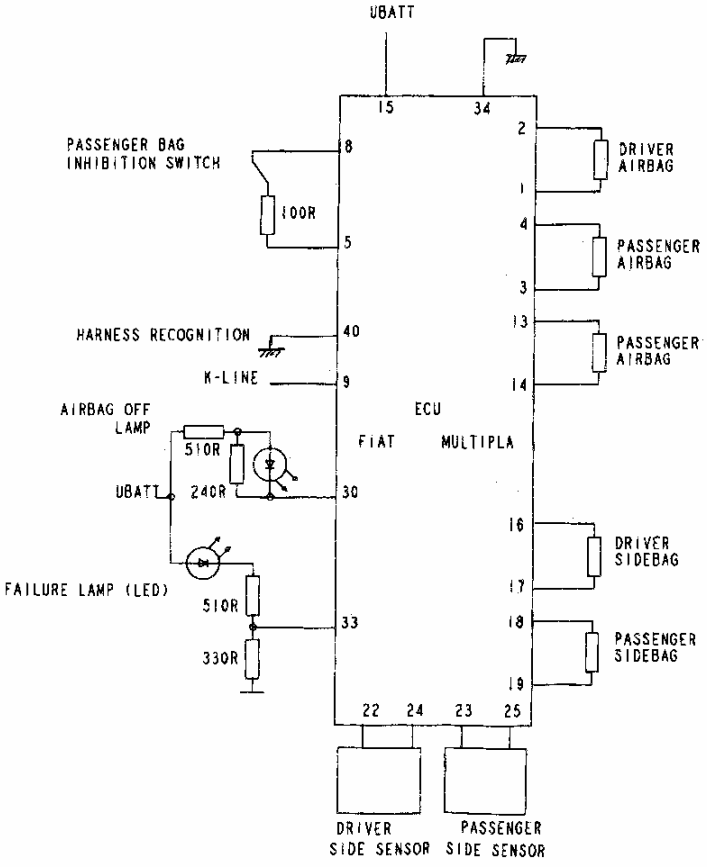


Fig. 4-24: Electrical wiring diagram of the Fiat Multipla [BAU00]

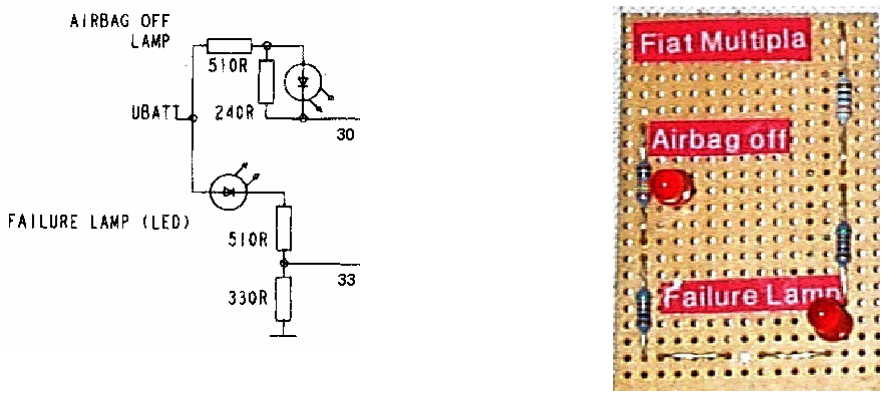


Fig. 4-25: Substitution wiring of the error warning light (left) and implementation (right)

The resistors with which the airbag ignition donuts are reproduced must yield the following readings (plug contact resistors as well as cable harness included):

- Driver airbag 2.0 Ohm up to 3.2 Ohm
- All other ignition squibs: 1.8 Ohm up to 2.6 Ohm

For simulation of airbag ignition donuts in this case 2.2 Ohm resistors were chosen. As mass neutral point a bolt point on the ECU casing is used where the pin mass, pin (34) and the harness recognition, pin 40 are tied in. Without the mass point on the ECU casing an error is entered in the fault memory and release of the airbag in the event of a crash is no longer possible.

Dismantling the passenger seat in a Fiat dealer's garage without cutting the voltage supply resulted according to the shop foreman in the "airbag defect" control light on the instrument panel lighting up. The ECU had to be replaced since the error memory with the diagnosis tester could no longer be deleted. According to information from the ECU manufacturer Siemens this is due to the missing mass point (pin 40) so that an equivalent error is entered into fault memory. In this case, the airbag would not have been released in an actual crash event.

With completely connected peripheral hookup and turning on of the current (range 11-16 volts) to the ECU, the warning light (failure LED) must light up for four seconds in error-free operations and subsequently turn off permanently. Should the device recognise an error then the light turns on again. In most cases there is then the possibility of deleting these errors with the Fiat/Lancia tester. After a crash this is no longer possible. According to consultation with the manufacturer, Siemens, the error message can be ignored since despite the error message with proper peripheral connection release of the airbag is guaranteed. The only condition is that after each release of the ignition impulse the ECU must be kept free of current for at least 5 seconds and prior to the crash experiment the communications line (K line) of the Fiat/Lancia diagnostic tester must be disconnected from the ECU.

The warning light (Airbag off) in the meanwhile blinks 16 times after turning on the current and indicates that this warning device is still functioning without any hitches. Subsequently the warning light goes off and thus signals that the passenger airbag is capable of functioning.

Wiring up of the Fiat system and the Fiat ECU have already been described in Fig. 4-16 and Fig. 4-17.

5 Conduct of the experiment

The experimental programme breaks down into three series of experiments:

1. Experiments with the airbag systems of Mercedes-Benz 300E and the S-Class
2. Experiments with the airbag systems of Opel Vectra, Ford Escort and Ford Monde
3. Experiments with the airbag systems of Ford Ka, Fiat Multipla and VW Lupo.

The various systems are summarised in the experimental series in order to test comparable systems under identical crash conditions and, on the other hand, to reduce slightly the number of crash experiments. During the actual experiments the fitting out of the tensile sheet brake and the impact speed are changed so that it is possible to obtain a convincing number of experiments both with and without airbag release. Additionally in preliminary experiments the correct wiring of the airbag systems studied can be checked. However, these preliminary tests will not be further documented here.

5.1 Mercedes-Benz 300E and Mercedes-Benz S-Class systems

The three airbag systems from Mercedes-Benz are mounted on the component sled. Care should be taken in doing so that the ECUs of the airbag system are mounted in the same direction as the vehicle is travelling. The airbag systems are connected to the voltage source (battery block) and the opto-coupler on the sled. The tri-axial acceleration sensor is connected to the MDS32 crash measurement equipment, as is the light barrier as well. The power supply to the measurement equipment carried along on the sled is turned on.

With the aid of the measurement computer and the WinCarat software the experimental configuration is set and offset compensation is carried out. Signal reception is started via a threshold value trigger. As soon as acceleration drops below a value of -5 g and then measurement readings are written into memory in a time span from 0.5 seconds before this trigger time and 3 seconds thereafter. This is possible due to the fact that the DAU first writes data in a ring memory from where the data can then be read out.

The experimental sled, regardless of the speed aimed at, is brought into its starting position and the light barriers are turned on together with the Tag-Heuer chronoprinter. Depending on the deceleration process, deformation rods (St 37) with different cross-sections are inserted into the lanes of the tensile sheet brake. After fitting out the tensile sheet brake and setting the impact speed the crash system's computer can be configured. The crash experiment can be carried out after accesses to the crash track are blocked off for safety reasons.

With the aid of the crash system's flywheel mass drive the component sled is accelerated up to a previously defined speed and detached from the drive about 5 m before the tensile sheet brake. After successfully recording all experimental data the latter can be read out with

WinCarat and saved on the hard drive. For data evaluation the DIAdem programme is then used.

After each experiment a check is made to see if the ignition signal has current in it. In order to limit the release range to the absolute minimum the tensile steels are chosen for the next experiment depending on the results of the preceding one. If release has been detected then the subsequent deceleration should be fashioned more lightly and consequently a smaller cross-section of the bending frame is selected.

Fig. 5-1 shows by way of example the graph of the acceleration signal with different impact speeds. The tensile sheet brake is in each case occupied with a 30 x 30 frame in the first and second lane. In the beginning, the course of all experiments is the same. With further experimentation one then sees a curve clearly emerging with which over time the sled block contacts the bending steel. The slower the sled originally is the longer it then takes it to reach the second lane. This moment can be recognised in the diagram by means of a steep rise in deceleration.

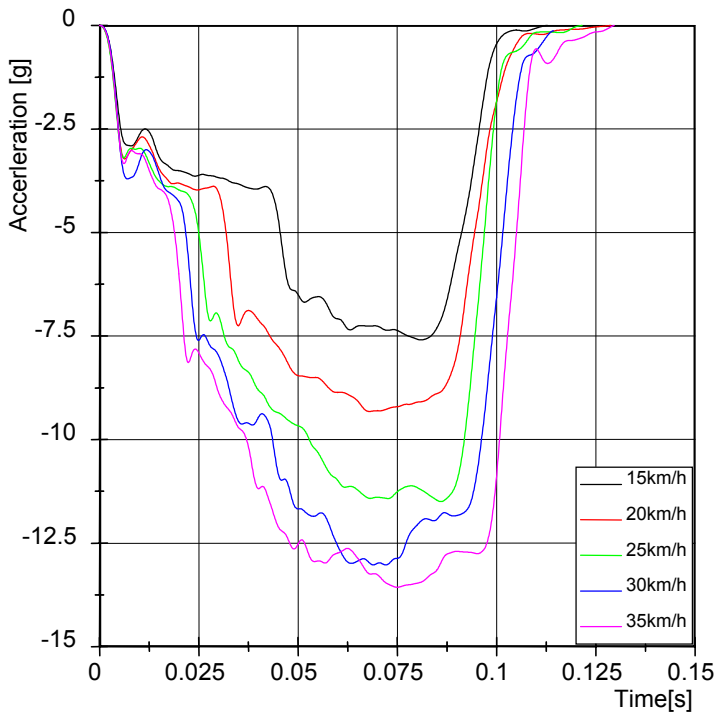


Fig. 5-1: Acceleration signal of different velocities

The following Fig. 5-2 provides a survey of the experiment parameters. For each experiment, the impact speed, the occupation of the tensile sheet brake as well as the steel geometry chosen are all indicated.

Test	381	382	383	384	385	386	387	388	389	390	391
Velocity [km/h]	30,91	20,64	20,69	20,8	20,78	20,78	26,26	26,3	26,17	26,23	26,04
Lane 1	30x30	25x25	30x30	40x40	30x30	30x30 25x25	30x30	30x30	25x25 25x25	30x30 25x25	30x30 30x30
Lane 2	30x30	25x25			30x30		30x30				
Lane 3											
Lane 4											
Test	**392**	**393**	**394**	**395**	**396**	**397**	**398**	**399**	**400**	**401**	**402**
Velocity [km/h]	30,49	30,42	30,51	35,31	15,38	15,42	20,71	20,75	25,91	25,94	35,37
Lane 1	30x30	30x30	30x30	30x30	40x40	30x30	30x30	30x30	30x30	30x30	30x30
Lane 2				30x30		30x30	40x40				
Lane 3		30x30	35x35					40x40	30x30	40x40	30x30
Lane 4	30x30										

Fig. 5-2: First test series

5.2 Ford Mondeo, Ford Escort and Opel Vectra systems

Fig. 5-3 shows the acceleration graph of the second experimental series.

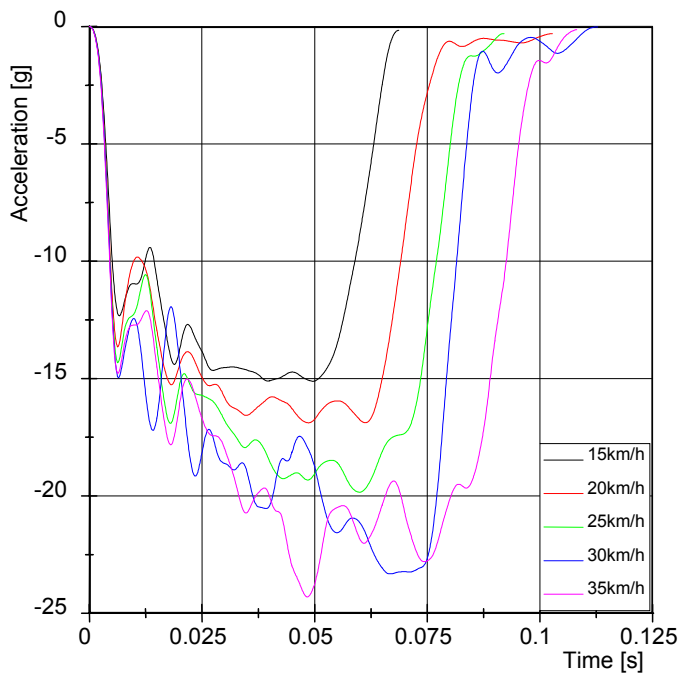


Fig. 5-3: Acceleration characteristics with identical deformation elements

Accelerations turn out to be somewhat higher in comparison with the first series of experiments. This can be explained by the fact that for the complete experimental series another steel charge was used which yielded a higher degree of solidity due to manufacturing peculiarities.

The principle experimental structure corresponds to that of the first series of experiments. The four Opel and the four Ford airbag systems are installed on the test sleds. According to the installation position in the vehicle, the Ford ECUs are mounted perpendicular to the direction in which the vehicle is travelling. The power supply works in this series of experiments via a transformer with a separate trailing cable since the eight ECUs for the battery blocks would have consumed too much electricity. The transformer voltage is set for 13.6 volts. The equipment has an error memory preventing multiple releases in direct succession to each other. Consequently after every experiment one must cut off the current. This erases the memory. Fig. 5-4 gives all the experiments carried out with various different experimental parameters for the second series of experiments.

Test	**437**	**438**	**439**	**440**	**441**	**442**	**443**	**444**	**445**	**446**
Velocity [km/h]	30,33	30	30,08	29,92	14,82	14,04	14,13	14,3	19,9	19,94
Lane 1	45x45	30x30	30x30 30x30	30x30	40x40	30x30	30x30	35x35	40x40	30x30
Lane 2		40x40					30x30			
Lane 3				30x30						
Lane 4										
Test	**447**	**448**	**449**	**450**	**451**	**452**	**453**	**454**	**455**	**456**
Velocity [km/h]	19,98	20,08	19,95	25,16	25,18	25,03	25,08	25,2	25,17	25,06
Lane 1	35x35	30x30	30x30	40x40	30x30	35x35	25x25	25x25	25x25	30x30
Lane 2		30x30	20x20				25x25			30x30
Lane 3								25x25	30x30	
Lane 4										
Test	**457**	**458**	**459**	**460**	**461**	**462**	**463**	**464**	**465**	
Velocity [km/h]	25,18	34,78	34,7	34,72	34,93	34,76	34,72	29,85	24,9	
Lane 1	45x45	40x40	30x30	30x30	45x45	45x45	40x40 30x30	40x40 30x30	40x40 30x30	
Lane 2			30x30							
Lane 3				30x30						
Lane 4										

Fig. 5-4: Second Test Series

5.3 Ford Ka, VW Lupo and Fiat Multipla systems

The acceleration graphs of the third series of experiments are almost identical to those of the first and second so that they will not be described again here. The following table Fig. 5-5 shows the experiments carried out with the airbag systems from Ford Ka, VW Lupo and Fiat Multipla.

Test	**314**	**323**	**324**	**325**	**326**	**327**
Velocity [km/h]	36,05	35,35	35,41	35,28	35,36	30,37
Lane 1	30*30 40*40	30*30 40*40	30*30 40*40	30*30	30*30	30*30
Lane 2	30*30		30*30	30*30		30*30
Lane 3		30*30			30*30	
Test	**328**	**329**	**330**	**331**	**332**	**333**
Velocity [km/h]	30,21	30,23	30,23	30,11	30,322	25,15
Lane 1	40*40	30*30	30*30 30*30	30*30 40*40	45*45	45*45
Lane 2		40*40			30*30	
Test	**334**	**335**	**336**	**337**	**338**	**339**
Velocity [km/h]	25,22	25,16	25,15	25,17	20,13	20,11
Lane 1	30*30	40*40	40*40	30*30	45*45	40*40
Lane 2	40*40		35*35			
Test	**340**	**341**	**342**	**343**	**344**	**345**
Velocity [km/h]	20,25	20,02	20,19	15,03	15,06	15,10
Lane 1	30*30	30*30	35*35 40*40	45*45	35*35	40*40
Lane 2	40*40					
Test	**346**	**347**	**348**	**349**		
Velocity [km/h]	35,54	35,37	35,33	35,47		
Lane 1	45*45	30*30	30*30 40*40	30*30 40*40		
Lane 2		40*40	30*30			

Fig. 5-5: Third test series

6 Evaluation of the test results

Using the example of the Mercedes-Benz 300E airbag system a detailed description will be given of how informative results can be obtained from the measurement data stemming from the experiments. With the aid of such experimental results the release strategy of the airbag systems will be determined and the functional adequacy of the system will be tested.

6.1 Test results from the Mercedes-Benz 300E airbag system

The basis of evaluation is the recorded acceleration signal. This signal contains high-frequency portions which are suppressed with a CFC-60 filter. In this case this is a 4-pole Butterworth low-pass with a linear phase and special commencement conditions conventionally used in crash tests. The signal is continued laterally reversed to the first and last channel value in order to eliminate the filter's transient response. The 3 dB limit frequency is 100 Hz and the suppression attenuation is -30 dB.

Since measurement data recording does not start with the first impact the acceleration graphs are cut out from the first noticeable increase and subsequently only those data are processed. Fig. 6-1 shows such a graph.

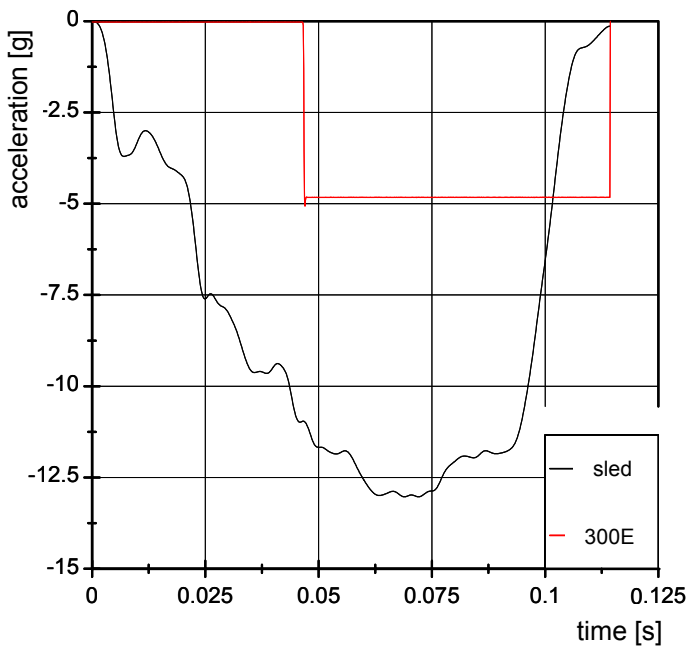


Fig. 6-1: Acceleration characteristic and opto-coupler signal in test 381

The measurement data depicted were recorded in experiment 381. The sled slammed at a speed of 30.91 km/h into the tensile sheet brake which was fitted out with one 30 x 30 square profile each in the first and second lane. After the test they show deformations of 475 mm and 335 mm. Deceleration is completed after 115 ms and is at most 13.5 g. The red curve graph shows the initial signal of the opto-coupler which is connected to the system's ignition circuit. In the event of an ignition impulse from the ECU to the airbag the starting voltage

jumps from 0 volts to 5 volts. The release time in this experiment is 47 ms measured from the first impact. If one considers all experiments conducted then it can be said that all airbag releases took place between 18 ms and 73 ms. Signal duration of the impulse lies in a range between 62 ms and 100 ms.

Since the airbag ignition impulse and the ignition impulse for the belt-tightener in these systems always occur simultaneously, in evaluation only the airbag ignition signal will be taken up.

6.1.1 Change of velocity versus time

Basically, the measure for release of an ignition impulse is the collision-related change in velocity Δv (see Chapter 2.4). To calculate the latter the longitudinal deceleration is integrated and the velocity derived from that is subtracted from the impact velocity. It is thus a measurement for velocity reduced in the crash at a specific point in time.

The Mercedes-Benz airbag system releases at variable Δv values. Essentially there is here a dependency on the gradient of the longitudinal deceleration measured over time. A steep rise in deceleration in principle lowers the Δv threshold value for airbag release. In the opposite direction, a slower rise in deceleration raises the threshold value. On this basis the results of the experiment are evaluated.

In Fig. 6-2 and Fig. 6-3 and the graphs of velocity change are depicted in a diagram for varying bending sheet occupation at the same sled velocitys.

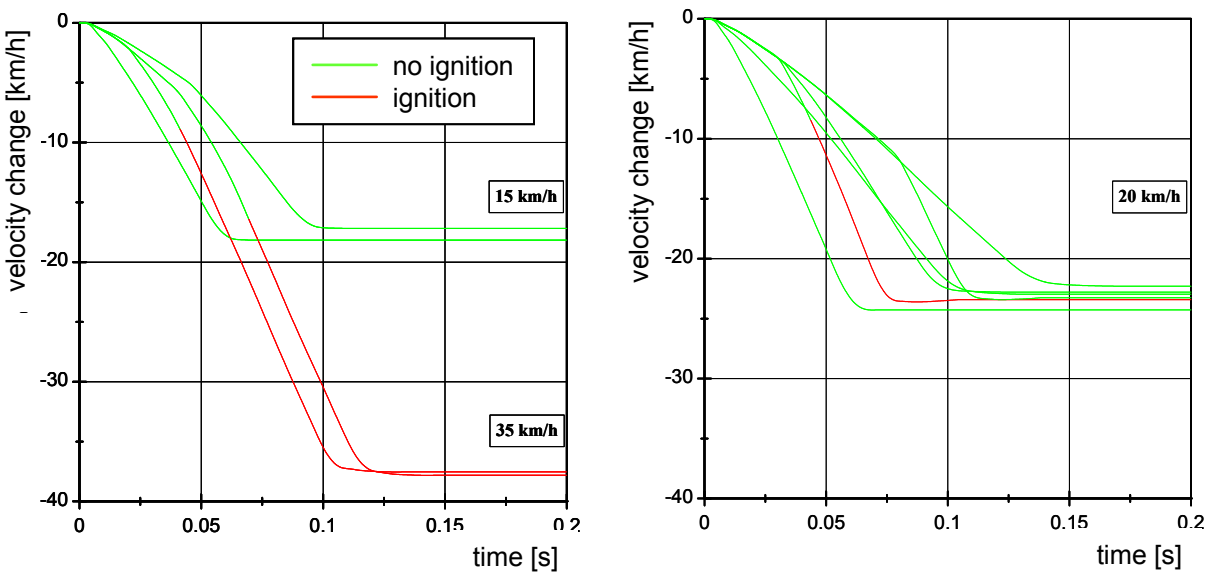


Fig. 6-2: Velocity change and ignition timing for sled velocitys of 15, 35 and 20 km/h

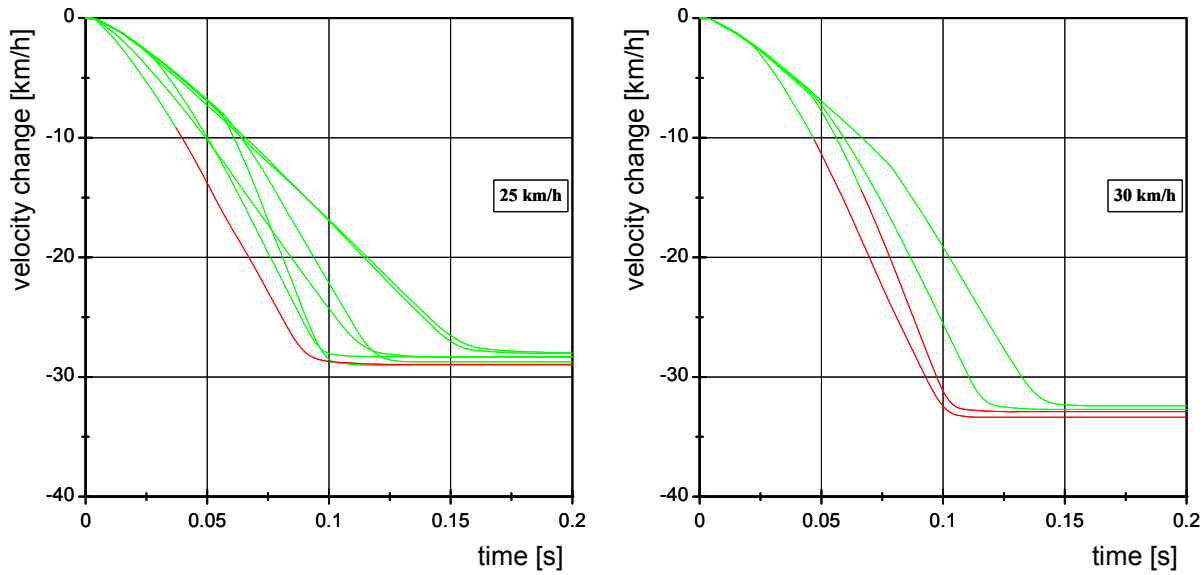


Fig. 6-3: Velocity change and ignition timing for sled velocitys of 25 and 30 km/h

The graphs without airbag release are coloured green in the diagrams. If an ignition impulse occurs then the graph switches from green to red whereby the change of colour marks off the moment of ignition. The velocity change graphs and the ignition moments of the ECU are shown for sled velocitys between 15 and 35 km/h. The velocity change up to the moment of release is in each case larger than 8 km/h and the ignition points of the ECU lie between 30 and 75 ms.

The diagrams bring out the fact that with a marked change in velocity entails an early release of the airbag while with a minor change in velocity the release moment occurs later. One can see a borderline between experiments with airbag release and those without airbag release. However it is striking that a graph at 20 km/h actually should have resulted in release. This experiment is studied in more detail later with a comparison with other Mercedes-Benz systems (cf. Chapter 6.2.3).

In the presentation of change in velocity at the moment of ignition over time for all sled experiments carried out, an exponential graph Fig. 6-4 emerges. If the velocity change graph cuts through the trend line, then airbag ignition results. Altogether a similar picture emerges as in Fig. 2-19.

The ignition moments of airbag releases lie in a ranger between 37 and 70 ms. The change in velocity at the moment of ignition is between 9 and 16 km/h.

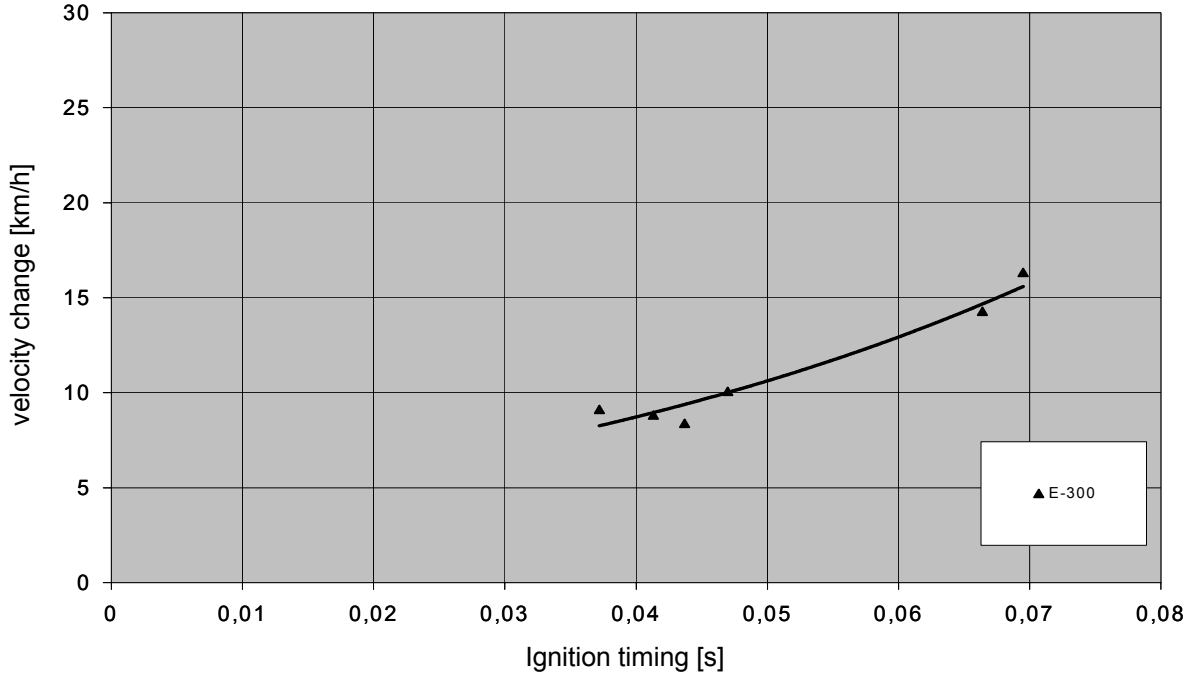


Fig. 6-4: Velocity change at ignition point of Mercedes 300E system

It turns out that the Δv threshold values as a function of rise in deceleration are in principle being recognised correctly by the electronic component of these systems. By means of the form of presenting changes in velocity across the displacement path this can be underscored even more in the next section of this chapter.

6.1.2 Change of velocity versus displacement

It is useful to consider as well the change in velocity for the data obtained as a function of the displacement. The displacement is produced by integration of the change in velocity. One assumes in such considerations that the passenger in an accident does not have his belt fastened and that his relative motion in relation to the inside space of the vehicle corresponds to the latter's change in velocity. This is a simplification since actual motion of the passenger is influenced by considerably more parameters such as seat parameters, body mechanics and in particular the restraint systems. In Fig. 6-5 all experiments presented in this form are listed.

Tests with airbag release are marked red, those without release are marked green. In experiments with airbag release the ECU's moment of ignition is labelled as a red marking point.

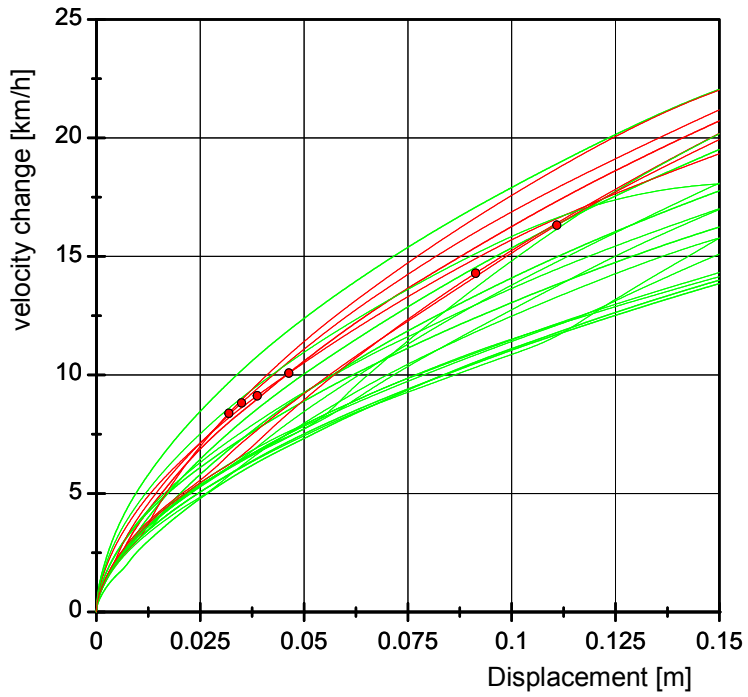


Fig. 6-5: Velocity change versus displacement

As in Fig. 6-3, the experiment marked off at the top in green attracts attention because it did not result in any ignition despite the high velocity. Otherwise the illustration shows a separation of ranges with airbag release and without airbag release. The marking points are all located on a line. Where the graph intercepts this line, the ECU ignites.

In Fig. 6-6 this state of affairs is depicted in greater detail. The moments of ignition of the airbag ECU are superimposed as a function of change in velocity and of the displacement. This illustration shows a linear connection of the moment of ignition as a function of change in velocity and of the displacement. The points hardly deviate from the differential straight line.

If one compares the dispersal of ignition moments around the trend line of Fig. 6-6 with Fig. 6-4 then it is striking that it turns out to be considerably less in the velocity - displacement diagram. A mathematical mean for assessing dispersal is the measure of certainty or determination coefficient R^2. It is an indicator for the degree of correlation between the estimated values for a trend line and their actual data. The determination coefficient can assume values from 0 to 1 where the reliability of the trend line increases as the coefficient approaches 1.

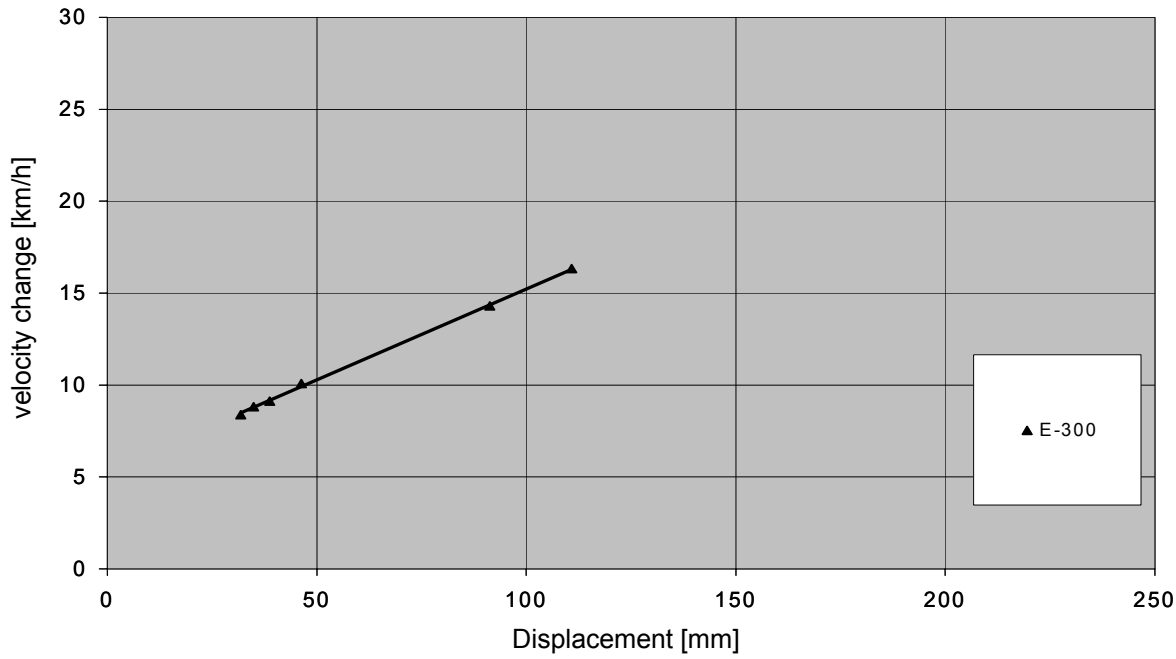


Fig. 6-6: Velocity Change versus displacement with corresponding ignition points

The measure of certainty in Fig. 6-6 comes to 0.9992 whereas in the velocity-time graph (Fig. 6-4) it only achieves a value of 0.9337.

The ECU's release criterion is better described with the velocity change - displacement graph. This appears to make sense since the moment of ignition is basically determined by the maximum available preliminary displacement and not by the moment when the accident begins.

6.2 Tests results of the Mercedes-Benz S-Class airbag system

Fig. 6-7 shows in characteristic manner the graph of measurement data recorded in experiment 381. The sled crashes with a velocity of 30.91 km/h against the tensile sheet brake which was fitted out with one 30 x 30 square frame each in the first and second lane. After the experiment they manifest deformations of 475 mm and 335 mm. Deceleration is completed after 115 ms and amounts at maximum to 13.5 g. The red and green graphs show the initial signal of the opto-coupler which is connected to the ignition wiring of each of the systems. The release times in this experiment are 50.5 ms and 50 ms. Both systems therefore make the ignition decision at almost the same time. If one considers all experiments carried out then it can be said that all airbag releases occur between 18 ms and 73 ms. The duration of the impulse signal lies in a range between 62 ms and 100 ms. Since the ignition impulse for airbag and belt-tightener always occurs simultaneously in these systems, in evaluation only the airbag's ignition signal will be dealt with.

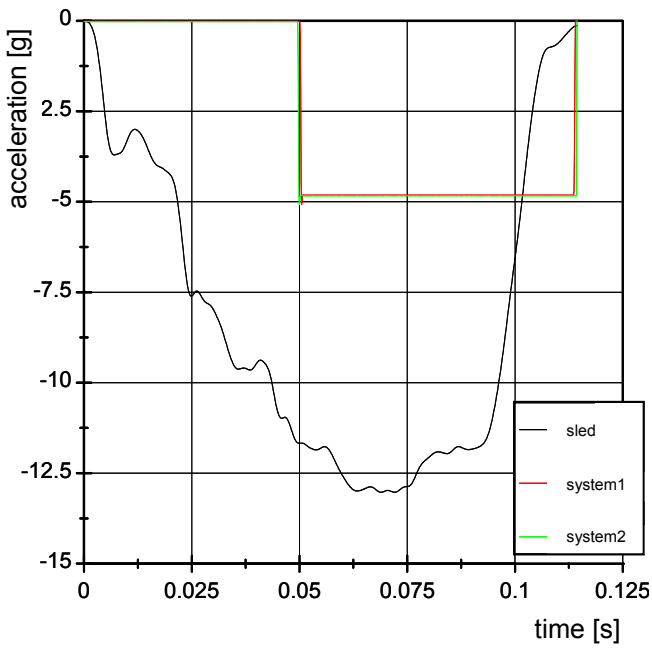


Fig. 6-7: Acceleration characteristics and opto-coupler signals at test 381

6.2.1 Change of velocity versus time

The Mercedes-Benz airbags also release at variable Δv values. Here this depends on the gradient of longitudinal deceleration measured over time. In Fig. 6-8 and Fig. 6-9 the graphs of change in velocity at the ECU's moment of ignition are depicted for sled velocitys from 15 through 35 km/h. The values relate to the S-Class 1 system.

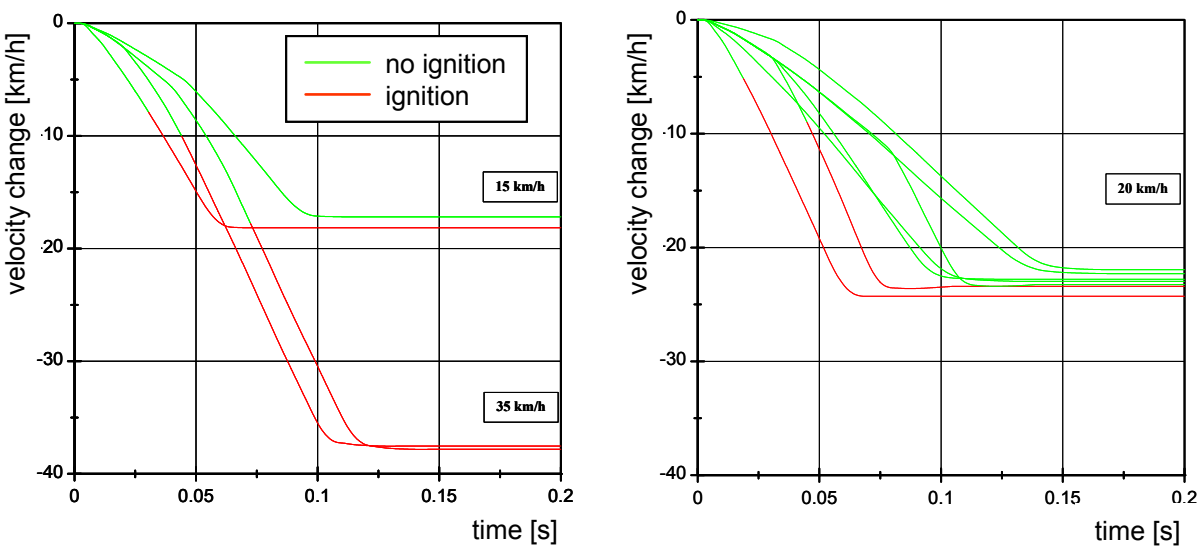


Fig. 6-8: Velocity change and Ignition timing for sled velocitys of 15, 35 and 20 km/h

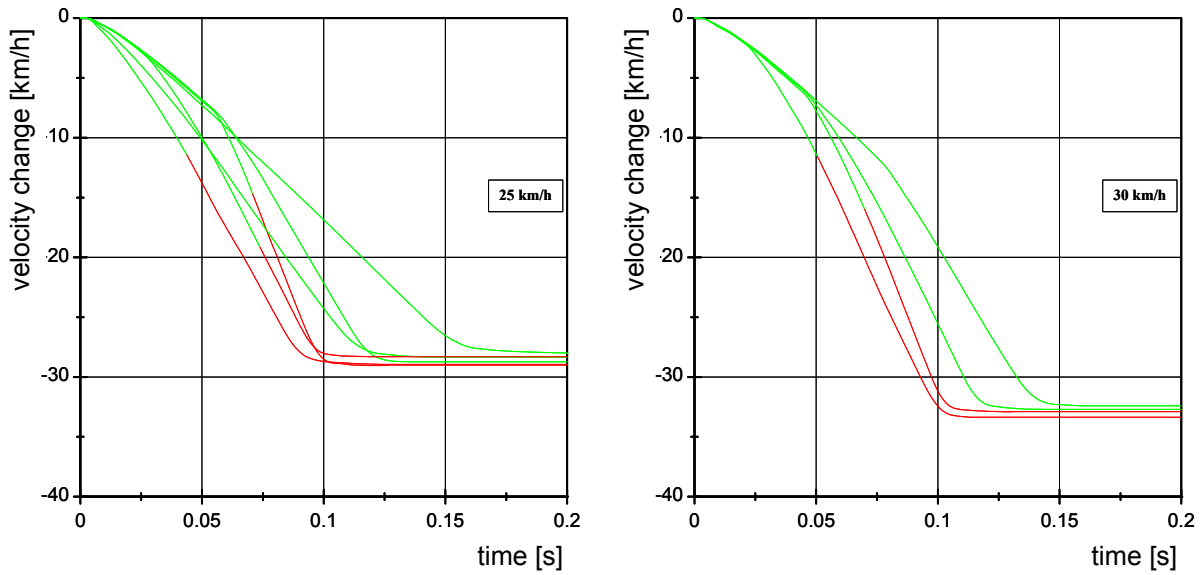


Fig. 6-9: Velocity change and Ignition timing for sled velocitys of 25 and 30 km/h

The velocity change up to the moment of release is in each case greater than 8 km/h and the ECU's ignition moments lie between 30 and 75 ms.

The diagrams make it clear that with a high change in velocity an earlier release of the airbag ensues while with a lesser change in velocity the release moment occurs later. A clear delineation between experiments with airbag release and without airbag release can be seen.

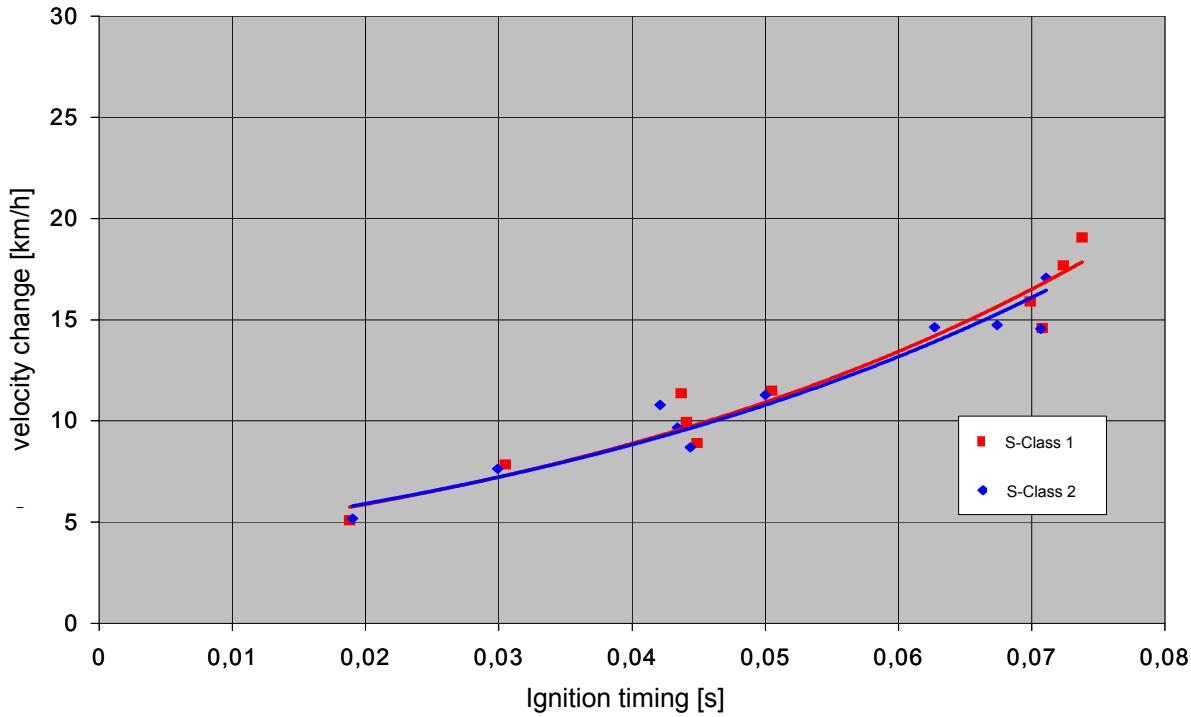


Fig. 6-10: Velocity changes at ignition points of Mercedes S-Class systems

If one plots the velocity change up to ignition for all experiments carried out, then for the individual systems an exponential graph (Fig. 6-10) emerges. With a major portion of the airbag releases the ignition moment lies in the range between 40 ms and 70 ms. The change in velocity up to the moment of ignition is between 8 and 17 km/h.

6.2.2 Change of velocity versus displacement

In Fig. 6-11 all changes in velocity are plotted as a function of the displacement. In the illustration a clear separation of ranges with airbag release and without airbag release become apparent. The marking points are all located on a line. Where a graph intercepts this line the ECU ignites.

In Fig. 6-12 this state of affairs is depicted in greater detail and for each of the systems. The ignition moments of the airbag ECU have been plotted as a function of the change in velocity and displacement. It also becomes apparent for the S-Class systems as well that there is a linear connection of the ignition moment as a function of the change in velocity and as a function of the displacement.

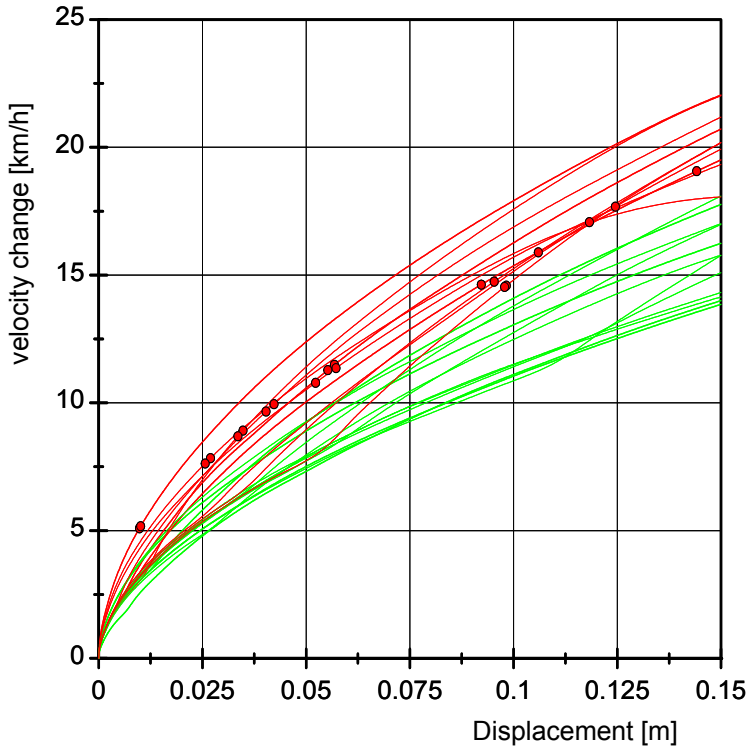


Fig. 6-11: Velocity Changes versus displacement and ignition points

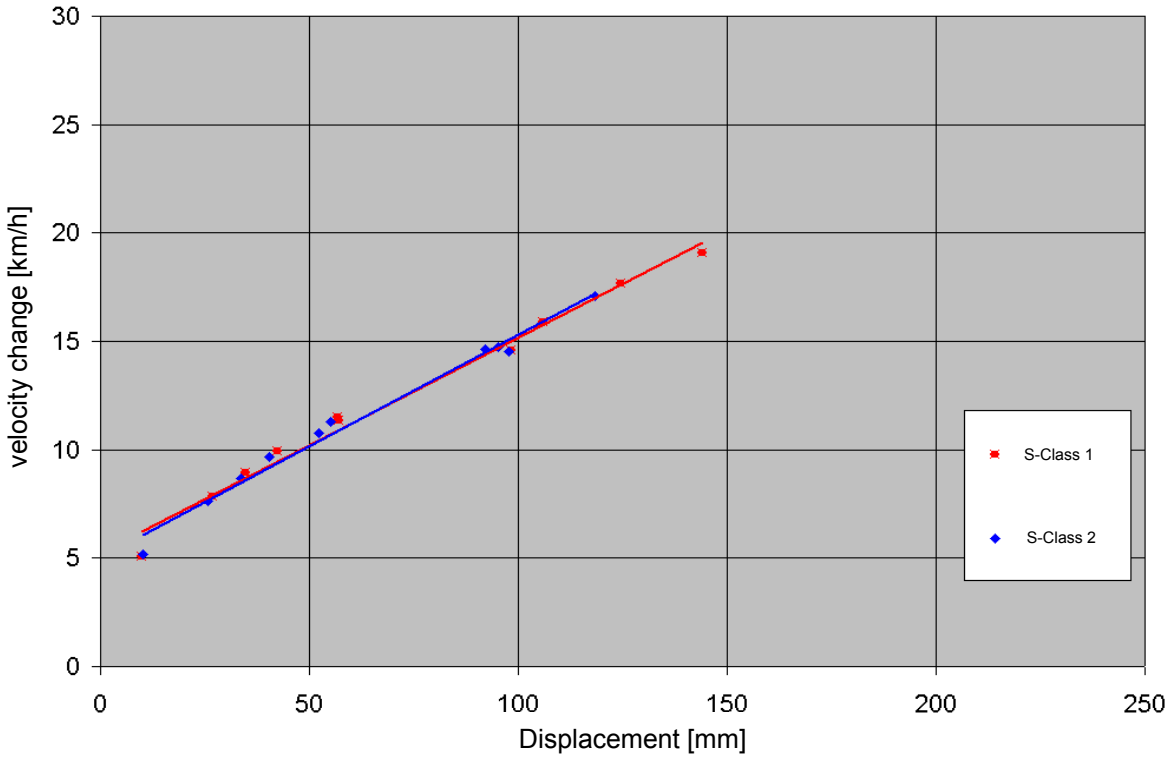


Fig. 6-12: Velocity Change versus displacement MB S-Classes

The measure of certainty in Fig. 6-12 is 0.986 for system 1 and 0.985 for system 2 while in the velocity-time graph (Fig. 6-10) it only achieves a value of 0.943 and 0.940.

6.2.3 Comparison of all Mercedes-Benz systems

It can be stated in general that the S-Class systems all assess the crash situation in the same way. In Fig. 6-12 one can clearly see the S-Class system's ignition impulses clustering closely together where system 2 has a tendency to release somewhat sooner. The ignition moment difference is 0.84 ms on average.

The system taken from the 300E (here: system 3) clearly differs in regard to the ignition moment. It normally ignites 3 ms earlier than the S-Class systems. The shift of the ignition moment to an earlier point appears to make sense since the structure of the vehicle's front section in the 300E is probably somewhat weaker than it is in the S-Class.

Here below, two experiments where the systems reacted differently will be considered separately.

Experiment 387:

In both S-Classes a noticeably greater time difference of 11.1 ms resulted between the ignition impulses, Fig. 6-13. The test sled impacts on the tensile sheet brake with velocity of

26.72 km/h, the tensile sheet brake having one 30 x 30 frame each in the first and second lane.

System 1 ignites 73 ms after impact. The velocity of the vehicle at the moment of ignition is about 7 km/h, the displacement 144 mm. If one additionally incorporates an airbag opening-up time of about 30 ms then a protective effect for passengers would only come about after 100 ms but at that moment the actual accident is long since over. Only a very weak signal flows in system 3's opto-coupler. Whether this would have resulted in proper ignition is a matter of doubt.

The initial deceleration is very minor and the entire deceleration graph is rather atypical for a real-life crash. For comparison, in Fig. 6-13 an experiment with the same initial velocity is depicted, but with greater deceleration in the first milliseconds which are of relevance for the ECU. This deceleration signal corresponds more closely to that of a front section structure. Here all devices release earlier and thus in good time.

Test 387 Test 391

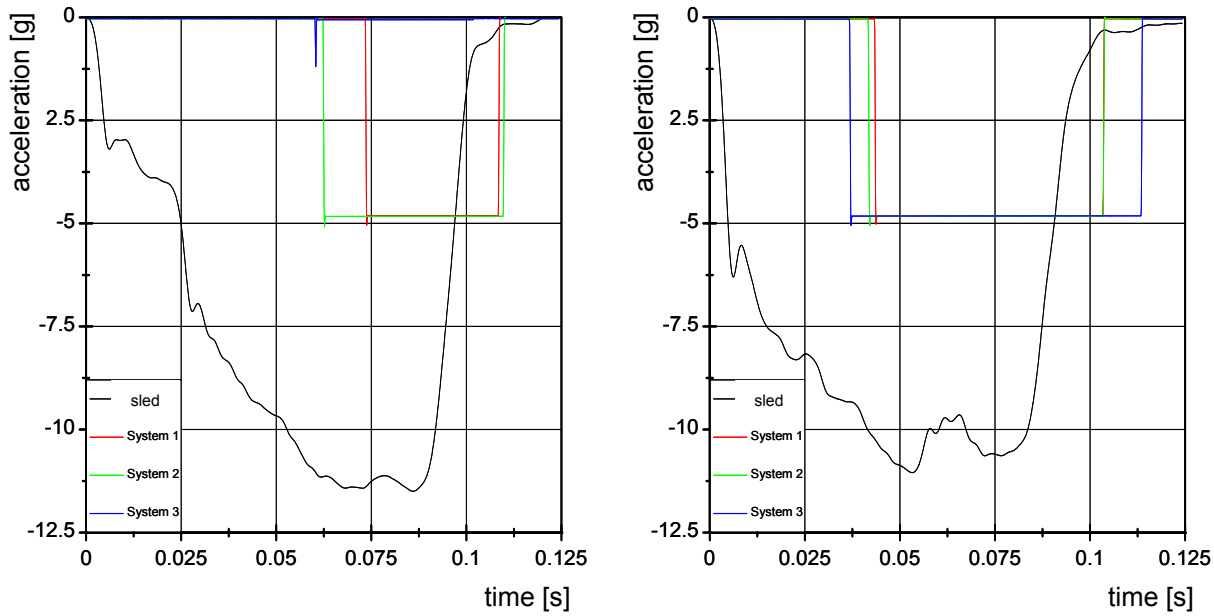


Fig. 6-13: Characteristic Signal Test 387 and 391

<u>Experiment 384</u>:

Here the 300E system does not ignite (by contrast with those of the S-Class) (cf Fig. 6-3, Fig. 6-5). With this experiment the sled crashes into the tensile sheet brake with a velocity of 20.8 km/h, the latter having a 40 x 40 square frame in the first lane. The graph of velocity change to which the ECUs were subjected in this test was entered in Fig. 6-14 (yellow line). One can recognise the point where the S-Classes ignite (marking). It is extremely early for the systems. Since the E class airbag system generally ignited somewhat sooner it has

probably interpreted this early and very steep rise in change of velocity as an acceleration impulse ("hammer blow") rather than as a real crash with the required airbag ignition.

By way of comparison, a further experiment with a velocity of 20 km/h has been drawn into the diagram (Experiment 398, purple line). It intercepts the characteristic graph somewhat later. Here all systems ignite properly.

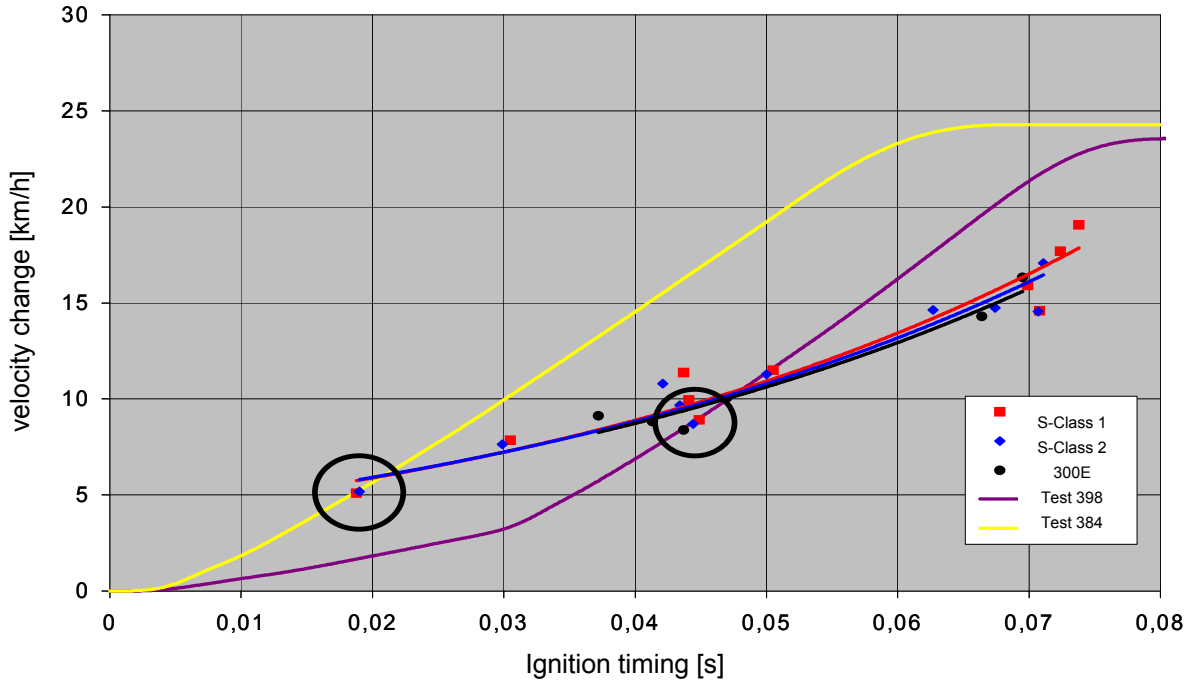


Fig. 6-14: Seperate estimate test 384 and 398

6.2.4 Airbag ignition

In the course of testing, the belonging to it airbag is ignited in the S-Class systems. For this, a steering wheel with a bracket for the airbag module is mounted on the sled. In order to simulate the real-life installation situation, the airbag module is approached via the flat spiral spring of the contact unit. Both modules ignite correctly, the cushions open up without trouble.

In Fig. 6-15 extracts of images are shown which were recorded when the airbags inflated with a digital high-velocity camera (1 shot per millisecond) in experiment 409. The tie data relate to the first visible reaction on the steering wheel module. The airbag inflation requires in both experiments a period of time of about 20 milliseconds. By comparison with the other modules, this is a very short event. The airbag in doing so moves with very high velocity directly in the direction of the passenger. Particularly striking is the ballooning in Image 4 (10 ms). This violent inflation process can entail additional strain on the driver. In the vicinity of the steering wheel ventilation openings can be seen through which smoke is clearly seen to escape in the final image.

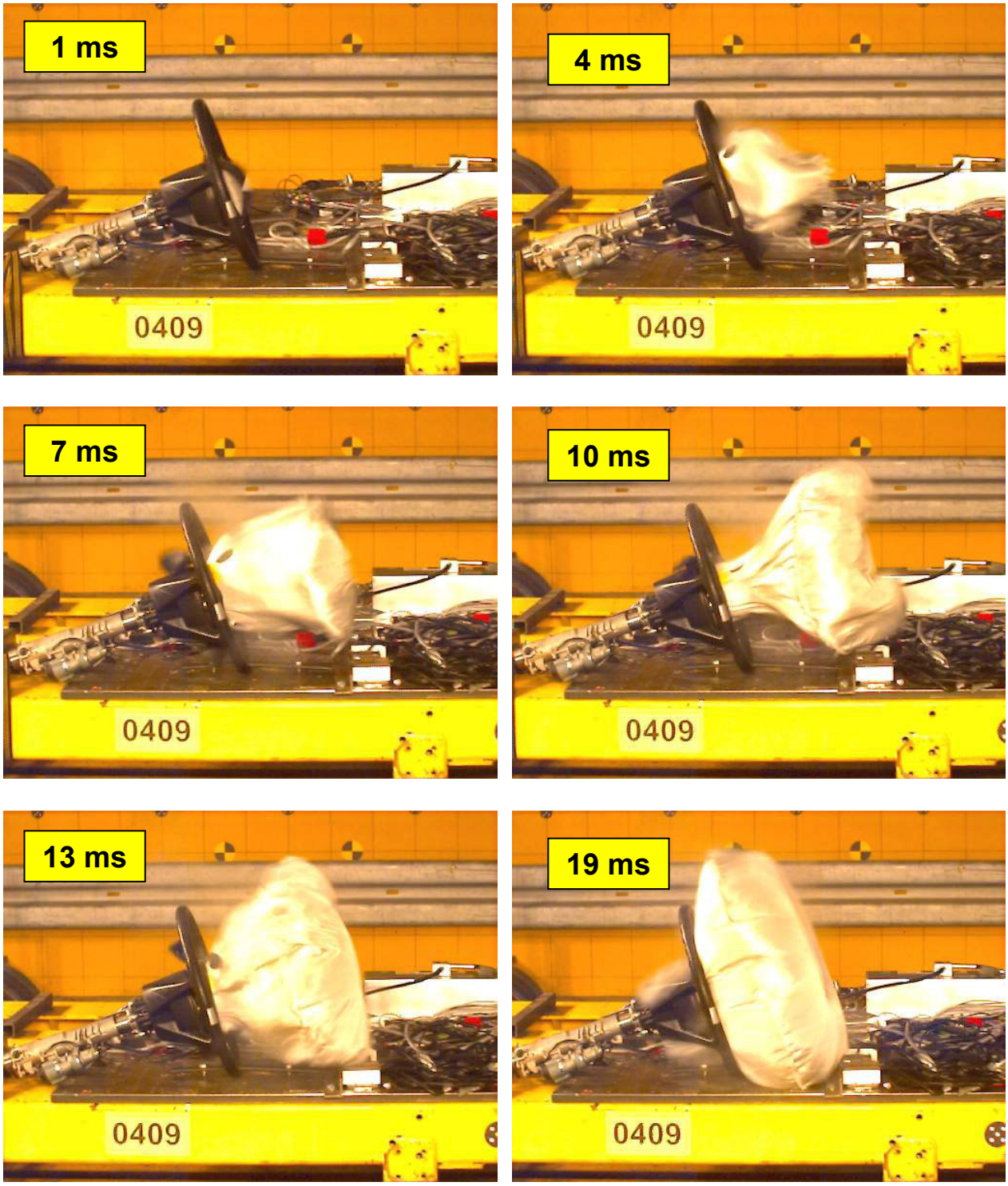


Fig. 6-15: Mercedes-Benz Airbag Inflation

6.3 Test results with the Opel Vectra airbag systems

6.3.1 Change of velocity versus time

The Opel system shows in comparison with the other systems tested principally different release characteristics which are explained below.

Fig. 6-16 shows in a characteristic manner the acceleration graph and the opto-coupler signals of the four Vectra systems in Experiment 437. The sled crashes with a velocity of 30.33 km/h into the tensile sheet brake and deforms a 45 x 45 frame by 220 mm.

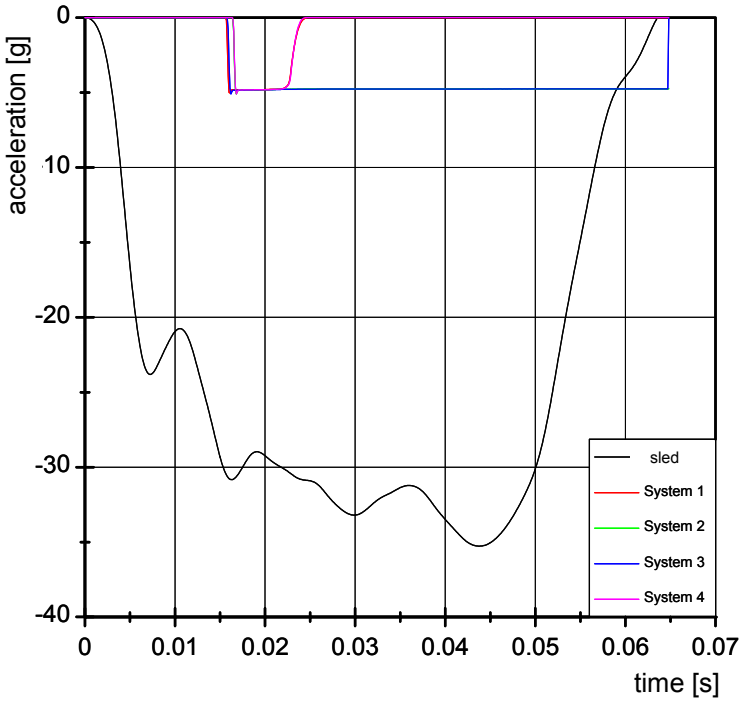


Fig. 6-16: Characteristic Line of Acceleration and Optocoupler Signal (Test 437)

In Fig. 6-17 the velocity change graphs and the moment of ignition of ECU O1 are shown for a sled velocity of 15, 20, 25, 30 and 35 km/h. The trajectories of the graph without airbag release are shown in green in the diagrams. If an ignition impulse occurs, then the line switches from green to red in which case the change of colour marks the moment of ignition. The change in velocity up through the moment of release amounts in each experiment to about 10 km/h, the ECU's ignition moments lying between 12 ms and 33 ms.

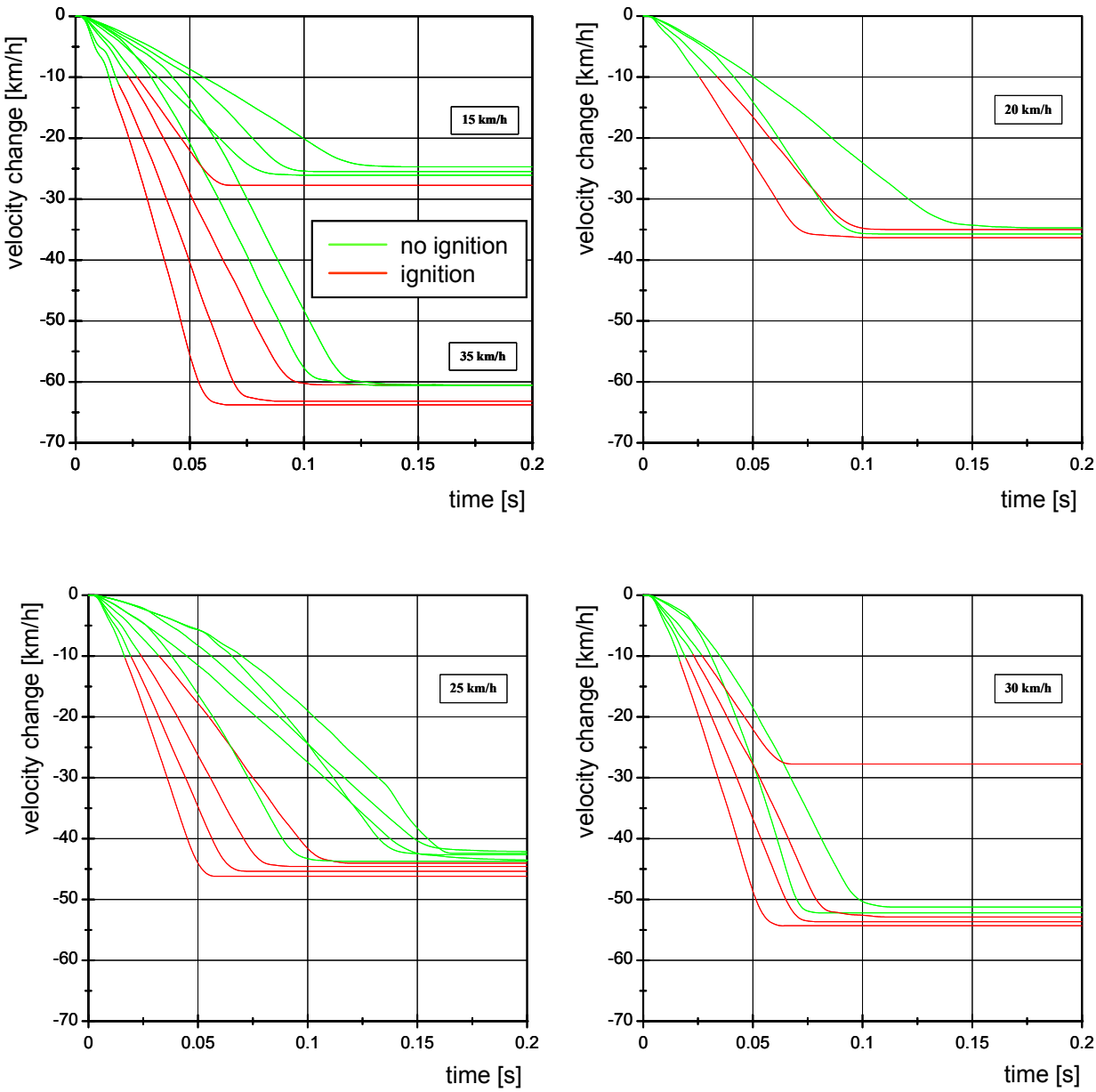


Fig. 6-17: Velocity changes of all tests

On the basis of this illustration, one can assume that the Opel ECU monitors a threshold of about 10 km/h as its release criterion. That threshold must be attained about 35 ms after the first crash acceleration signal to have the airbag ignited.

Fig. 6-18 clarifies that the ignition moments can be depicted approximately by means of a horizontal straight line at a velocity change of 10 km/h. Release thus only occurs as a function of the period of time from the first recorded acceleration signal up through attainment of the threshold value. One recognises that the ignition moments cluster in a smaller region by comparison with the other systems.

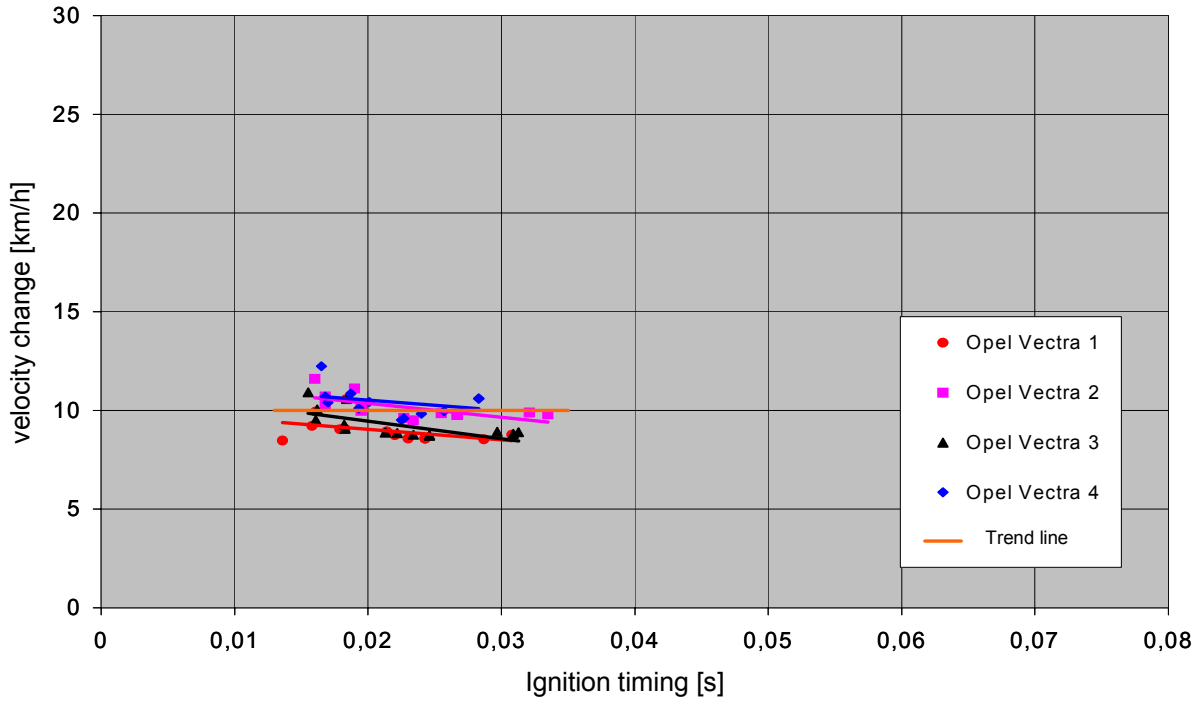


Fig. 6-18: Velocity Change at Ignition Point of Opel Systems

If one looks at the graphs of the change in velocity across the displacement then one arrives at a similar conclusion.

6.3.2 Change of velocity versus displacement

In Fig. 6-19 the changes in velocity across the displacement have been plotted. The experiments with airbag release are painted red while the tests without airbag release are shown as green. In experiments with airbag release the moment of the ECU's ignition is shown as a red marking point. Here too the release threshold can be found at 10 km/h. The displacement lies between 12 mm and 38 mm.

In Fig. 6-20 the release moments are depicted in greater detail and separately for each system. The ignition moments of the airbag ECU are depicted as a function of change in velocity and of the displacement. This illustration shows an accumulation of points in a comparatively small area.

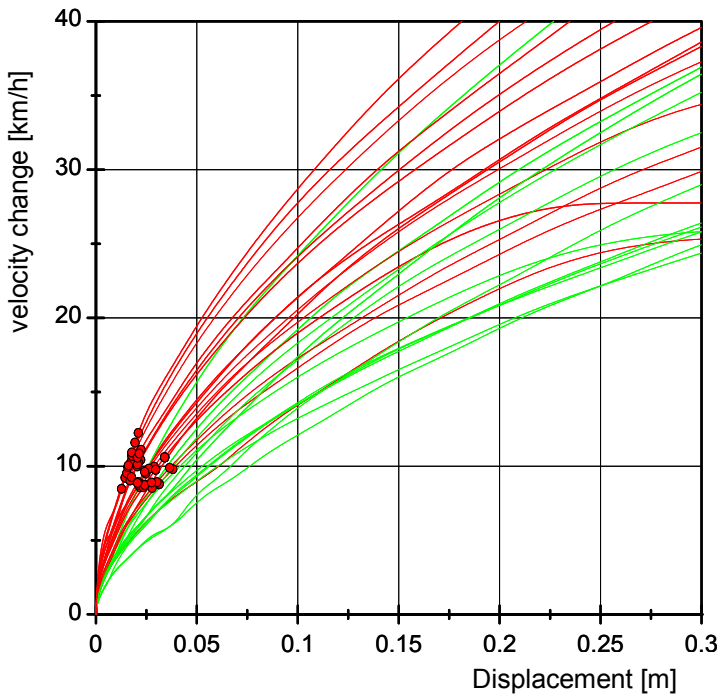


Fig. 6-19: Velocity change versus displacement and ignition points

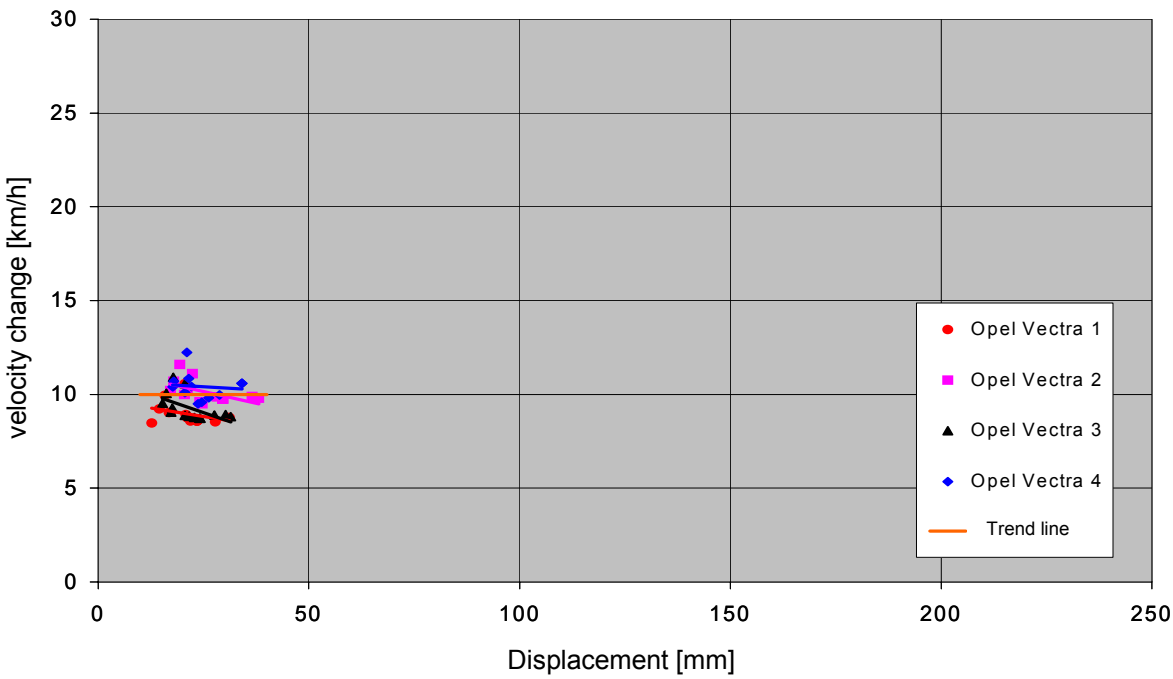


Fig. 6-20: Velocity change versus displacement

6.3.3 Comparison of all Opel systems

What strikes the observer about the results in Fig. 6-20 is that the individual trend lines diverge quite markedly from each other. Only the trend lines of systems O1 through O3 fit each other, as do O2 through O4 as well. The systems O1 and O4 as well as O2 and O3 are of the same construction in regard to their designation number so that the different designation numbers cannot explain the divergences.

In general, the crash situations are nonetheless assessed similarly by the ECUs. Only in experiments 447, 452 and 459 are there some units which do not release. The latter are scrutinised more closely in Fig. 6-21. In addition, with Fig. 6-20 the experiment sled graphs and the relevant ignition moments of the individual units are supplemented.

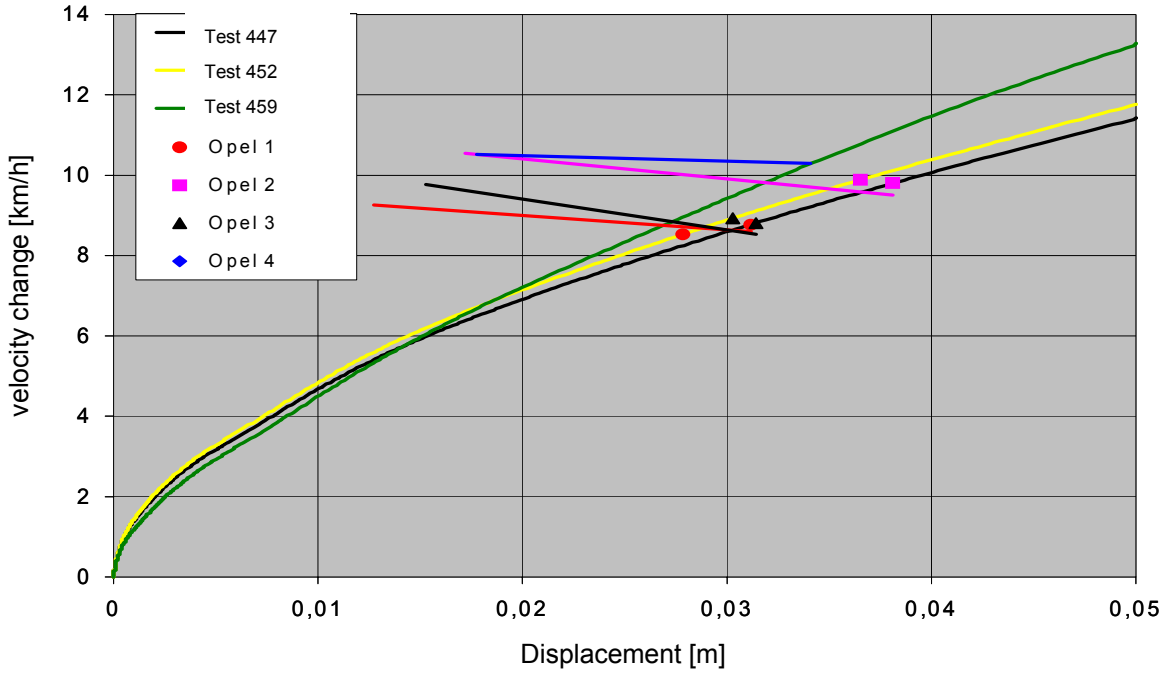


Fig. 6-21: Seperate estimate test 447, 452 and 459

<u>Experiment 447 and Experiment 452</u>:

In both experiments system 4 fails to ignite. The impact velocity in Experiments 447 and 452 is 20 km/h and 25 km/h respectively. Both times a 35-frame was in the first lane so that decelerations occur similarly. Systems 1 through 3 ignite at times of 28.7 ms and 33.8 ms with corresponding velocity changes from 8.7 though 10 km/h. One recognises that the deceleration graph of the sled does not cut the trend line of system 4 in these two experiments. By comparison with other systems it only makes a decision to ignite at higher velocity rates of velocity change. The system has thus made the right decision according to its configuration.

Experiment 459:

O3 is the only system that ignites in Experiment 459. At the ignition moment (31.3 ms) the change in velocity is 9 km/h and it is 10 km/h at 33 ms. If one only considers Fig. 6-21 in this way then the graphs of velocity change and displacement cut all trend lines. In Fig. 6-22 however it becomes clear that the time readings lie at the extreme limit. By comparison, an additional experiment has been entered in the diagram. In Experiment 460 the sled also crashes into the tensile sheet brake at 35 km/h however it is designed softer so that only a flat line results and no ECU finds a necessity of igniting.

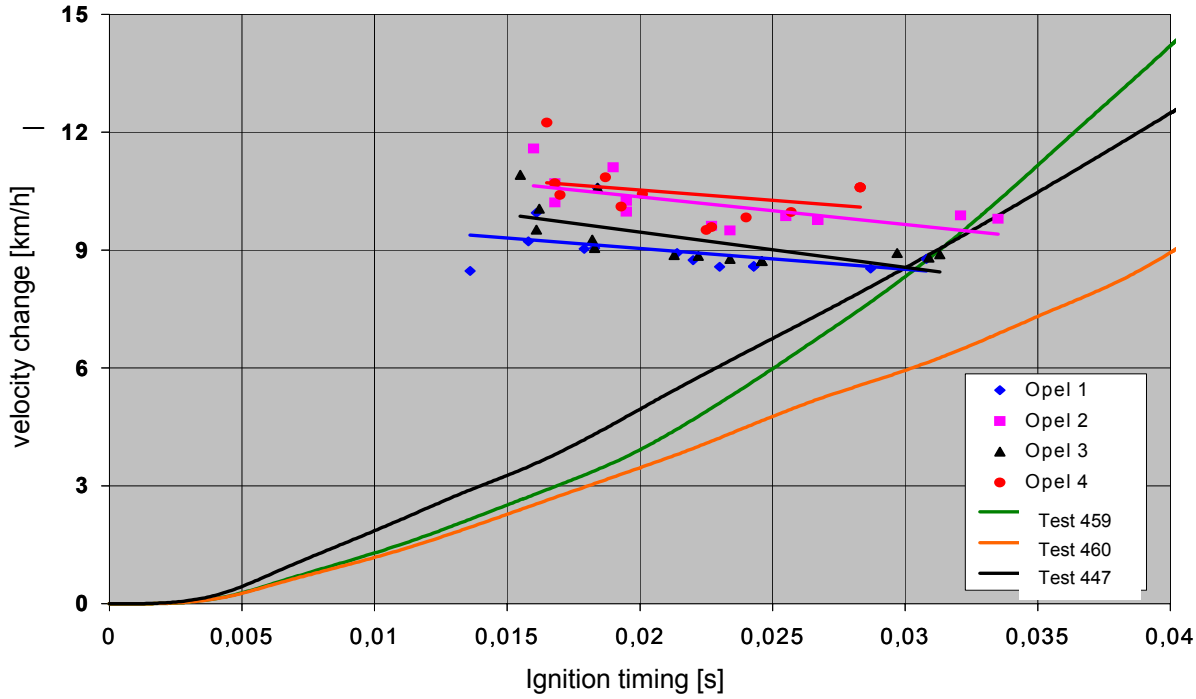


Fig. 6-22: Ignition timings of tests 459 and 460

6.3.4 Airbag ignition

Fig. 6-23 shows by way of excerpt the inflation process of the airbag as recorded with a digital high-velocity camera in Experiment 459. In accordance with the data measured, a first reaction in the airbag module is recognisable after 33 ms. On video data the moment of initial contact is perceivable by means of a flash triggered by contact between the sled block and the bending steel.

The period of time that the four airbags need to inflate is somewhat different in the different experiments. Inflation times of 27, 28, 31 and 38 ms occurred. The Opel airbag inflation time thus lasted the longest of all systems tested. This must be taken into consideration in assessing the early ignition moments compared to the other systems. In pictures the airbag module with the contact unit is not built directly into the steering wheel but is merely attached to it with an adaption. This thus explains the slanted position of the module in relation to the

steering wheel. It is not lifted out of the steering wheel by the ignition action. The information on times relates to the first visible reaction in the airbag.

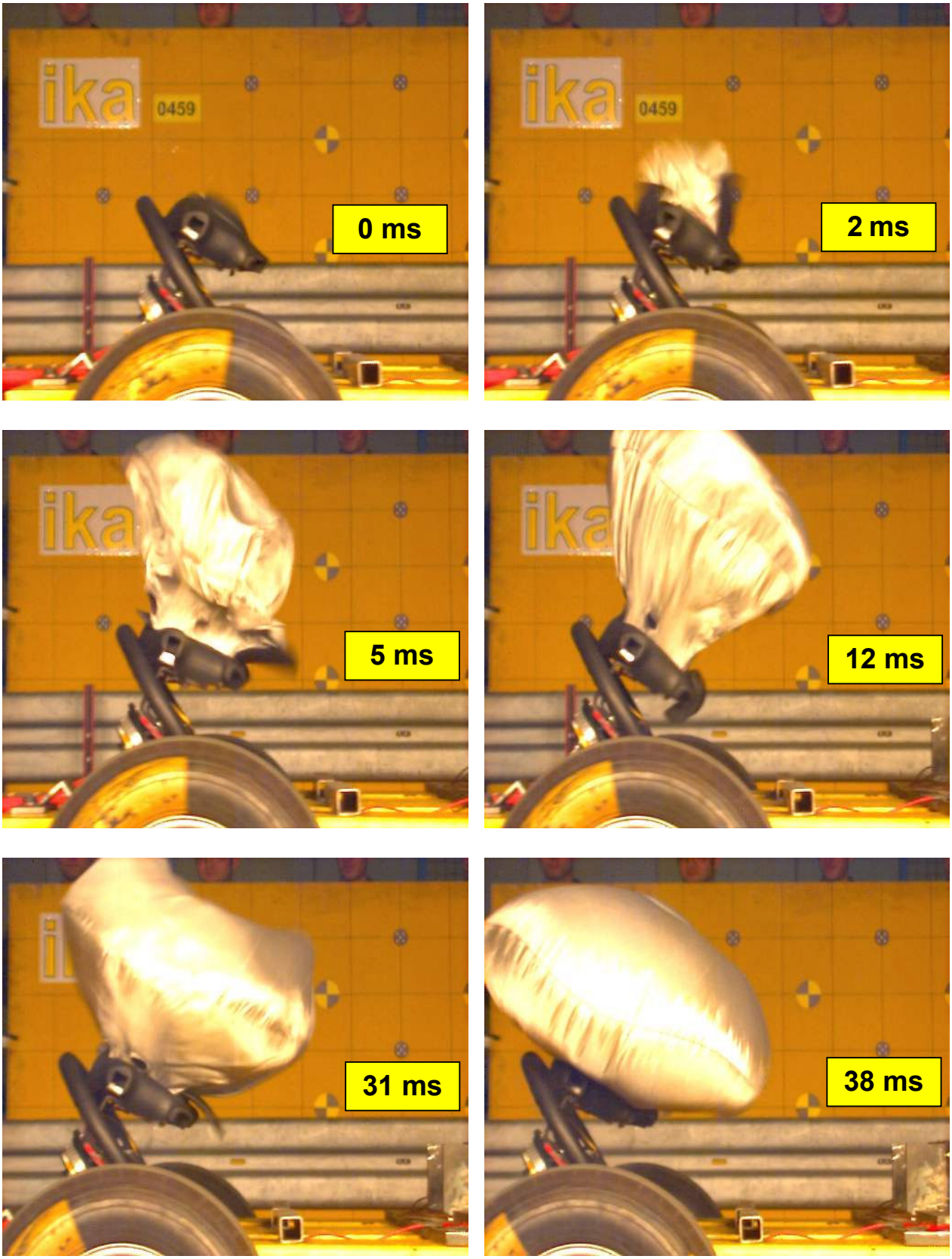


Fig. 6-23: Opel Airbag Inflation

6.4 Test results from the Ford Mondeo airbag system

Since the Ford system was tested in the same experimental series with the Opel systems, the deceleration graph is the same. Release however occurs according to a rule which rather resembles the Mercedes airbag system.

The deceleration signal and the opto-coupler signal of the Mondeo system in Experiment 437 can be seen in Fig. 6-24.

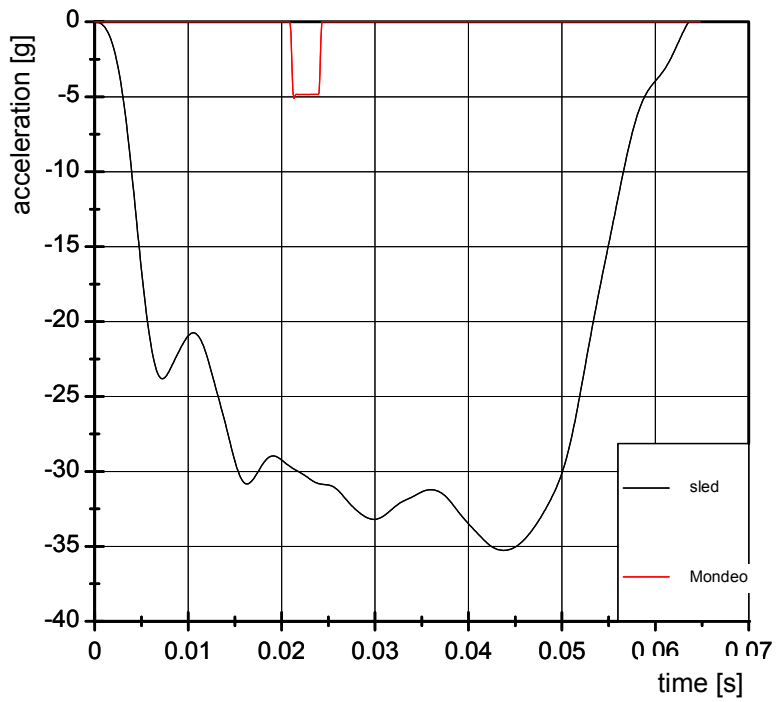


Fig. 6-24: Characteristic Line of Acceleration and Optocoupler Signal (Test 437)

For evaluation of the test results, first of all a look at the velocity graphs will be taken.

6.4.1 Change of velocity versus time

In Fig. 6-25 the velocity change graphs are plotted with the corresponding ignition moments for the Ford Mondeo system. The same graphs emerge as for the Opel systems. The ignition features of the Mondeo airbag system differ markedly nonetheless.

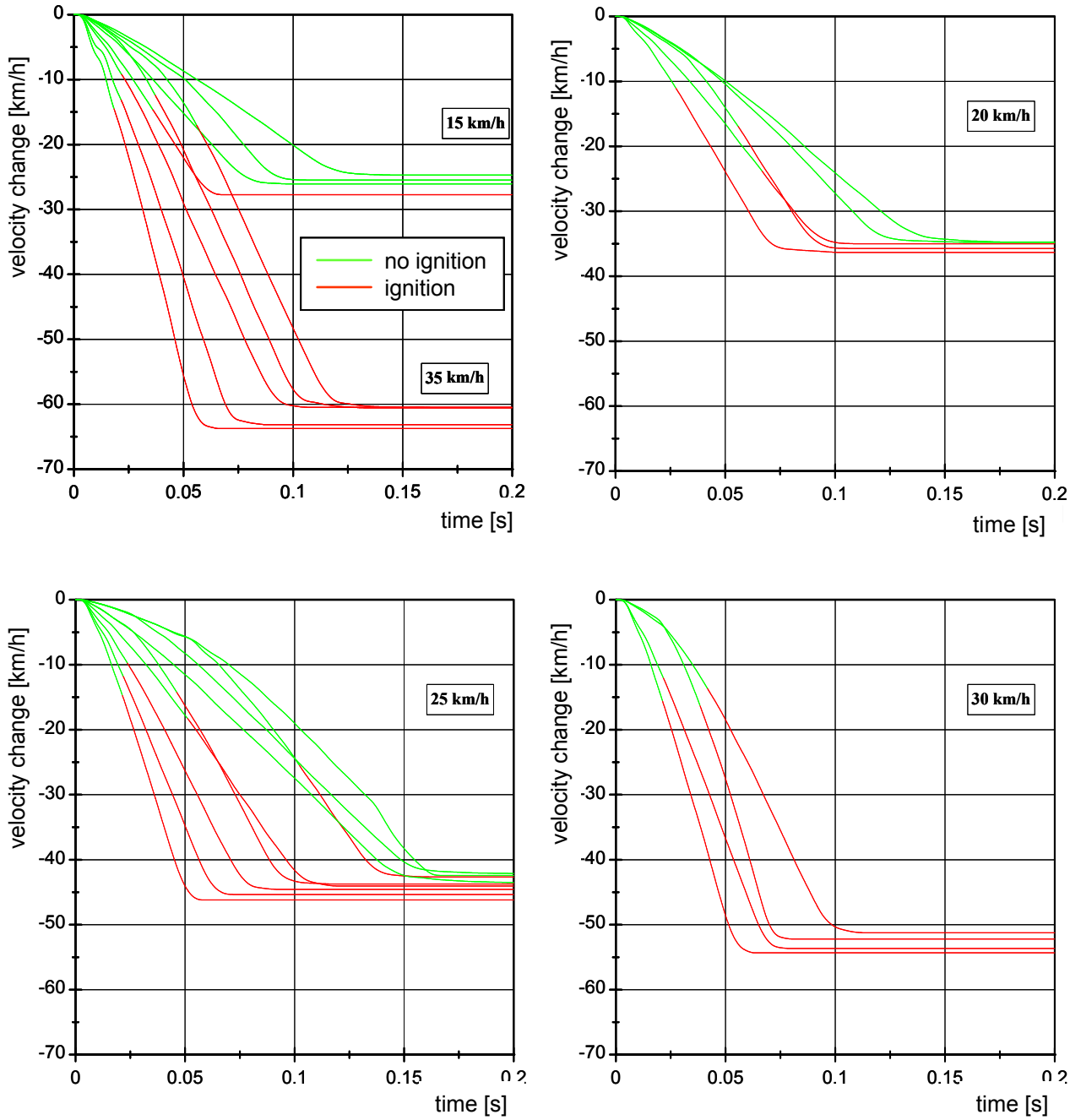


Fig. 6-25: Velocity changes of all tests (Ford Mondeo)

One can already recognise the variable Δv threshold values in these diagrams. They lie in the range from 9 km/h to 24 km/h. The functional connection becomes clearer in Fig. 6-26. The dispersal width of the ignition moment is clearly greater when compared with the Mercedes-Benz systems. The measure of certainty comes to only 0.548 in Fig. 6-26. In absolute terms, this dispersal around the characteristic line is quite large. One reason for this could be the lower sensing rate of ECU recording in the Ford Mondeo system resulting in the fact that exceeding the release threshold is recognised less precisely.

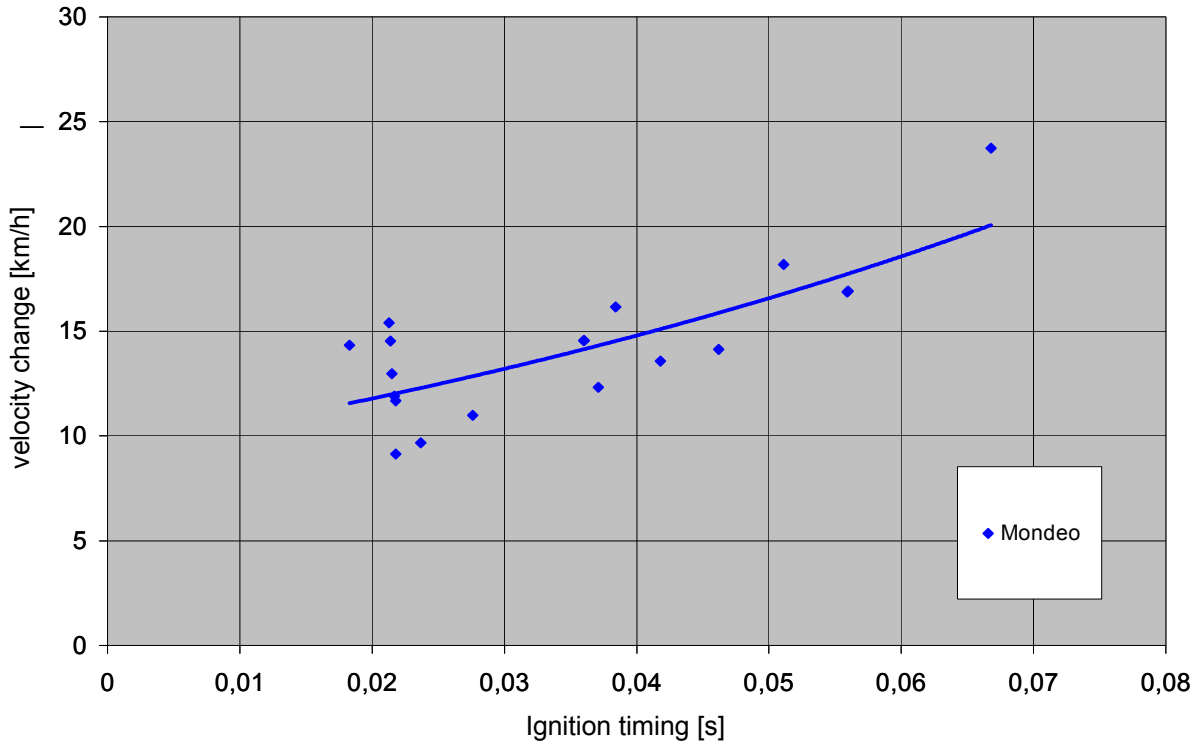


Fig. 6-26: Velocity change at ignition point of the Ford Mondeo system

6.4.2 Change of velocity versus displacement

In Fig. 6-27 the ignition moments are entered in the velocity-displacement diagram. One can see that the Ford ECU releases significantly more frequently than the Opel systems do, for example.

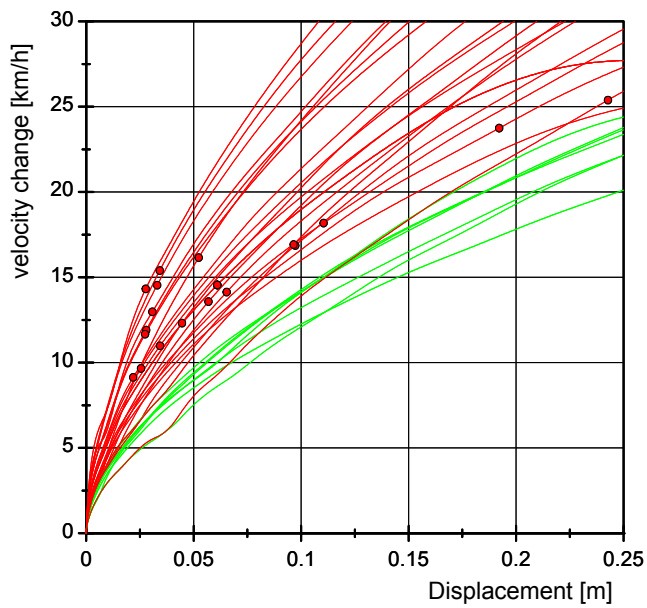


Fig. 6-27: Velocity change versus displacement and ignition points

In Fig. 6-28 it becomes clear that the presentation of the trend line over the displacement clearly shows a lower dispersal (R^2=0.8048). This tendency occurred before in the Mercedes-Benz systems. Obviously the presentation of change in velocity over the displacement is better suited to calculating the release threshold than illustration of the change in velocity versus time.

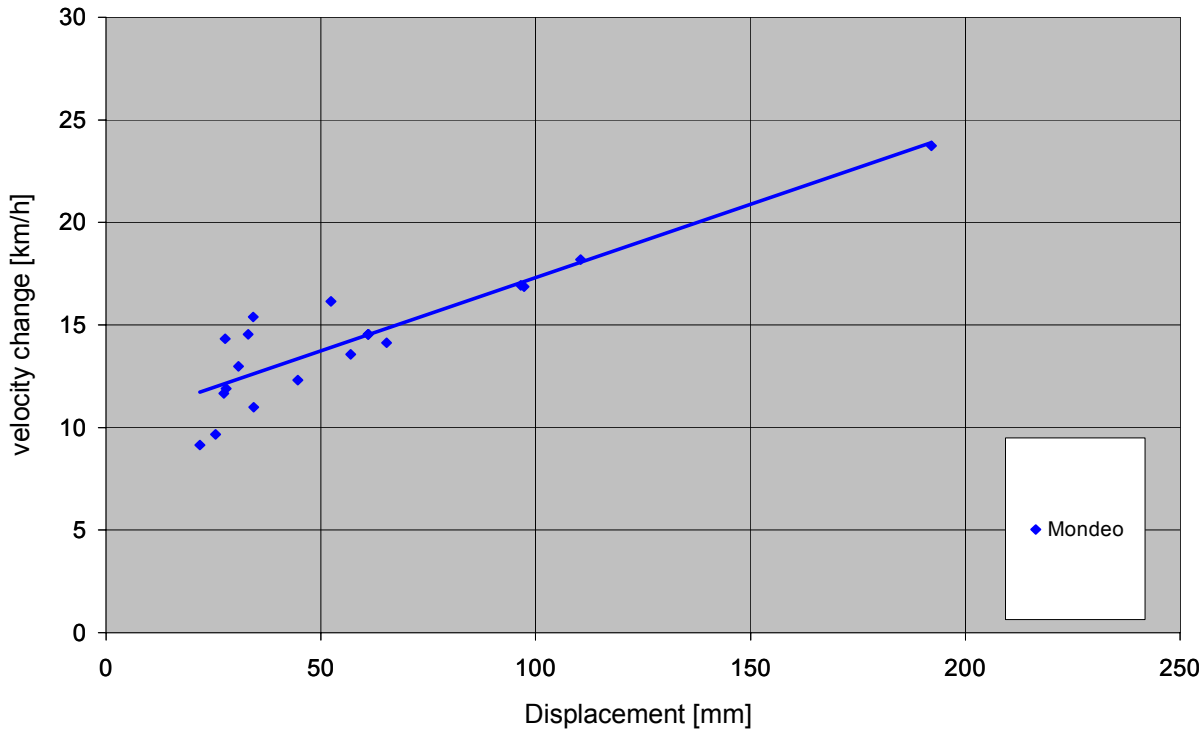


Fig. 6-28: Velocity Change versus displacement with ignition points

6.5 Test results of the Ford Escort airbag systems

Of the three ECUs tested, only two emit signals during the experiments. From the Escort 3 system only in the first preliminary test could an ignition signal be recorded. Since this model constitutes the most up-to-date system it is possible that it has a software block preventing repeated releases. But it is more probably that the ECU's hardware, e.g. the acceleration sensor, was damaged in the crash. The device was tested electrically at the ika. A current flow of 100 mA could be detected. However, it was not possible to obtain a signal via the diagnosis connection. It must therefore be assumed that the device was damaged in the crash. But since it emitted an ignition impulse in a real-life crash situation the airbag would have been able to fulfil its protective function.

The Escort systems show release features similar to those of the Mondeo. Fig. 6-29 depicts first of all the signal graph constituting the basis.

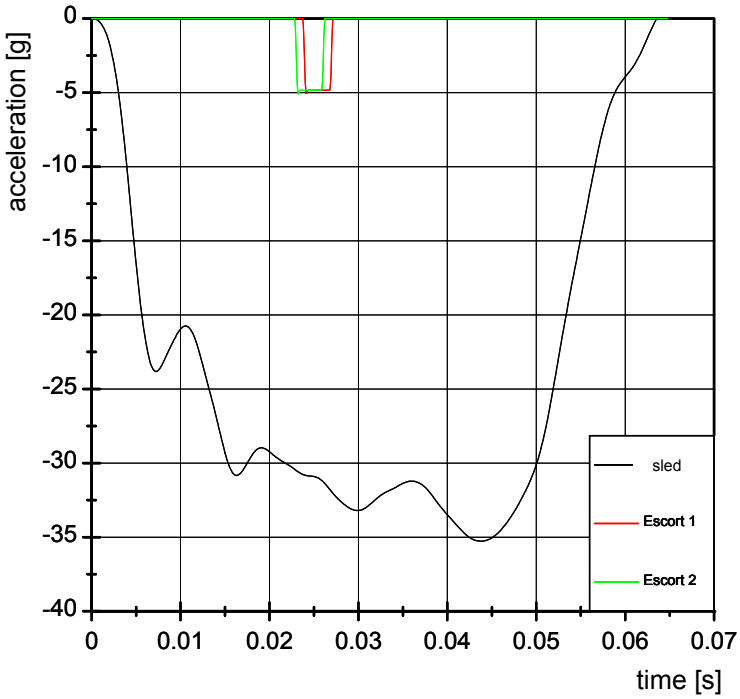


Fig. 6-29: Acceleration characteristic and Opto-coupler signal of test 437

6.5.1 Change of velocity versus time

Based on the same deceleration values, in Fig. 6-30 and Fig. 6-31 the same velocity change graphs result as in the Mondeo or Opel systems. However now the Escort 2 ECU ignition moments are recorded.

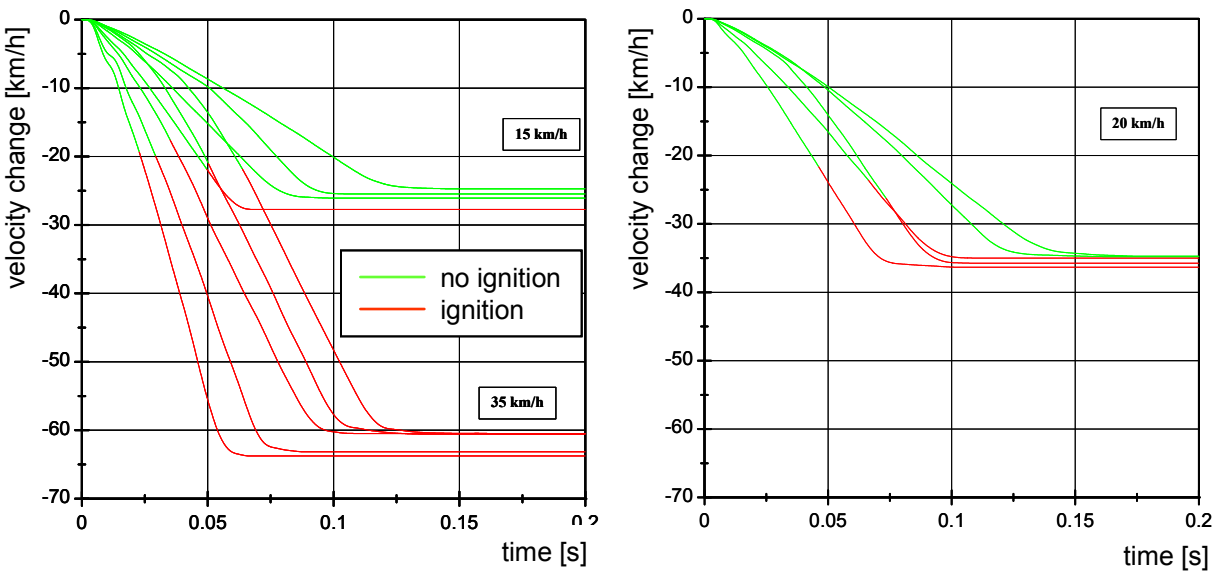


Fig. 6-30: Velocity change and ignition timing for Sled Velocitys of 15, 35 and 20 km/h

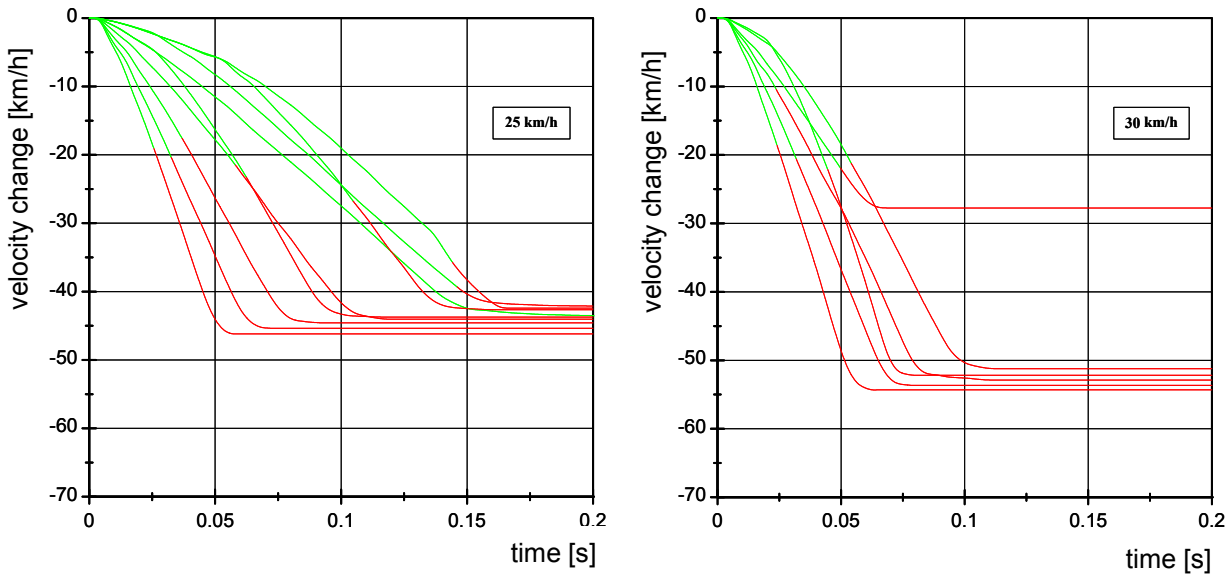


Fig. 6-31: Velocity change and ignition timing for sled velocitys of 25 and 30 km/h

In these diagrams one recognises the variable Δv values. They lie in the range from 10 km/h through 26 km/h. Fig. 6-32 shows this even clearer. The measure of certainty of the exponential trend graphs is R^2=0.701 in Escort system 1 and R^2=0.703 in system 2. Both trend lines run parallel to each other and have an offset of about 1.5 km/h. Still, the two release thresholds can be aggregated into a single trend line (marked in blue) by means of averaging. This trend graph will also be used later in comparing all systems tested.

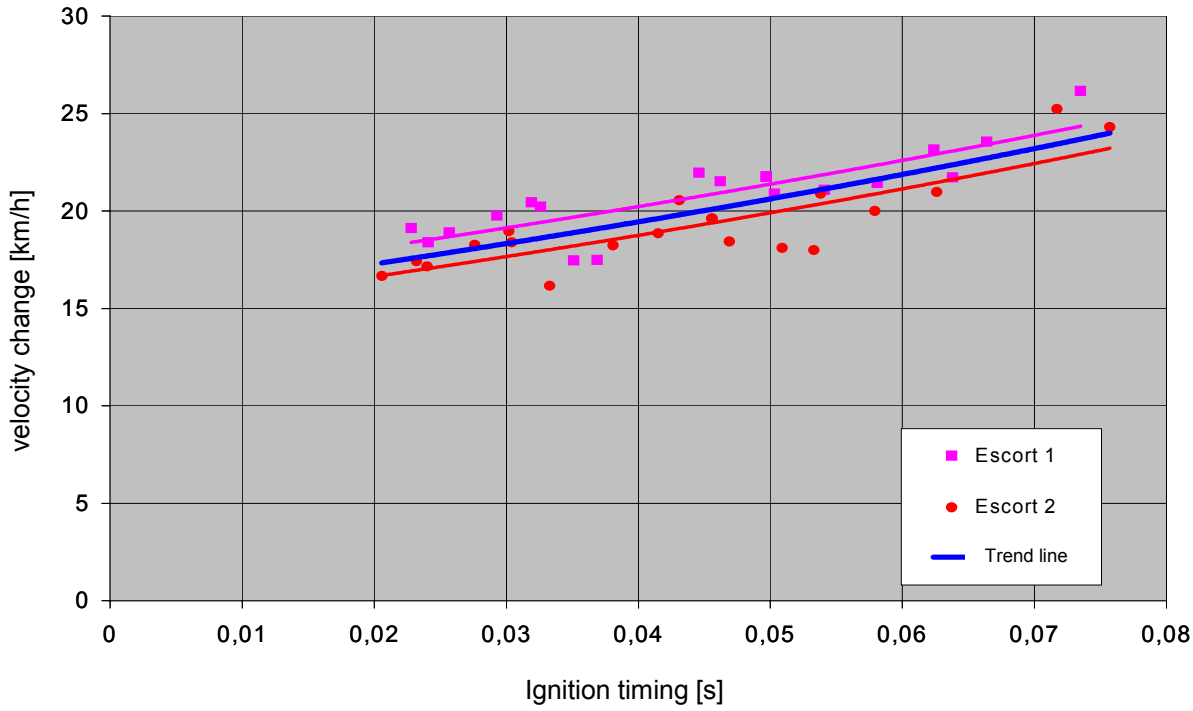


Fig. 6-32: Velocity change of the Ford Escort systems

6.5.2 Change of velocity versus displacement

Fig. 6-33 shows all velocity change graphs of this test series with the corresponding ignition moments of the two Escort ECUs. With the red graphs, airbag release occurred, the green lines characterise experiments without ignition impulse. A clear-cut separation of the two areas can be seen. Particularly interesting are the two lowest lines. In one case the tensile sheet brake only has one frame in the first lane. This does not result in release. In the other case, the second lane is occupied as well. One clearly sees the buckling-off shape of the line. In this way the sled is more strongly decelerated and the sensor supplies a higher deceleration signal which nonetheless ultimately results in a positive decision to ignite.

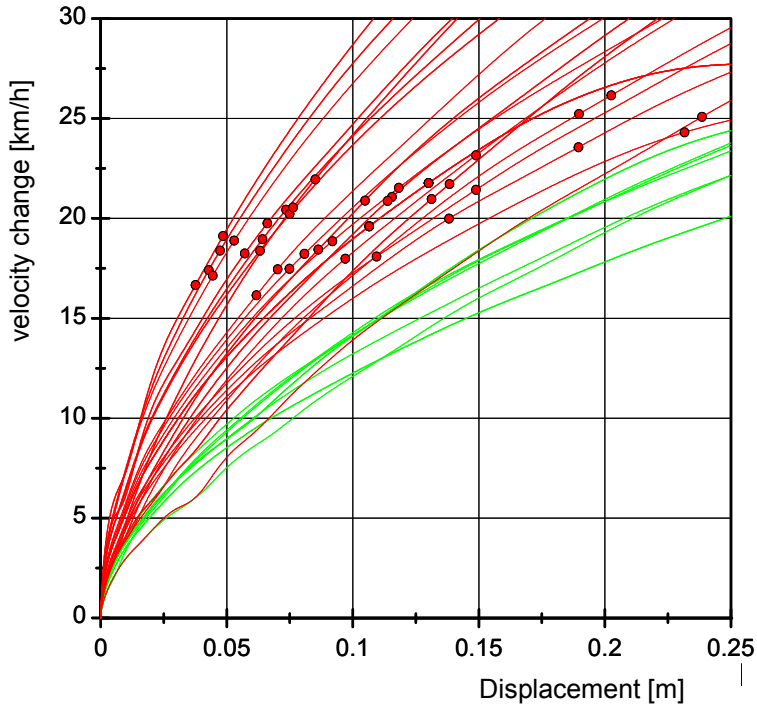


Fig. 6-33: Velocity change versus displacement and ignition timings

In Fig. 6-34 the ignition impulses for the two ECUs are entered separately. Here too both trend lines run exactly parallel to each other. The difference between the two lines is 1.27 km/h. This divergence is probably explainable by manufacturing related tolerances. Moreover, a clear dispersal of the Escort systems can be observed. The measure of certainty in the presentation of velocity change over the displacement itself for Escort system 1 is only R^2=0.7819 and for Escort system 2 only R^2=0.7934. Similar to the Ford Mondeo system, it must be presumed that a lower sample rate of sensor data processing by the ECUs causes this relatively high dispersal. The two trend lines computed have here too been aggregated into a collective system trend line.

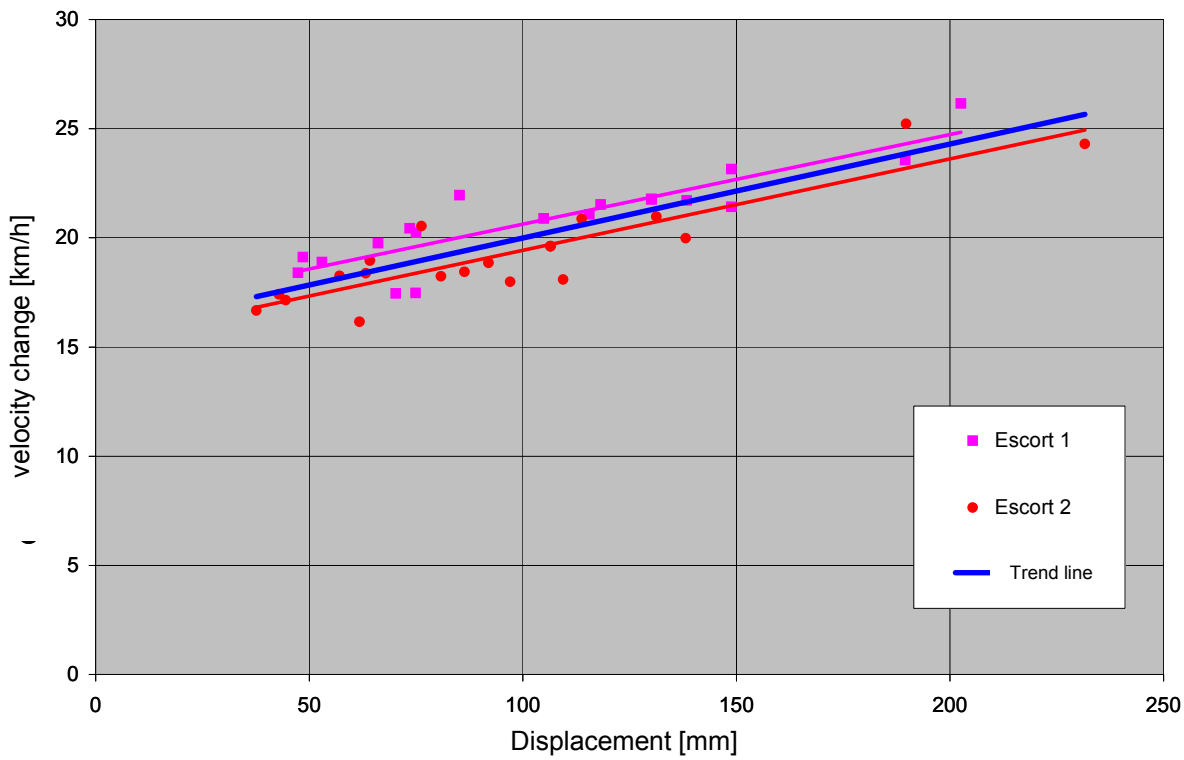


Fig. 6-34: Velocity change versus displacement with ignition points

6.5.3 Comparison of the Ford Escort and Ford Mondeo systems

The airbag device of the Mondeo differs from the Escort systems both in the rise of the compensation degrees as well as in the required change in velocity.

In Fig. 6-35 for a direct comparison all ignition moments of the intact ECUs have been entered. With one sole, exception, the ECUs assess the deceleration graphs identically and always make the same ignition decisions but to some extent at strongly differing times. The Mondeo system on average ignites 8 ms earlier than the Escort systems.

Experiment 444:

Only in Experiment 444 does Escort system 2 ignite. In order to be able to assess this measurement result, sled deceleration in Fig. 6-35 has additionally been recorded.

From this one recognises that the two non-igniting systems have made the correct decision since the velocity change displacement graph does not intercept the trend line. But it comes so close to the trend line of the Escort 2 system that the latter system makes a positive decision.

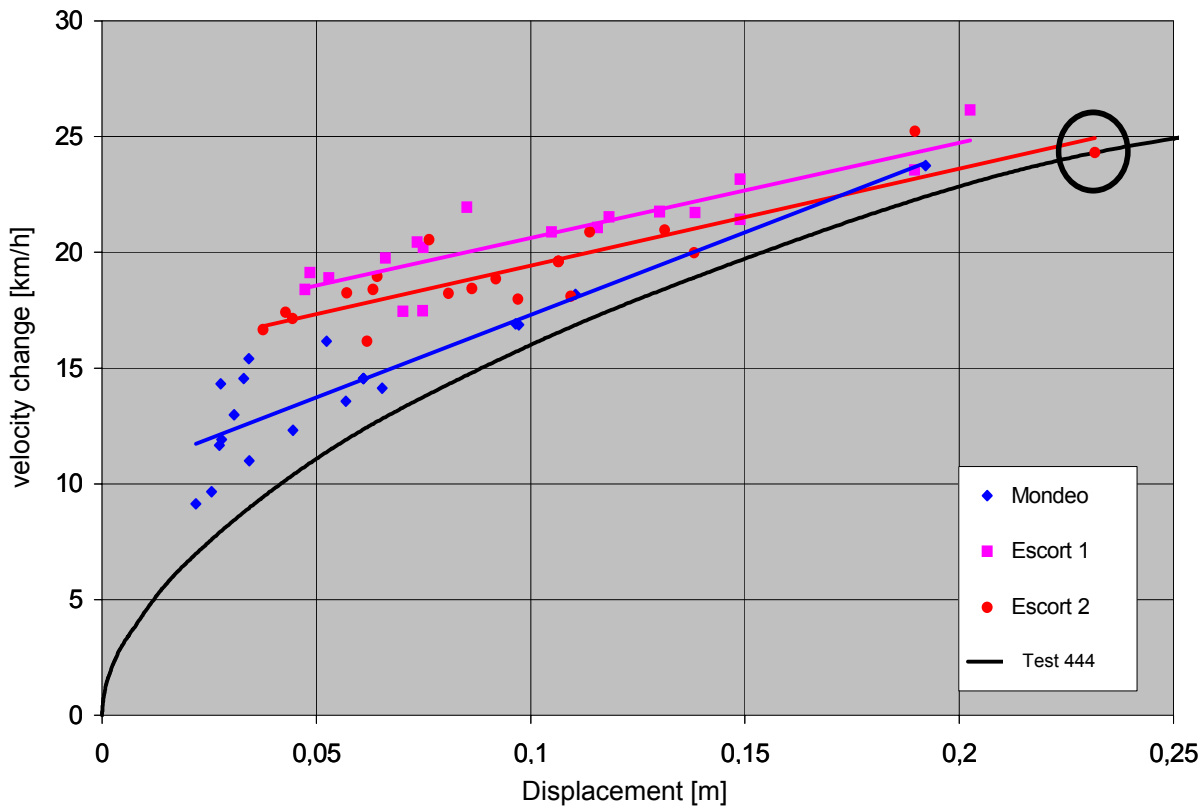


Fig. 6-35: Comparison of the Ford systems (test 444)

6.5.4 Airbag ignition

Fig. 6-36 shows images of airbag inflation in Experiment 450. The airbag needs only 24 ms to complete inflation, with the other three airbag ignitions the inflation action required 27 ms and twice 25 ms. By comparison with this, the Opel cushions needed on average 31 ms. This time advantage of the Ford systems is explainable by the lower inflation volume of the Euro airbag of about 35 litres.

One can see that, as the Ford airbag inflates, it does not move directly towards the passengers but rather “opens out.” This is achieved with a special inflation technology. In it, the strains (e.g. punch-out effect) put on the passenger by inflation are considerably reduced.

Since no original Ford steering wheel was used as a holder for the airbag and contact unit, the airbag module has to be fastened with an adapter resulting in its being set back somewhat from the steering wheel used.

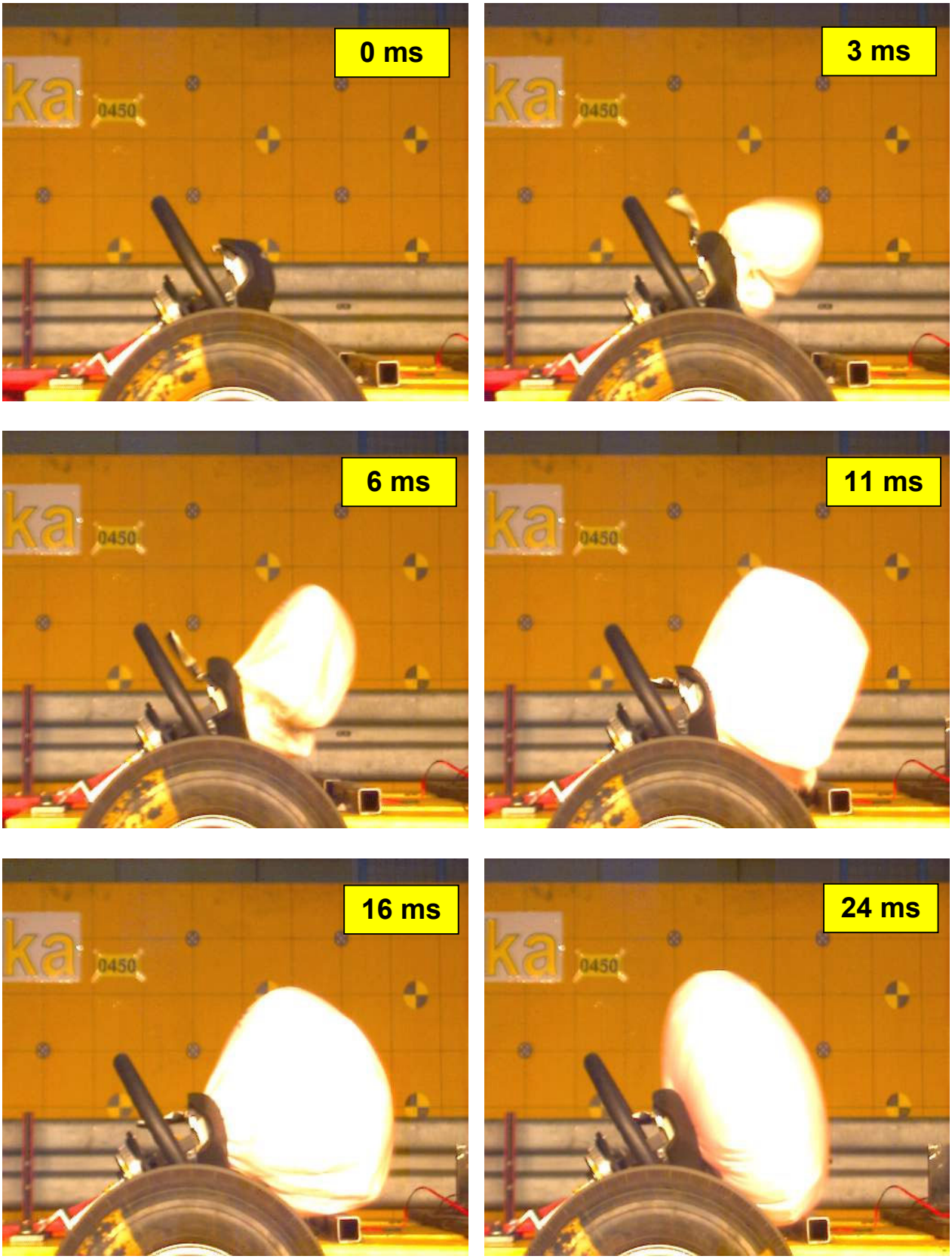


Fig. 6-36: Airbag Inflation Ford Escort

6.6 Test results of the Ford Ka airbag system

In Fig. 6-37 the acceleration graph and the ignition impulse of the ECU for the driver and passenger airbag is shown during a 20 km/h crash against the tensile sheet brake for the Ford Ka airbag system.

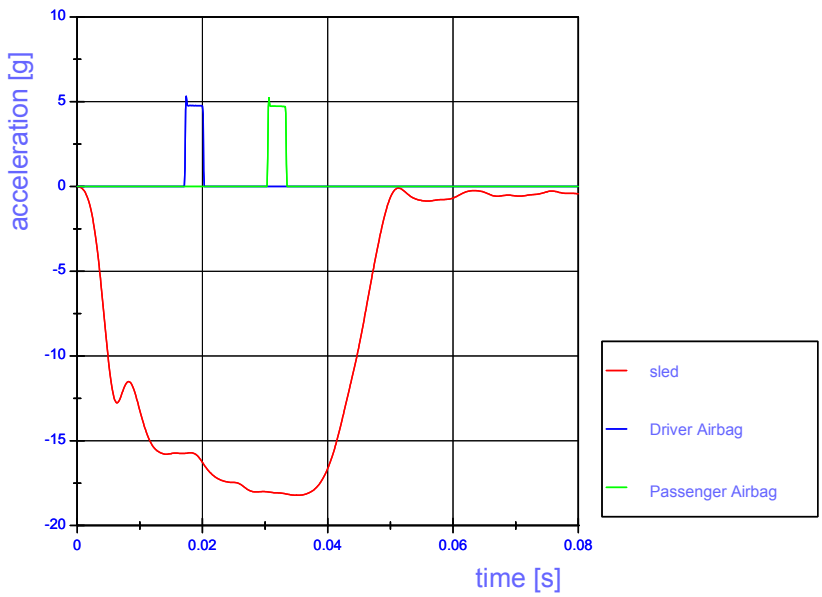


Fig. 6-37: Acceleration Characteristic and Control Unit Ignition Pulses for Driver and Passenger Airbag (20 km/h Impact with Deceleration Device)

Fig. 6-37 shows that the release moment of the ECU's ignition impulse lies around 16 ms for the driver airbag. Acceleration at this time is -16.6 g. The entire deceleration lasts 52 ms. The signal duration of the ECU's impulse for the driver and passenger airbag is in both cases 3 ms and is constant in all experiments in this test series. The driver airbag's ignition impulse begins in all experiments 13 ms after the driver airbag impulse. Further experiment evaluation for this reason only attaches importance to the driver airbag ignition impulse. The ECU of the Ford airbag system was tested after an airbag ignition in a Ford workshop with the aid of a diagnostic tester. Readout of the error memory indicated that a successful airbag ignition had occurred.

6.6.1 Change of velocity versus time

In the next few illustrations the velocity change graphs for different sled velocitys are shown. In Fig. 6-38 the velocity change graphs and the ignition moments of the driver airbag are shown for a sled velocity of from 15 km/h to 20 km/h. The change in velocity up through the moment of release is in each case greater than 6.5 km/h and the ignition moments of the driver airbag lie between 17 and 47 ms.

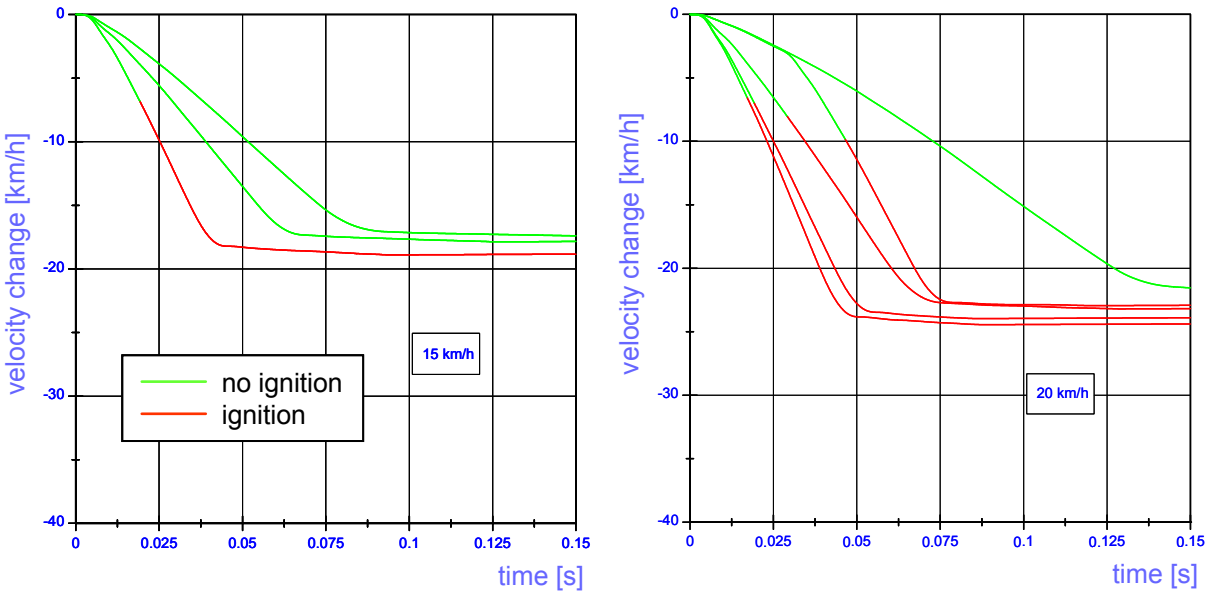


Fig. 6-38: Velocity change and ignition points for sled velocitys of 15 km/h and 20 km/h

In Fig. 6-39 the velocity change graphs and ignition moments of the driver airbag for a sled velocity of 25 km/h and 30 km/h are shown. The change of velocity up through the moment of release is in each case greater than 6.5 km/h and the ignition moments of the driver airbag lie between 16 ms and 40 ms.

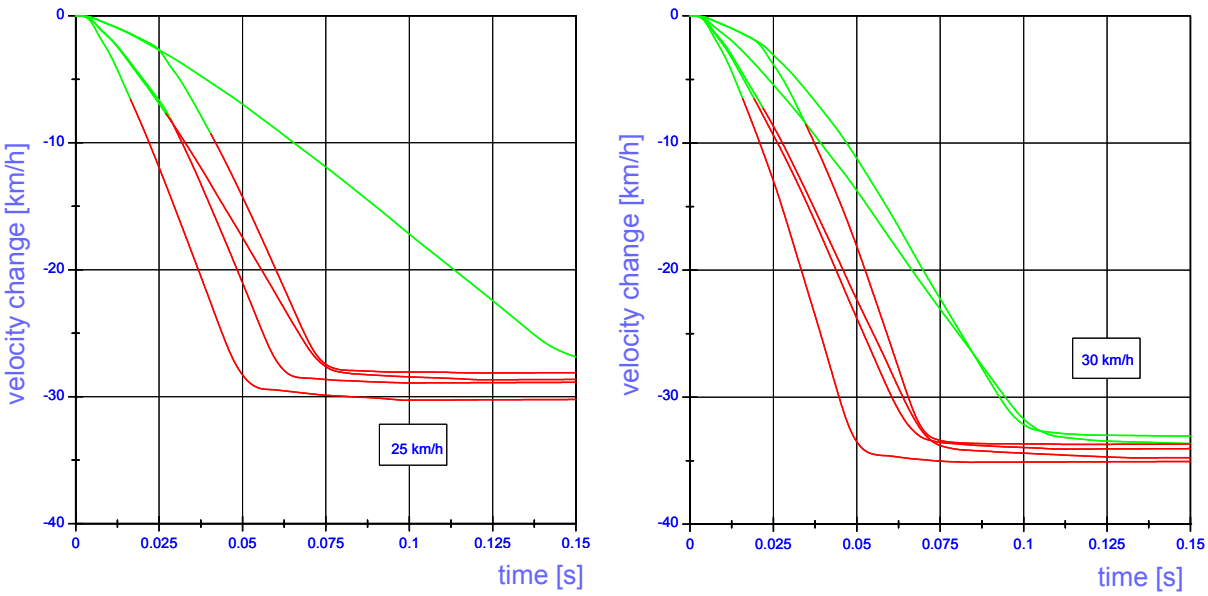


Fig. 6-39: Velocity change and ignition points for sled velocitys of 25 km/h and 30 km/h

In Fig. 6-40 the velocity change graphs and the ignition moments of the driver airbag for a sled velocity of 35 km/h are shown. The change in velocity up through the moment of release is in each case greater than 6.5 km/h and the ignition moments of the driver airbag lie between 18 ms and 32 ms.

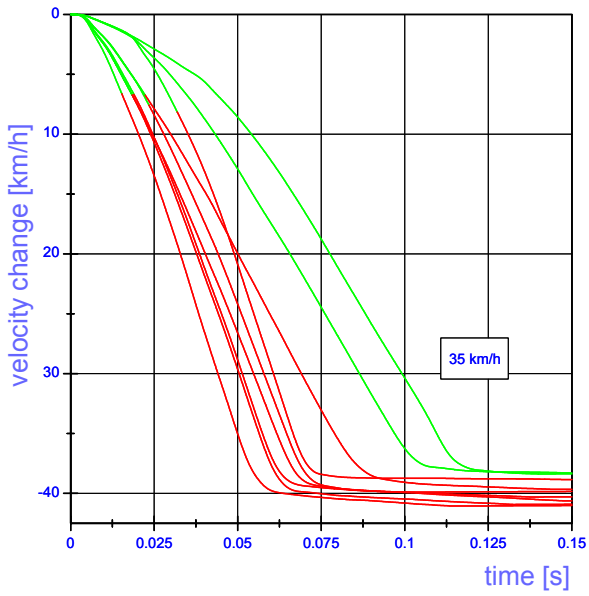


Fig. 6-40: Velocity change and ignition points for sled velocitys of 35 km/h

The illustrations show that here too an early release of the airbag results with a high change of velocity equivalent to a steep rise in the graph. With lesser upward slopes the release moment shifts in the direction of longer periods. Fig. 6-41 shows the picture of the change in velocity at the ignition moment over time for all sled tests carried out.

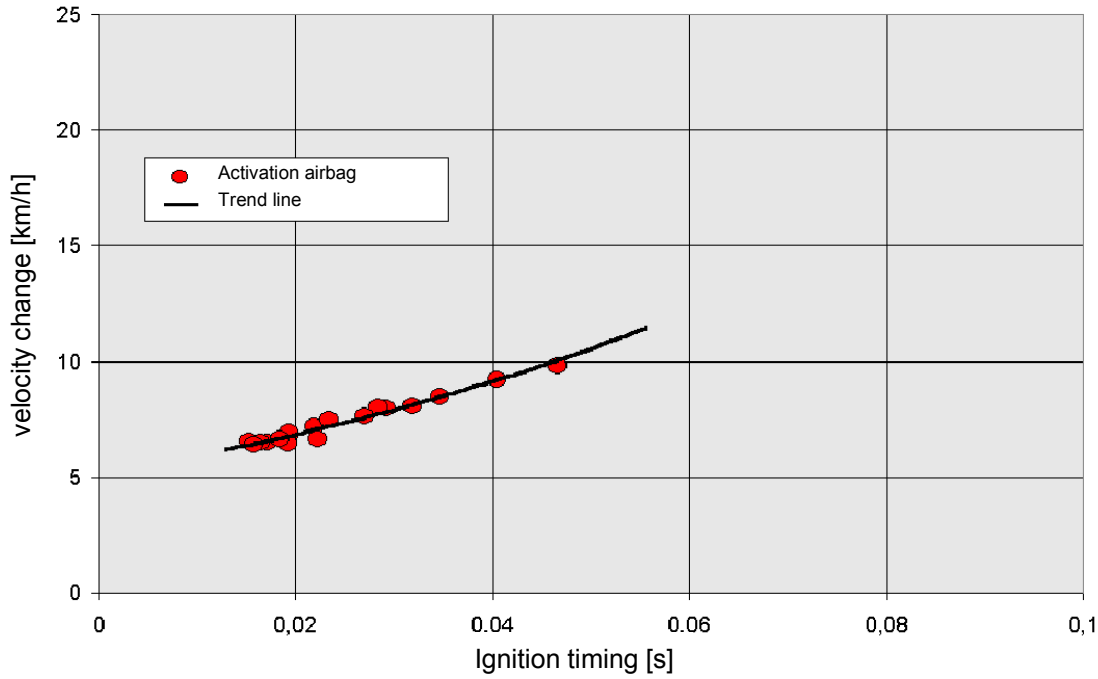


Fig. 6-41: Velocity change at ignition points

A release threshold can be shown for this system as well and again it is an exponential graph (measure of certainty R^2=0.959) marking off a clear border between experiments with airbag

release and those without release. The ignition moment of most airbag releases lies in the range between 15 ms and 30 ms. In this release range of the driver airbag lies the change in velocity at the moment of ignition between 6.5 km/h and 8 km/h.

In all experiments the release threshold is correctly recognised. With the form of presentation of change in velocity versus the displacement this will be underscored all the more in the course of this chapter.

6.6.2 Change of velocity versus displacement

In the left section in Fig. 6-42 the change in velocity versus the displacement for different sled velocitys is presented. In the right section of the illustration the change in velocity versus the displacement is shown in a characteristic manner for a sled velocity of 25 km/h. In both sections of the illustration a separation of areas with an airbag release and one without are shown. Separation of the ranges becomes more distinct if one looks at the graph graphs of the ECU's ignition moment.

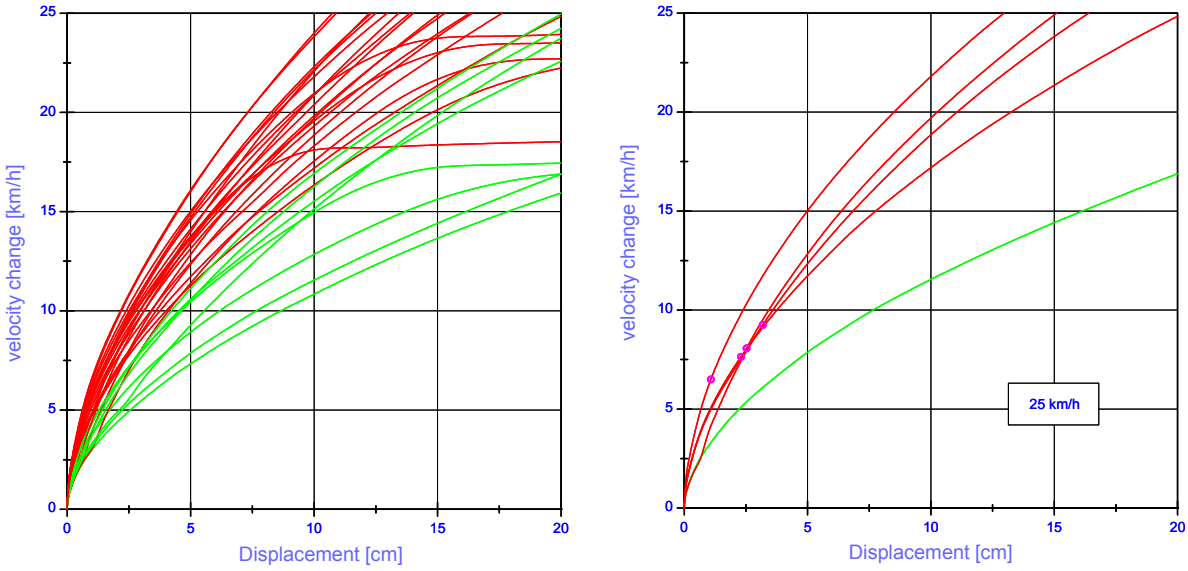


Fig. 6-42: Velocity change versus displacement with ignition points for various sled velocitys (left) and for one specific velocity of 25 km/h (right)

In Fig. 6-43 the ignition moments of the airbag ECU are shown as a function of change in velocity and displacement. In this illustration a linear association is shown between the moment as a function of change in velocity and the displacement (regression coefficient R^2=0.988). In most experiments the ignition impulse was triggered up to a change in velocity of 8 km/h and a displacement of 25 mm.

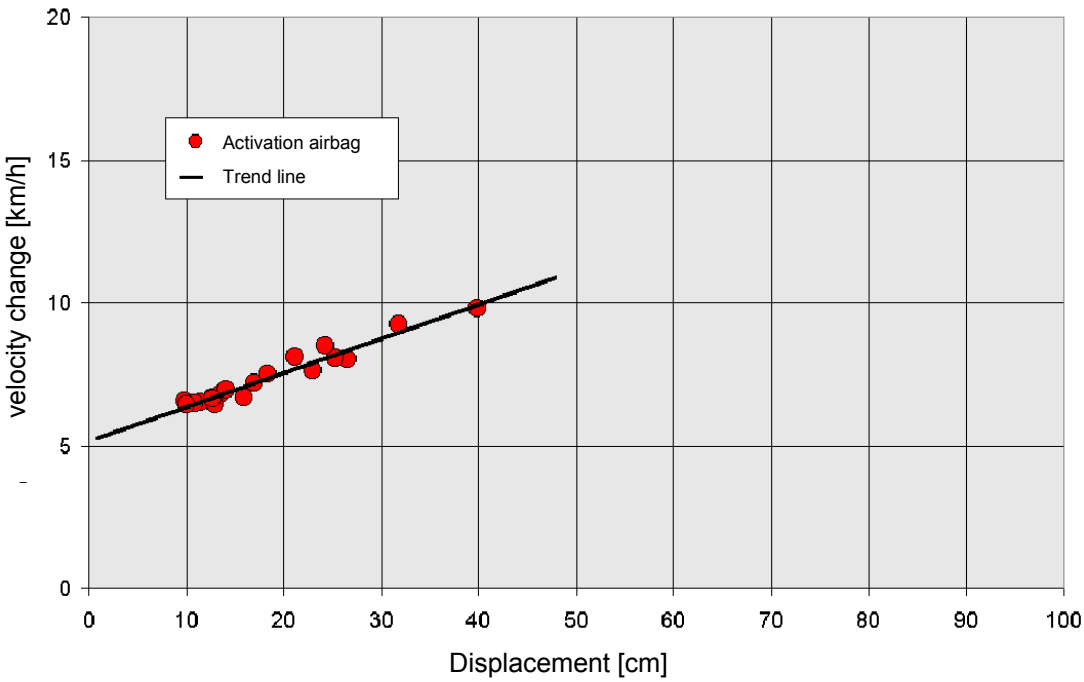


Fig. 6-43: Velocity Change versus displacement with ignition points

6.7 Test results of the Fiat Multipla airbag system

In Fig. 6-44 the acceleration graph and the ignition impulse of the driver and passenger airbag ECU are shown during a 20 km/h crash against the tensile sheet brake for the Fiat Multipla airbag system.

The illustration shows that the release moment of the ECU's ignition impulse lies around 21 ms for the driver airbag. Acceleration at this moment is -16.4 g. The entire deceleration process lasts 52 ms. The signal duration of the ECU impulse for the driver airbag is 69 ms and for the passenger airbag 29 ms and is constant throughout all experiments in the same test series. The ignition impulse of the passenger airbag begins in all experiments 10 ms after the driver airbag impulse. For this reason further evaluation of the experiment will only deal with the driver airbag's ignition impulse.

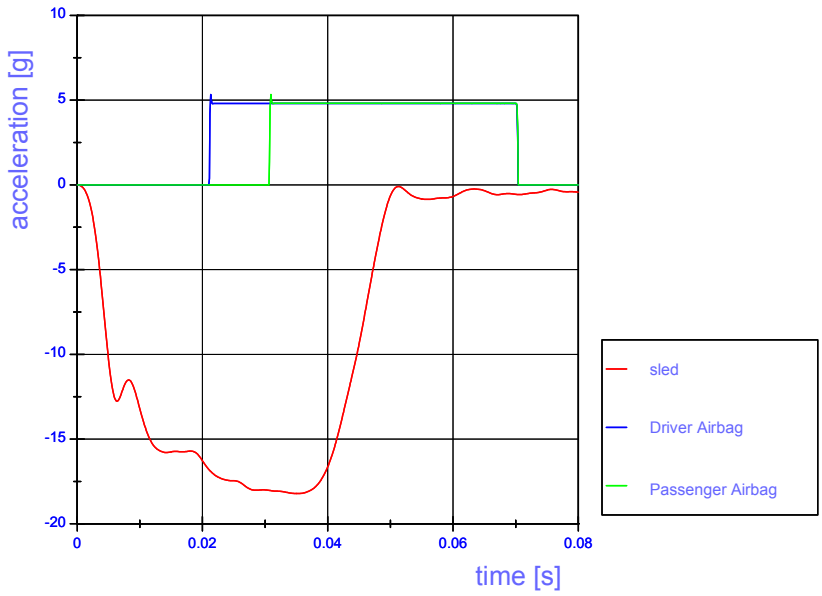


Fig. 6-44: Acceleration Characteristic and ignition timing for driver and passenger airbag in a 20 km/h impact (Fiat Multipla)

After the first airbag ignition the Fiat Multipla ECU was sent for checking to the manufacturer Siemens. There the fault memory was read out with the aid of a special diagnostic tester which was in a position to obtain data from the data memory which went beyond the possibilities of a normal diagnostic tester. Such data allows for a complete analysis of the crash graph with the ignition moment. A readout of the fault memory showed that there had been a successful airbag ignition.

Subsequent to this, Siemens made such an extended Fiat/Lancia diagnostic tester available to ika for the duration of experiments in order to analyse the fault memory so that after each crash the error memory of the airbag system could be read out. During the test series no error reports were lodged with the ECU's data memory.

6.7.1 Change of velocity versus time

In the next few illustrations the velocity change graphs for different sled velocitys are shown. In Fig. 6-45 the velocity change graphs and the ignition moments of the driver airbag are shown for sled velocitys of 15 km/h and 20 km/h. The change in velocity up through the moment of release is 8.5 km/h and the ignition moment of the driver airbag is 21 ms.

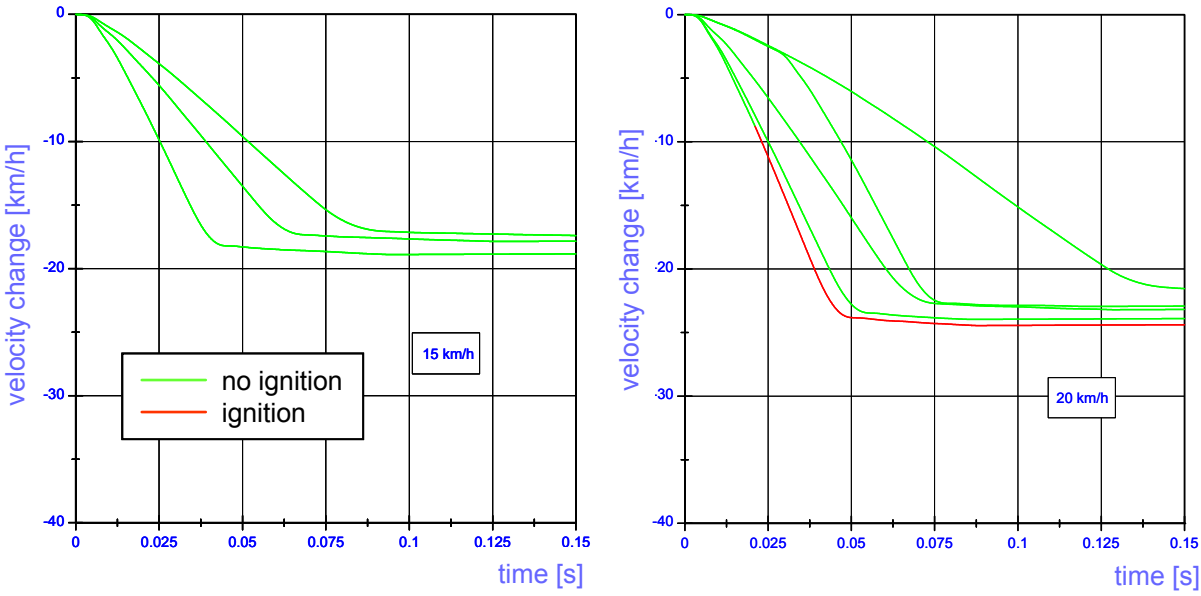


Fig. 6-45: Velocity Change and ignition timing for sled velocitys of 15 km/h and 20 km/h

In Fig. 6-46 the velocity change graphs and ignition moments of the driver airbag are presented for sled velocitys of 25 km/h and 30 km/h. The change in velocity up through the release moment is in each case greater than 7.8 km/h and the ignition moments of the driver airbag lie between 18 ms and 60 ms.

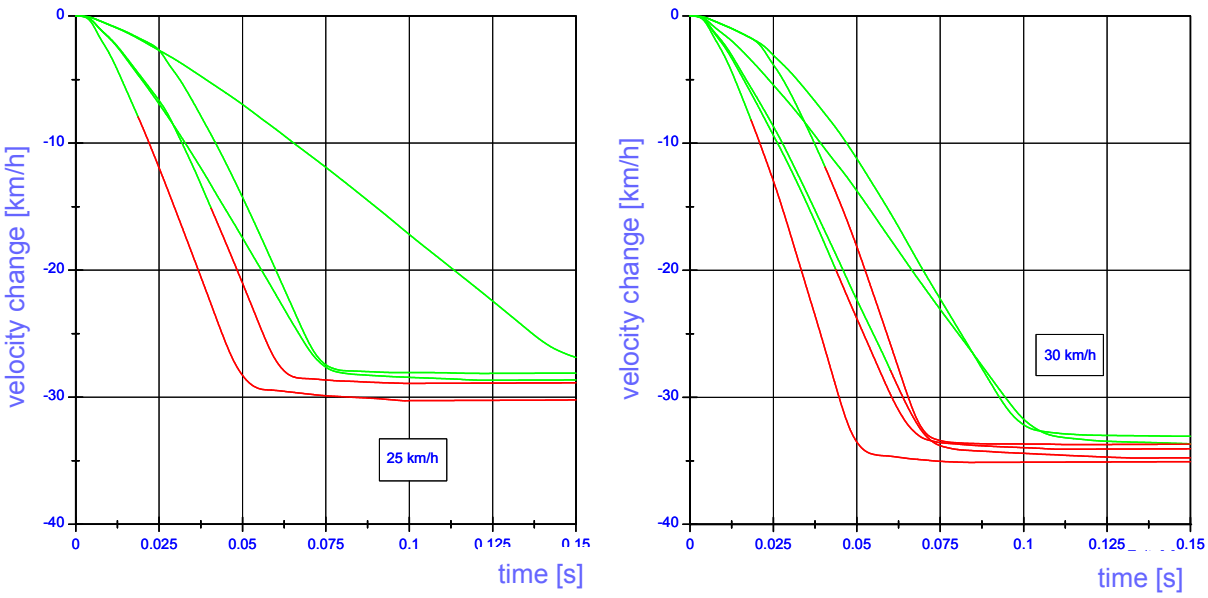


Fig. 6-46: Velocity Change and ignition timing for sled velocitys of 25 km/h and 30 km/h

In Fig. 6-47 the velocity change graphs and ignition moments of the driver airbag are shown for a velocity of 35 km/h. The change in velocity in each case is greater than 7.8 km/h and the ignition moments lie between 17 ms and 110 ms.

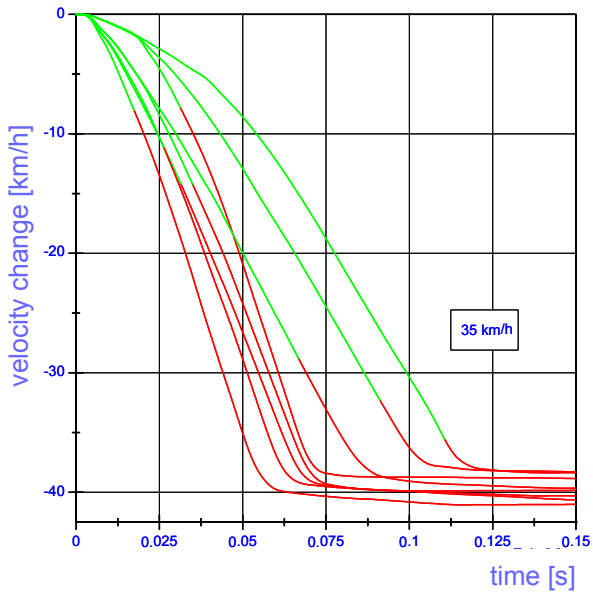


Fig. 6-47: Velocity Change and ignition timing for sled velocitys of 35 km/h

In three experiments the ignition impulse for the driver airbag is only emitted after 60, 90 or 110 ms (all at a sled velocity of 35 km/h). The three experiments with this late ignition moment show by the release moment a change in velocity greater than 27 km/h. According to previous experience a release decision would have had to be made considerably earlier. Inquiries made to the ECU manufacturer Siemens resulted in the information that these three experiments were based on acceleration graphs that taking the front body section profile of the Fiat Multipla into account could not be attained in a real-life vehicle. Consequently the ECU reactions were correct.

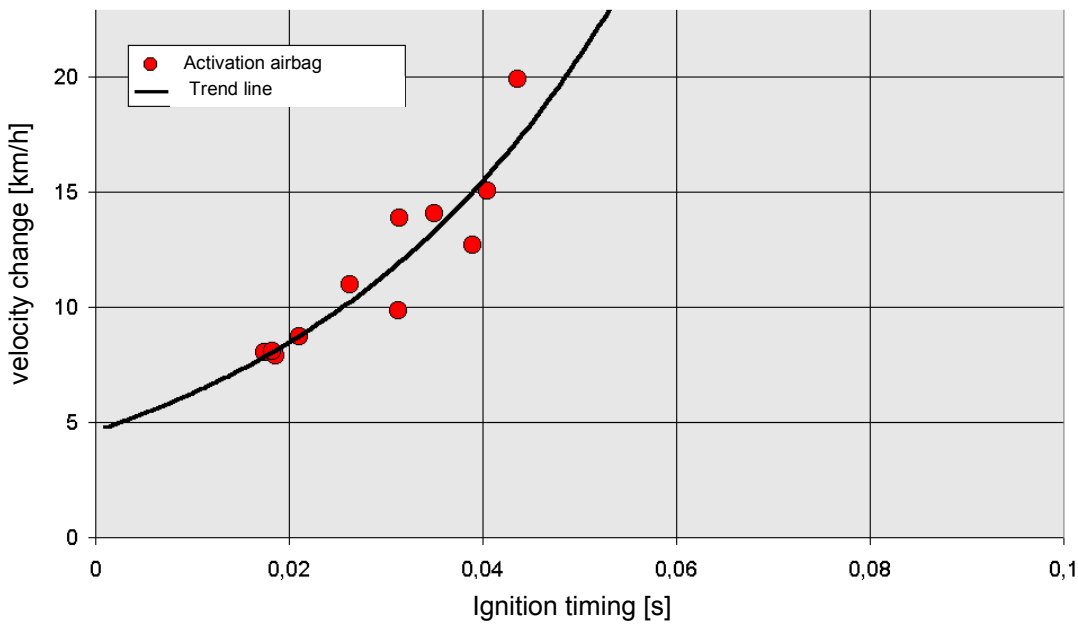


Fig. 6-48: Velocity change at ignition point

Fig. 6-48 shows a presentation of change in velocity at the ignition moment versus time for all sled experiments carried out. The trend graph once again has an exponential graph (measure of certainty R^2=0.892). The three experiments with late ignition times are ignored in this presentation.

The ignition moment of most airbag releases lies in the range between 18 ms and 40 ms. In this release range of the driver airbag the change in velocity at the moment of ignition lies between 8 km/h and 15 km/h.

6.7.2 Change of velocity versus displacement

Consideration of change in velocity versus the displacement shows Fig. 6-49. In the left section of the illustration the graph trajectory for different sled velocitys is shown. In the right section the change in velocity over the displacement is shown for a sled velocity of 25 km/h. In both sections of the illustration separation of areas with and without airbag release can be seen.

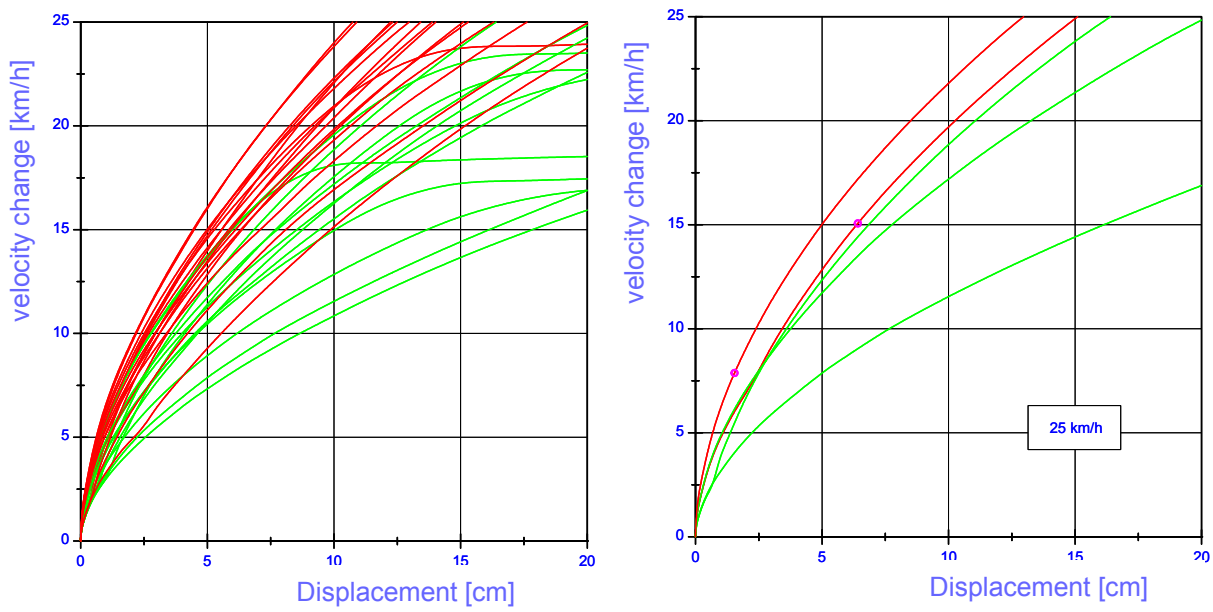


Fig. 6-49: Velocity change versus displacement with ignition points for various sled velocitys (left) and for 25 km/h (right)

Separation of the areas becomes more distinct when the graph trajectory at the ECU's ignition moment is studied, Fig. 6-50. The three experiments with displacement values beyond 200 mm (experiments with late ignition moment) are ignored in this presentation for the reasons given above.

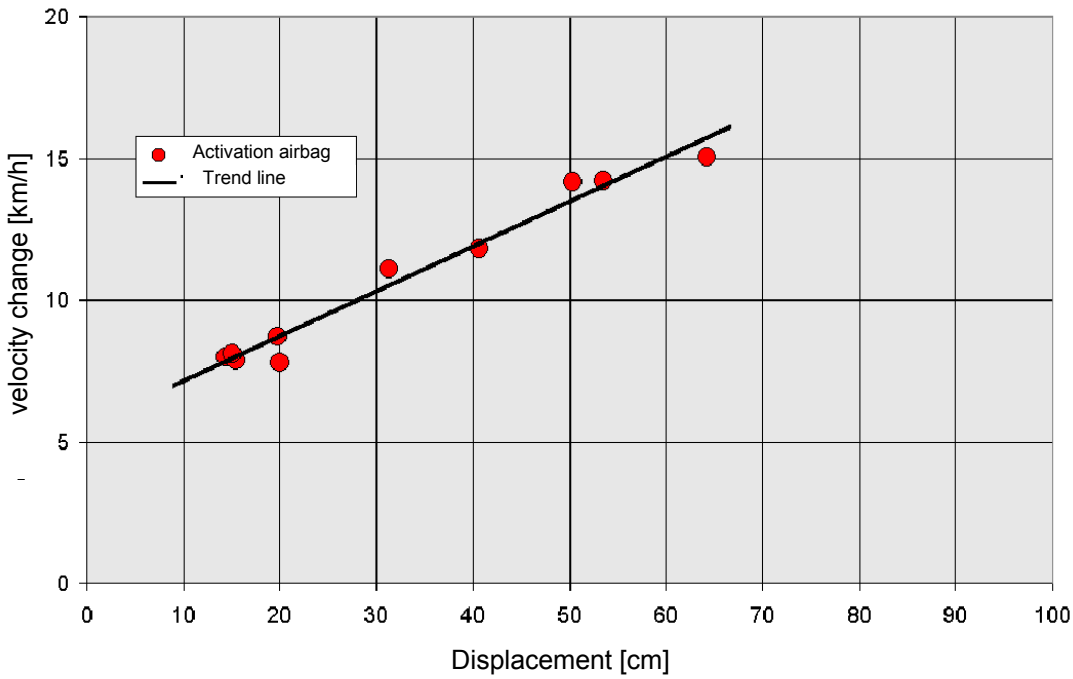


Fig. 6-50: Velocity change versus displacement with ignition points

In this illustration one again sees a linear relationship between the ignition moment as a function of change in velocity and the displacement (measure of certainty R^2=0.947). With most experiments, the ignition impulse was triggered up to a change in velocity of 11 km/h and a displacement of 40 mm.

6.8 Test results of the VW Lupo 3L TDI airbag system

In Fig. 6-51 the acceleration graph and the ignition impulse of the ECU are shown for the driver and passenger airbags during a 20 km/h crash against the tensile sheet brake for the VW Lupo 3L TDI airbag system.

The illustration shows that the release moment of the ECU ignition impulse lies at 16 ms for the driver airbag. Acceleration up to this moment amounts to -15.3. The entire deceleration process lasts 52 ms. The signal duration of the ECU impulse for the driver airbag is 50.5 ms and for the passenger airbag 50 ms and is constant throughout all experiments in the same test series. The ignition impulse of the passenger airbag begins in all experiments 0.5 ms after the driver airbag impulse. Further evaluation of the experiment will for this reason only deal with the driver airbag ignition impulse.

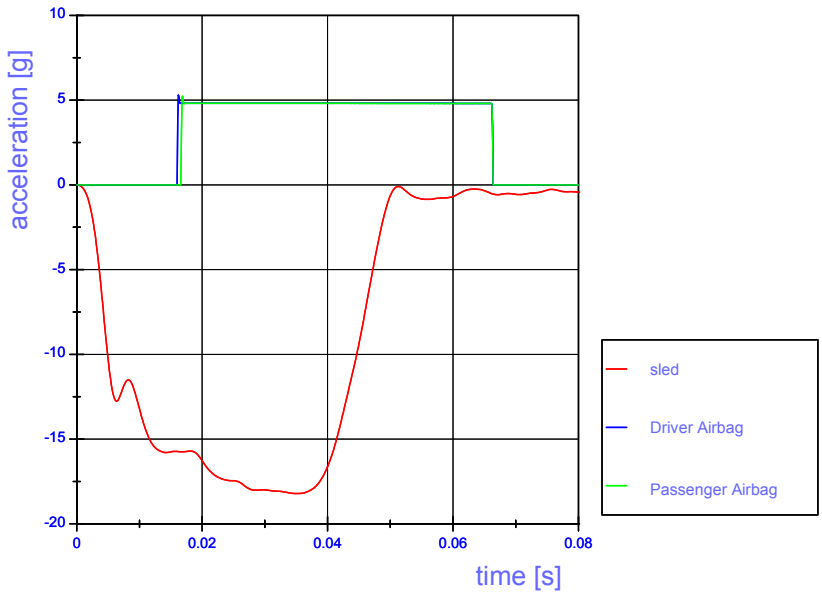


Fig. 6-51: Acceleration Characteristic and ignition timing for driver and passenger airbag in a 20 km/h impact (VW Lupo)

The VW airbag system ECU was likewise sent after the first airbag ignition to the manufacturer Siemens. The latter checked the fault memory with the aid of a special diagnostic tester. A readout of the error memory showed the system to have been functioning flawlessly. Unfortunately this special tester could not be used for all experiments in the test series since Siemens could not make a tester available to ika due to the limited number available.

6.8.1 Change of velocity versus time

In the next few illustrations the velocity change graphs for different sled velocitys are shown. In Fig. 6-52 the velocity change graphs and the ignition moment of the driver airbag are shown for sled velocitys of 15 km/h and 20 km/h. The change in velocity up through the moment of release is in both cases greater than 5.5 km/h and the driver bag ignition moments lie between 16 ms and 18 ms.

In Fig. 6-53 the velocity change graphs and ignition moments of the driver airbag are given for sled velocitys of 25 km/h and 30 km/h. The change in velocity up through the moment of release is in both cases greater than 6 km/h and the ignition moments of the driver airbag lie between 15 ms and 39 ms.

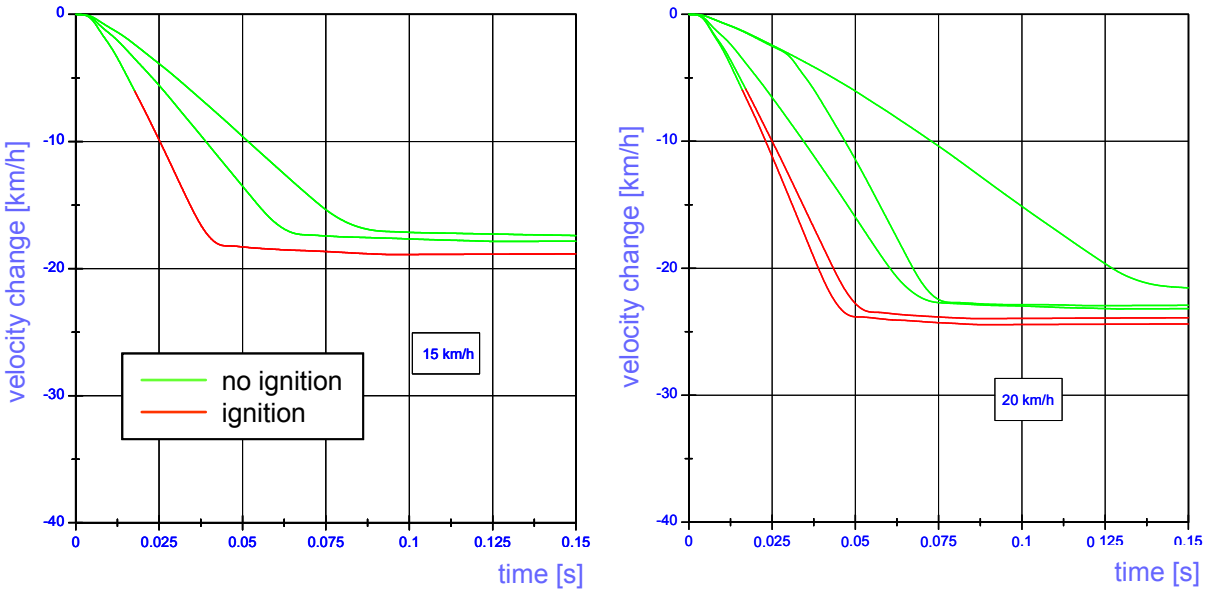


Fig. 6-52: Velocity change and ignition points for sled velocitys of 15 km/h and 20 km/h

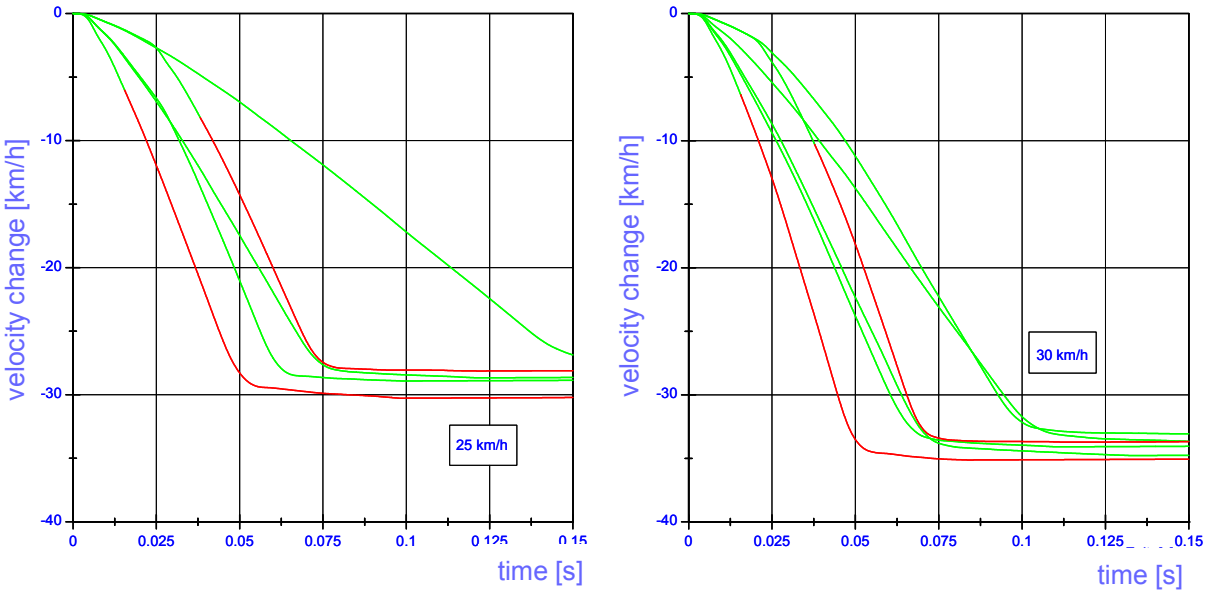


Fig. 6-53: Velocity change and ignition points for sled velocitys of 25 km/h and 30 km/h

In Fig. 6-54 the velocity change graphs and the ignition moments of the driver airbag are shown for a sled velocity of 35 km/h. The change in velocity up through the moment of release is in both cases greater than 5.5 km/h and the ignition moments of the driver airbag lie between 14 ms and 38 ms.

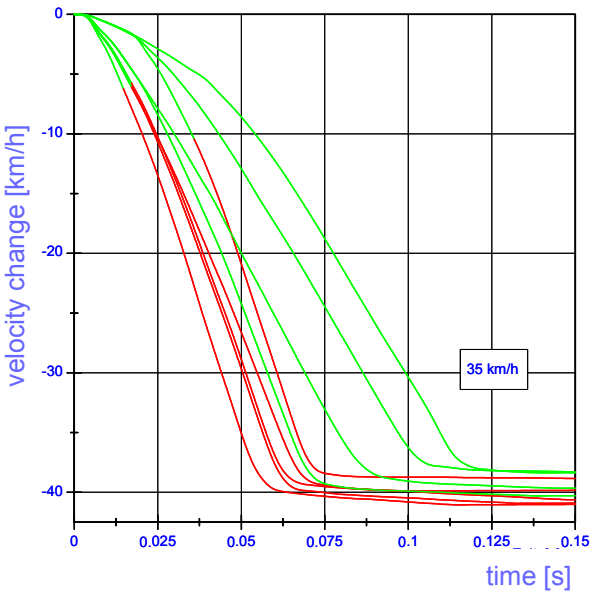


Fig. 6-54: Velocity change and ignition points for sled velocitys of 35 km/h

Fig. 6-55 shows the change in velocity at the moment of ignition over time for all experiments carried out. Once again an exponential graph emerges as a release threshold (measure of certainty R^2=0.919) providing a clear-cut delineation of experiments with and without airbag release. The ignition moment of most airbag releases lies in the range between 14 ms and 18 ms. In this release range of the driver airbag the change in velocity at the moment of ignition lies between 5 km/h and 7 km/h.

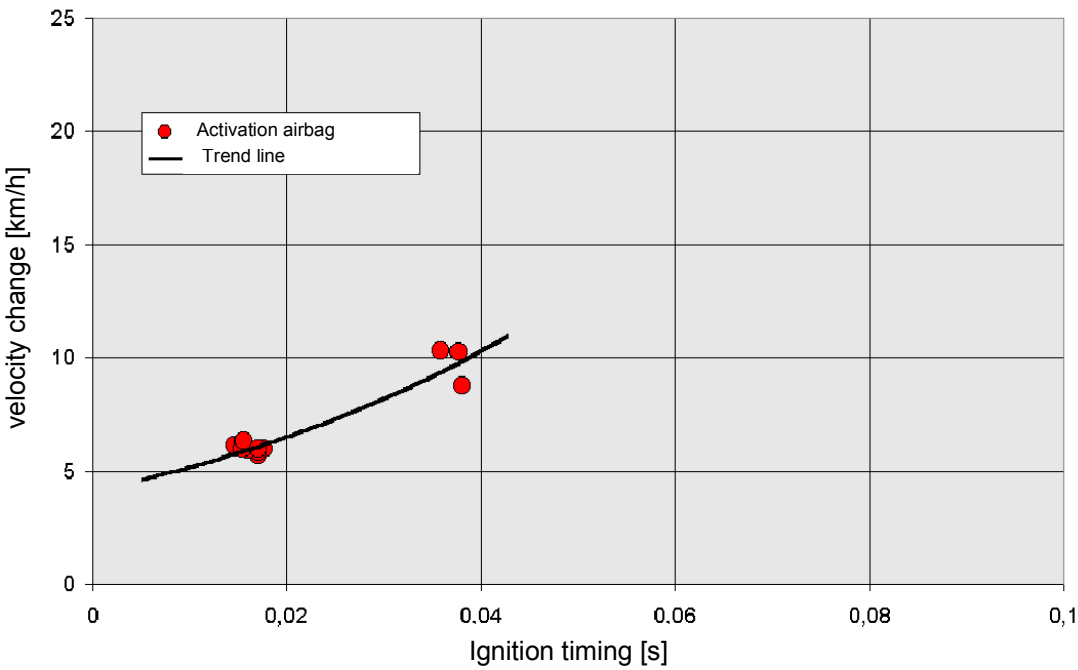


Fig. 6-55: Velocity change at ignition points

6.8.2 Change of velocity versus displacement

Fig. 6-56 shows once again the change of velocity versus the displacement.

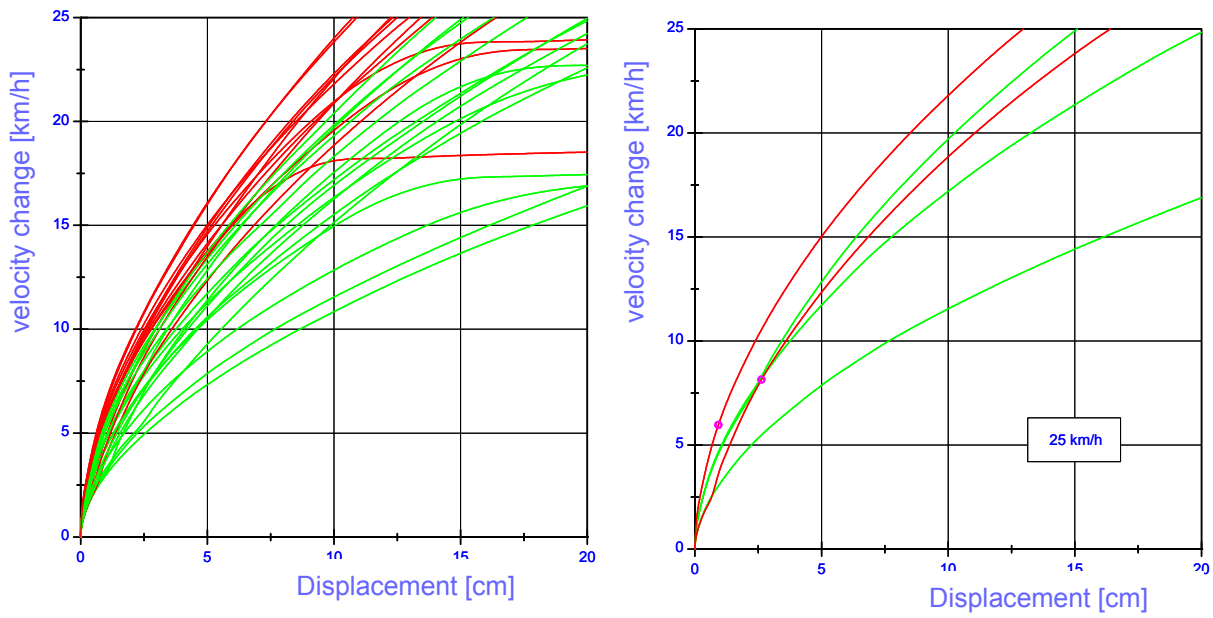


Fig. 6-56: Velocity change versus displacement with ignition points for various sled velocitys (left) and for 25 km/h (right)

In Fig. 6-57 the ignition moments are presented as a function of change in velocity and displacement.

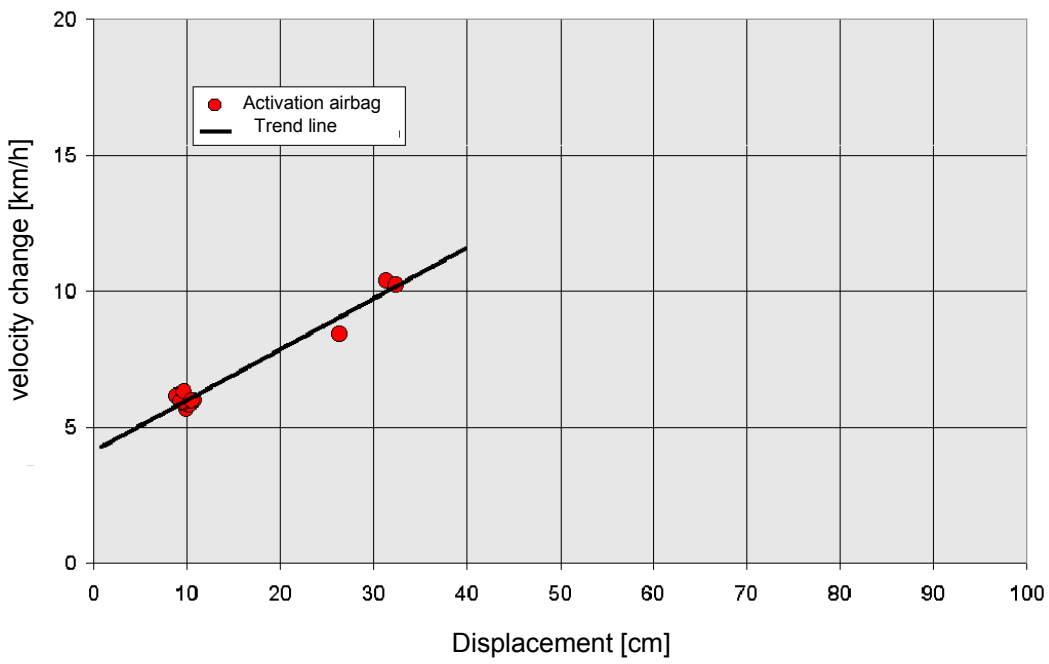


Fig. 6-57: Velocity Change versus displacement with ignition points

Here too there is an obvious linear association between the ignition moment as a function of change in velocity and the displacement. The measure of certainty is R^2=0.959. With most of the experiments the ignition impulse was triggered up to a change in velocity of 6.5 km/h and a displacement of 12 mm.

6.9 Comparison of all airbag systems tested

In this chapter a final summary of all test results will be presented. Fig. 6-58 shows by model year of the systems the measured signal duration, the release time period, the delay until ignition of the passenger airbag (if applicable) and the average inflation duration of the airbag (if applicable).

	Model Year	Signal Duration [ms]	Triggering Period [ms]	Time Delay for Ingnition of Passenger Bag [ms]	Inflation Duration of Airbag [ms]
Mercedes-Benz 300E	'86	46 - 67	37 - 70	-	-
Mercedes-Benz S-Klasse	'84 / '84	62 - 100	18 - 73	-	20 / 20
Opel Vectra	'94 / '94 / '95 / '95	5 - 12 / 67 - 105	13 - 33	-	38 / 27 / 31 / 27
Ford Mondeo	'94	3 - 5	18 - 66	-	25
Ford Escort	'94 / '94 / '95	3 - 6	22 - 73	-	27 / 24 / 25
Ford Ka	'96	3	16 - 47	13	-
VW Lupo 3L TDI	'99	50	14 - 39	0	-
Fiat Multipla	'99	49	17 - 60	10	-

Fig. 6-58: Model year, signal duration, triggering period, time delay for ignition of passenger airbag and inflation duration of airbag

Even in this survey significant differences can be seen between the various systems. While the Ford Ka only emits a signal for 3 ms the signal duration in the VW Lupo comes to 50 ms. Just as marked is the difference between the ignition moments of the passenger airbag. While some systems simultaneously ignite the driver and passenger airbags (e.g. VW Lupo), with other systems there is a time lapse between the two ignitions of 13 ms (Ford Ka). In all systems studied, however, the time lag between the two ignitions was constant.

Most clearly were the differences in considering the release periods of time. Opel Vectra and VW Lupo fail to release at all after a period of about 35 ms. With the Mercedes-Benz 300E airbag system the release threshold only just begins at that time. In addition, Mercedes-Benz and Ford Escort and Mondeo systems, by comparison with the other systems, have a significantly longer triggering period. The Ford Ka, Opel and VW systems release in a much narrower time range. It is furthermore worthy of note that the Ford Ka airbag ignites earlier than the Mondeo and Escort ones. This can be explained by the fact that in the Ford Ka a much smaller deformation and displacement is available and that the passengers must be protected with an airbag at an earlier moment.

Otherwise no unambiguous relationship of these readings to vehicle parameters like empty weight or year of make can be discerned.

In addition, for evaluation of ignition times the inflation duration of the airbag must also be taken into account. Thus, for instance, the Ford Escort systems on average inflate 15 ms later than the Opel Vectra systems. But the airbag modules in the Opel Vectra also need 31 ms on average up through full inflation while the Ford modules only need about 24 ms. In this way the protective effect of the inflated airbag in an Opel Vectra occurs 8 ms later. Ignition in the Opel Vectra must therefore occur sooner.

On the basis of release thresholds as well differences in the logic of release can be clearly shown. Here the Ford Escort, Opel Vectra and Mercedes S-Class systems will be treated together in a single line due to their largely identical release features.

Fig. 6-59 shows first of all release thresholds in the velocity change - time diagram. The release thresholds can be approximated very well with exponential functions in all of the systems.

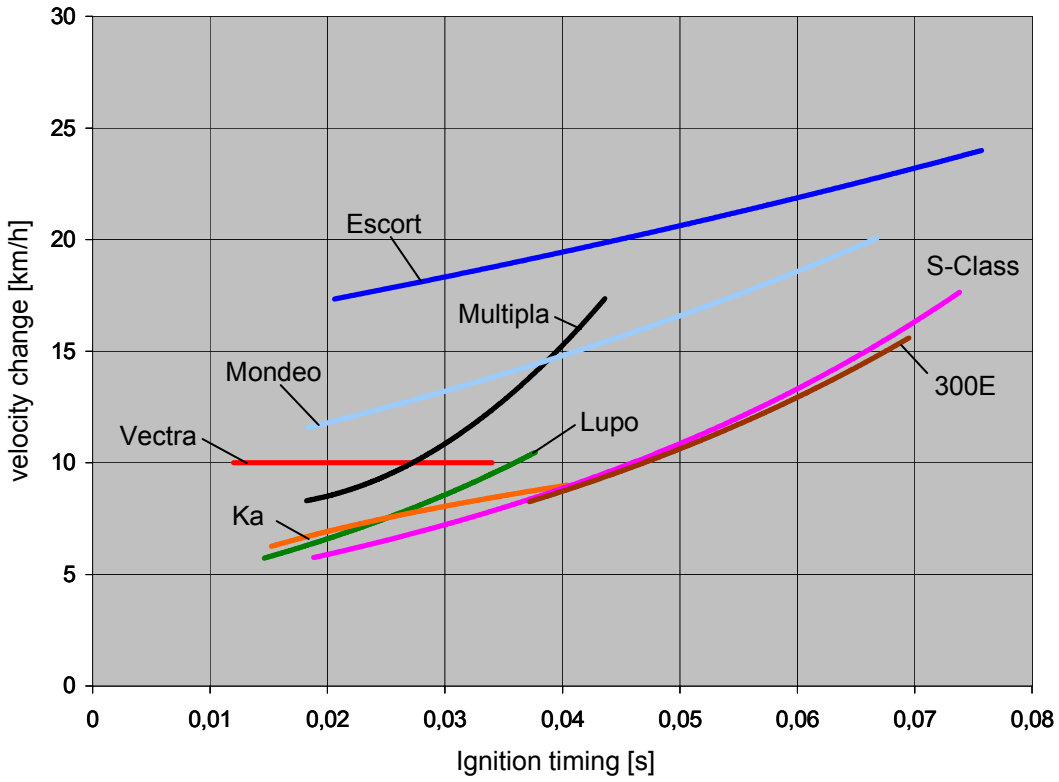


Fig. 6-59: Velocity Change versus ignition timing for all systems

Apparently the Opel and Ford systems, in order to release at a given point in time, need a greater change in velocity than do the Mercedes-Benz systems, for instance.

The Opel Vectra systems are the only systems that do not react adaptively to the severity of the accident but rather monitor a set velocity change threshold value of about 10 km/h. If the

change in velocity traverses this limit than the airbag is ignited. Additionally, the threshold value must be attained within a period of from 13 ms to 33 ms if the ECU is to classify the deceleration process or the accident as serious and to consider airbag ignition to be necessary.

Similar processes emerge for the velocity change - displacement diagram (Fig. 6-60). It turns out here that airbag release can be depicted for all systems as a linear function of velocity change over the displacement. This approximation was even significantly better in all experiments.

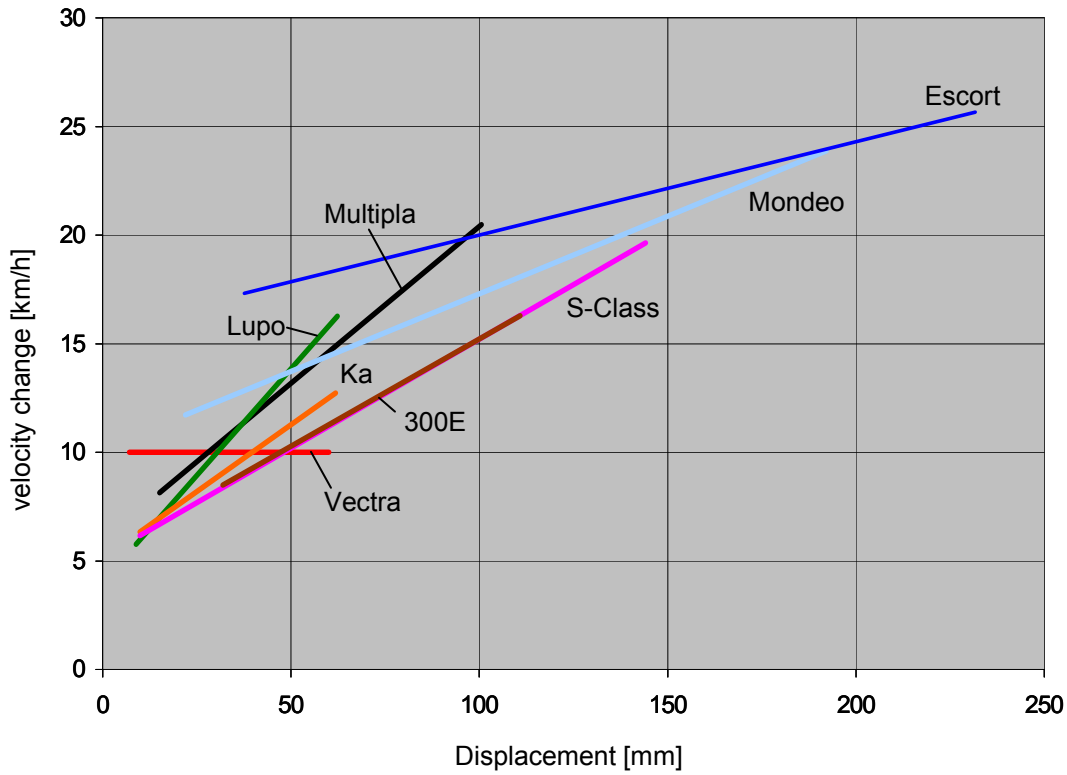


Fig. 6-60: Velocity change versus displacement for all systems

In most crash situations airbag ignition occurs before the passenger has moved forward for more than 10 cm. The Mercedes and the Ford systems tend to ignite at a later point in time which accordingly corresponds to a greater displacement.

If one views the front body section of the Mercedes-Benz S-Class and 300E then the solidity values and the total mass of the S-Class are certainly clearly greater. One could assume that this would make precise coordination of the ECU's release features with each of the vehicle types in order to provide optimum protection to passengers. The trend lines of the two vehicle types diverge only slightly from each other. Complicated adjustment to each of the front body section structures cannot be detected. The 300E ignites in a crash only somewhat earlier. Thus in the event of a crash there is a certain adjustment to higher deceleration values which can impact on passengers in the 300E by comparison with the S-Class.

One is struck by the fact that, with the exception of the Opel systems, the exponential trend lines transition from Fig. 6-59 to linear graphs in Fig. 6-60. This raises the question of whether the trend lines from the velocity change-time diagram can be equivalently transferred to the displacement diagram. However, this is not possible since it is here a matter of principally differing trend lines and presentation forms of different types. The ordinate in both cases is admittedly the change in velocity. But there is no generally valid mathematical relationship in the axis of abscises between the ignition moment and the displacement up through the moment of ignition. The displacement is determined in each crash individually from the deceleration graph by means of a two-fold integration. The various values cannot thus be transferred without inclusion of the experimental data in each other.

This also explains why the measure of certainty R^2 is different in the two configurations. Since deviations from the trend line in the velocity change - displacement graph turn out to be smaller, it must be assumed that the ECUs also assess the displacement as a basis for judging the crash situation.

7 Airbag test procedure

The experiments carried out have shown that all systems always recognised the pre-programmed release threshold without mistake and consequently that all airbag releases or decisions not to release were carried out correctly. Nonetheless, it would still make sense to reflect on the test procedure for airbags since the number of systems studied was much too small to arrive at any statistically underpinned statements. Reports about improper release of airbags, recall actions precisely in regard to the airbag and the general issue of electronic system ageing underscore this necessity.

The entire “airbag” system like all electronically controlled systems in a car consists of main components like sensors, ECU’s, cable harnesses and actuators which here corresponds to the basic airbag with an ignition donuts. Test procedures should as far as possible comprise all components of the system. Particularly in the case of the airbag, however, this is only possible to a certain extent.

Thus, for instance, the actual airbag can naturally not be ignited during the test procedure since this would cause repair costs which are far to high. On the basis of thorough investigations carried out by the airbag manufacturers (climate tests, acid baths, etc., …) however it can be assumed that neither the propellant nor the airbag suffer significant ageing and thus inflate properly in case they are ignited.

Likewise, direct testing of the sensor signals is practically impossible since the sensors would have to be exposed to accelerations of the type occurring in a real-life car crash. At first, an alternative idea was to put a relatively small acceleration to the whole bodywork of the car instead of real crash deceleration and just see if there is any corresponding signal from the sensor. Those shakers that are currently being used for checking the play in the ball joints of the steering might be used for this procedure. With an access to the ECU, which is the only sensible position for picking up the sensor information, it could be seen what the airbag electronic is recognizing. But this procedure is not very sensible. Acceleration signals like those coming from the shaker are filtered out by the airbag ECU’s because they are seen as noise. That makes the shaker stimulation useless. Furthermore, the shaker signals will be most probable very untypical for deceleration signals and it is doubtful whether the body of the car can be moved in all necessary directions (e.g. side impact).

The only thing one could think of here would be to have external stimulation of the sensors so that the sensor signals emitted would be equal to real-life acceleration signals. With the large number of different physical measurement principles (see Chapter 2.3.5) and the concomitant change in the type of simulation as well as with the highly variant sensor installation positions this appears to be hardy feasible. In a vehicle itself one normally consciously chooses varying measurement principles for measure and “safing” sensors in order to built additional safety into the system.

Therefore the test procedure must be limited to control of the ECU and the cable harness.

In order to be able to carry out a real functionality test of airbag electronic systems, acceleration signals would have to be fed to the evaluation unit which correspond to those of a real-life crash situation. In principle, acceleration graphs in the form of rectangular signals of varying size and duration would suffice. These rectangular signals would be integrated up from the airbag electronic system to straight lines of change in velocity. Depending on whether the changes in velocity thus calculated are great enough or not an ignition impulse would be emitted by the ECU, Fig. 7-1.

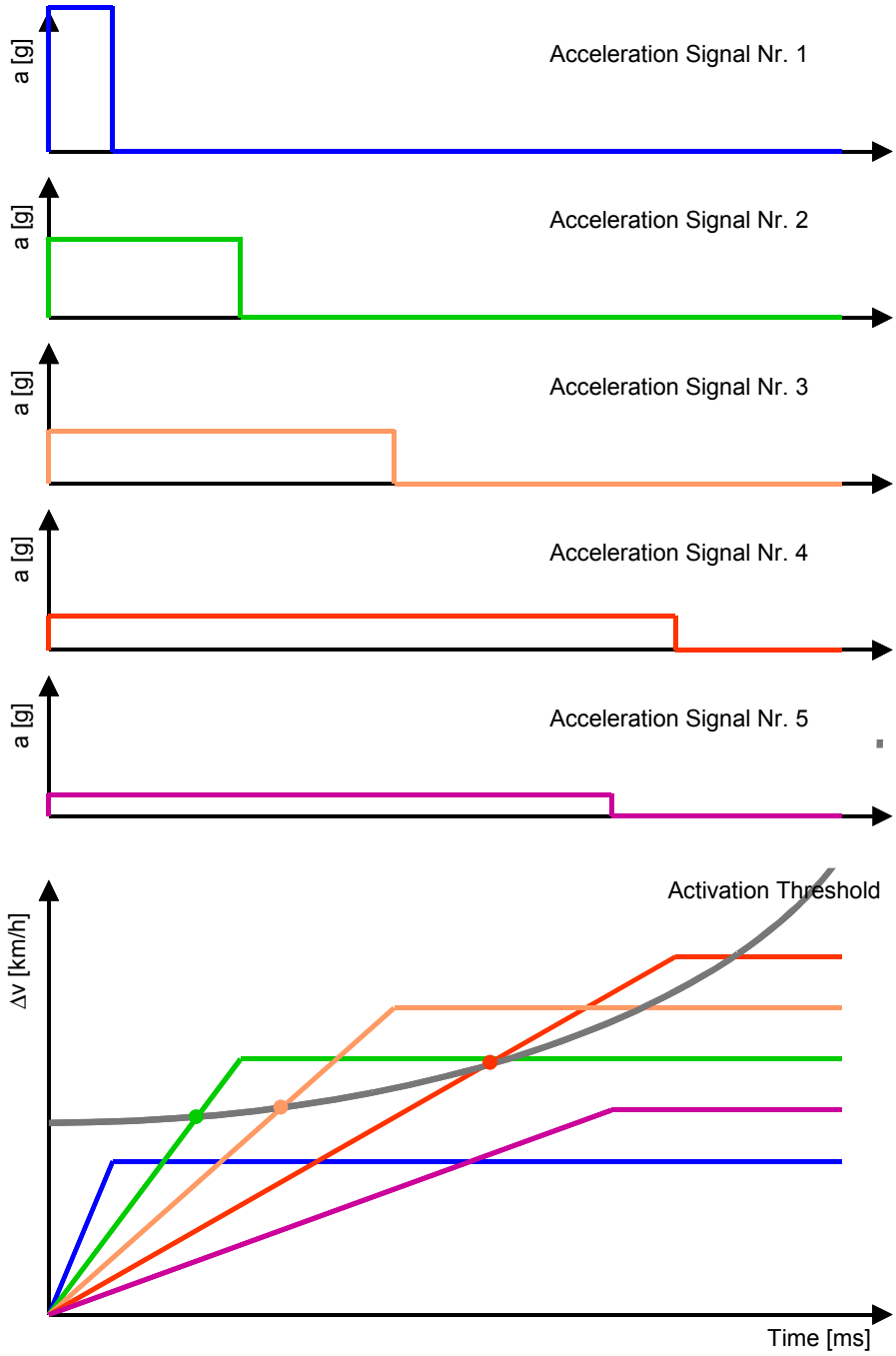


Fig. 7-1: Functionality test of airbag electronics

Here, besides the signals that would have to entail release (No. 2, 3 and 4) such signals would be of interest which may not allow a release of the airbag. For example, these are extremely short acceleration peaks (No. 1) or ever very long decelerations at a lower level (No. 5).

From the acceleration graphs entailing emission of an ignition impulse, the characteristic release graph of the airbag electronic system could be very simply reconstructed. The crash experiments carried out have unambiguously shown that there basically exponential functions have been deposited provided that one scans the change in velocity over time. If the change in velocity is plotted over the displacement then straight lines always emerge as release thresholds. If the release threshold measured diverges very much from one of these basic shapes, then the airbag is clearly malfunctioning.

Such a test cold be carried out under two preconditions:

1. There must be a possibility of specifying the acceleration signals from the airbag electronic system.
2. The ignition impulse emitted must be picked up and the time between the beginning of acceleration signal emission and ignition impulse must be measured.

For specifying acceleration signals there are two possibilities. The test signals can be emitted by an external diagnostic tool to the airbag electronic system, or the test signals can be directly induced in the ECU in which case here as well a diagnostic tool would be needed to start retrieval of the signals. Both alternatives must in any case be able to connect with the airbag electronic system via a diagnostic interface and here a standard diagnostic interface for all types of vehicle would be something to aim at.

The second possibility has the advantage that no “spurious” signals would have to be transmitted to the ECU, something which could lead to errors. The precise graph of the internally induced signals would not even need to be known to the test operator. The test operator would merely initiate retrieval of the internal signals via the diagnostic tool and at the conclusion of the test would be informed on his diagnostic instrument about the results, possibly in the form of a characteristic release graph measured. With this procedure, time measurement and determination of the release threshold would occur by means of the airbag’s electronic system.

With any specification of acceleration signals with a diagnostic tool with signal emission, time measurement and evaluation can be taken over by the testing equipment providing the test operator with much greater flexibility in carrying out the test. However, the interface must be extended to include the possibility of feeding acceleration signals to the ECU from the diagnostic tool. Here expected further developments in airbags could help out. Future airbags will not just have two sensors in the longitudinal vehicle direction (one measurement sensor as well as a “safing” sensor, but will have a number of sensors recording deceleration at very different points on the vehicle. So-called “pre-crash” sensors will be included here which sense the immediate environment of the vehicle and thus collect information on the

type and severity of the accident even before the actual crash begins. All these sensors will transmit their information over a fast bus system to a central evaluation unit which will then decide when and which airbags are to be used in order to provide passengers with the best possible protection. Possibility of access to this bus system would offer all opportunities to transmit any kind of test signals to the airbag's electronic system.

With both procedures the ignition impulse must be picked up and evaluated. For this, access to the safing sensor would appear most feasible, one which in the vehicle's condition prevents inadvertent ignition of the airbag.

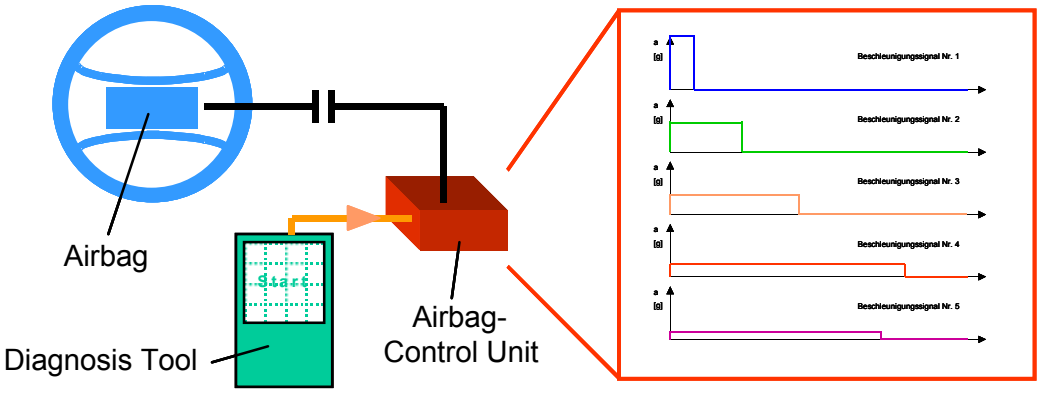
Depositing the acceleration signals in the ECU is in any case the safer variant since in that way it is ensured that the airbag electronic system always picks up the appropriate signals. That acceleration graphs must be very tightly adapted to each system has been shown by the comparison between the release times of the Opel Vectra and Mercedes-Benz 300E systems. In addition, it is a certainty that all relevant functions are actually tested, something which is not guaranteed if the test procedure can be designed with extreme flexibility. Moreover, manufacturers are not forced to provide access to signal feeding but may form the test signals in accordance with the exigencies of their systems. Therefore, depositing acceleration signals in the airbag's ECU is considered to be the preferred possibility.

With the current systems, comparable in-house diagnostic routines are already being deposited (see Chapter 2.3.6). But literature provides no clues as to how the test signals can be designed precisely and which reactions they entail in the airbag's electronic system. Nonetheless it must be assumed that the complete signal path from entry of the acceleration signal up through emission of the ignition impulse would not be tread so that the procedure described above constitutes a clear extension of the self diagnosis routines.

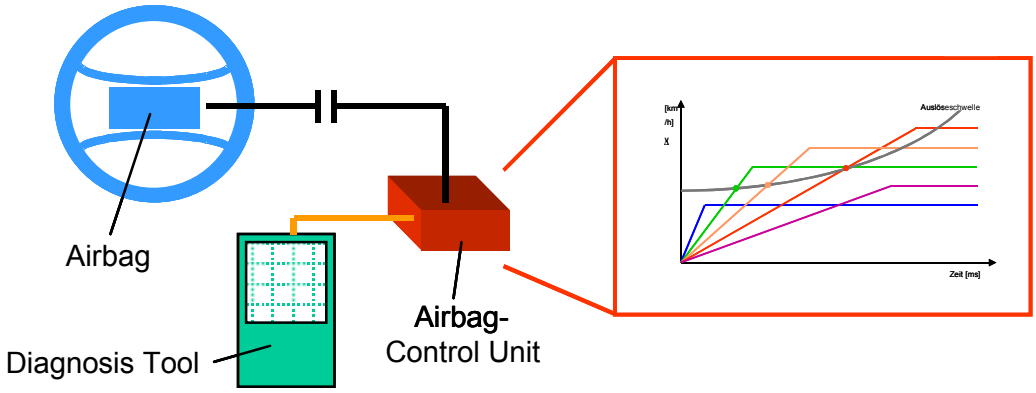
The claim of many automotive manufacturer that the airbag's electronic system may only release a few times because of the high degree of strain could be clearly refuted in the framework of this study. The crash experiments carried out have shown that the airbag's electronic system can be ignited several times without any trouble and without putting an unbearable strain on the electronic system due to high ignition currents. For the test procedure, it is furthermore imaginable to let the ignition impulse run over a high ohmic resistor, something which would further reduce the strain on the airbag's electronic system during the test. Fig. 7-2 clarifies in schematic manner how functional and impact testing is carried out.

If a standard diagnostic interface would be available for functionality testing of airbag electronic systems then additional tests on the system's functional adequacy can also be carried out.

1. Call test Signals



2. Function and Action Test Execution



3. Output Results on Diagnosis Tool

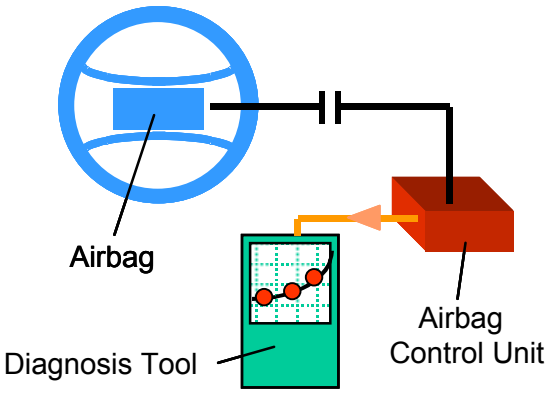


Fig. 7-2: Schematic Function Test

First of all, it makes sense to check that all system components are present as well as correct. It is quite thinkable that after an accident and due to the high costs involved not all airbags are renewed or that components have been built in which are hardly compatible with

the original airbag system. A system check made at the very beginning of testing could detect such errors.

Like all electronically controlled systems the airbag too has its own diagnostic unit providing the opportunity of storing recognised malfunctioning in a fault memory. The readout of this fault memory indicates to what extent the system itself has already recognised a malfunctioning or a disturbance. Thus, for example, frequently deposited but not currently acute reports are an indication of a malfunction building up in the system. For that reason evaluation of this memory is extremely helpful in the context of a test procedure.

The diagnosis routines are not only checking the components of the airbag-system permanently, but also the proper work of the ECU itself. This function is usually called “Watch-dog”. If the ECU is working properly, plausible deceleration signals will lead to a release of the airbag and implausible signals will cause an error to be stored in the fault memory. Therefore, implausible acceleration signals need not to be part of the test. But the functionality of the “Watch-dog” and with it the proper working of all self-diagnosis routines should be checked.

Future airbag systems will be fitted out with a whole series of so-called “smart” features meant on the one hand to improve determination of the right ignition moment and, secondly, to release the necessary airbag to protect the passengers. This, for instance, would include extended recognition of seat occupancy with an estimate of passenger weight as well as of the passenger’s sex, an “out-of-position” recognition to minimise passenger injuries by the airbag as well as a multistage ignition of the actual airbags. All of these “smart” features can be integrated in the test procedure relatively easily. Thus, as an example, the tester can change his seat position during testing. The system would then have to correctly recognise weight and sex of the passenger or, if the sitting position is too close to the airbag, the latter would have to be deactivated. Likewise, different acceleration signals can be combined so that the airbag system is fooled into recognising various accident situations. Depending on the accident situation, only the front or only the side airbags may then be ignited.

In summary, the airbag test procedure can be described as follows:

I. System check
II. Read out of the fault memory
III. Check of the “Watch-dog”
IV. Functionality test
V. Testing of the “smart” features

8 Summary

Airbags are a standard feature in most new vehicles today. A large number of vehicles already have more than one airbag. All of these systems use a number of acceleration sensors located at different positions on the vehicle. The deceleration occurring after an impact is detected by the systems, evaluated and if necessary the decision taken to trigger the individual airbags. A self-diagnosis system monitors the integrity of the systems before and during journeys. If malfunctions are recognized the system is deactivated, a message saved in the fault memory and the driver notified by an indicator light which comes on.

In this work package the operation of older airbag systems was investigated.

In order to be able to make a statement about the condition of the airbag systems, the electronic components of the systems were subjected to closer scrutiny. For this purpose, the sensor mechanism, the cable harness and the ECU were mounted onto a test sled of a crash test facility. Experiments at different impact velocities as well as variable decelerations were carried out and the test results were analysed individually as well as in comparison with each other. Furthermore, the airbag modules of the individual systems were triggered and checked to see that they inflated correctly.

Fig. 8-1 shows by model year of the systems the measured signal duration, the release time period, the delay until ignition of the passenger airbag (if applicable) and the average inflation duration of the airbag (if applicable).

	Model Year	Signal Duration [ms]	Triggering Period [ms]	Time Delay for Ingnition of Passenger Bag [ms]	Inflation Duration of Airbag [ms]
Mercedes-Benz 300E	'86	46 - 67	37 - 70	-	-
Mercedes-Benz S-Klasse	'84 / '84	62 - 100	18 - 73	-	20 / 20
Opel Vectra	'94 / '94 / '95 / '95	5 - 12 / 67 - 105	13 - 33	-	38 / 27 / 31 / 27
Ford Mondeo	'94	3 - 5	18 - 66	-	25
Ford Escort	'94 / '94 / '95	3 - 6	22 - 73	-	27 / 24 / 25
Ford Ka	'96	3	16 - 47	13	-
VW Lupo 3L TDI	'99	50	14 - 39	0	-
Fiat Multipla	'99	49	17 - 60	10	-

Fig. 8-1: Model year, signal duration, triggering period, time delay for ignition of passenger airbag and inflation duration of airbag (at ika measured values)

Even in this survey significant differences can be seen between the various systems. While the Ford Ka only emits a signal for 3 ms the signal duration in the VW Lupo comes to 50 ms. While some systems simultaneously ignite the driver and passenger airbags (e.g. VW Lupo), with other systems there is a time lapse between the two ignitions of 13 ms (Ford Ka). However, in all systems studied the time lag between the two ignitions was constant. The investigation clearly showed differences in the time period before release. No unambiguous

relationship of these readings to vehicle parameters, such as empty weight or year of manufacture, could be discerned. It was concluded that the data used does not appear to have been specifically adapted to the car in which the airbag is used. It would seem that there is the potential for optimisation.

For the analysis of the test results, presenting “changes in velocity” versus the “time” on the one hand and versus the “displacement” up to the airbag system’s moment of ignition on the other proved to be the most meaningful in order to be able to follow the airbag system’s release strategy. In the first case, the release thresholds could be approximated very well with exponential functions in all of the systems. In the second case a linear relationship became evident between the change in velocity and the displacement so that it was possible to decide on the basis of this characteristic line whether malfunction was present or not in an airbag system.

Apparently the Opel and Ford systems, in order to release at a given point in time, need a greater change in velocity than do the Mercedes-Benz systems. The Opel Vectra system is the only system that does not react adaptively to the severity of the accident but rather monitors a velocity change threshold value of about 10 km/h. If the change in velocity traverses this limit, the airbag is ignited. Additionally, the threshold value must be attained within 13 ms to 33 ms if the ECU is to classify the deceleration process or the accident as serious and to consider airbag ignition to be necessary.

Similar processes emerge for the velocity change - displacement diagram (Fig. 8-2).

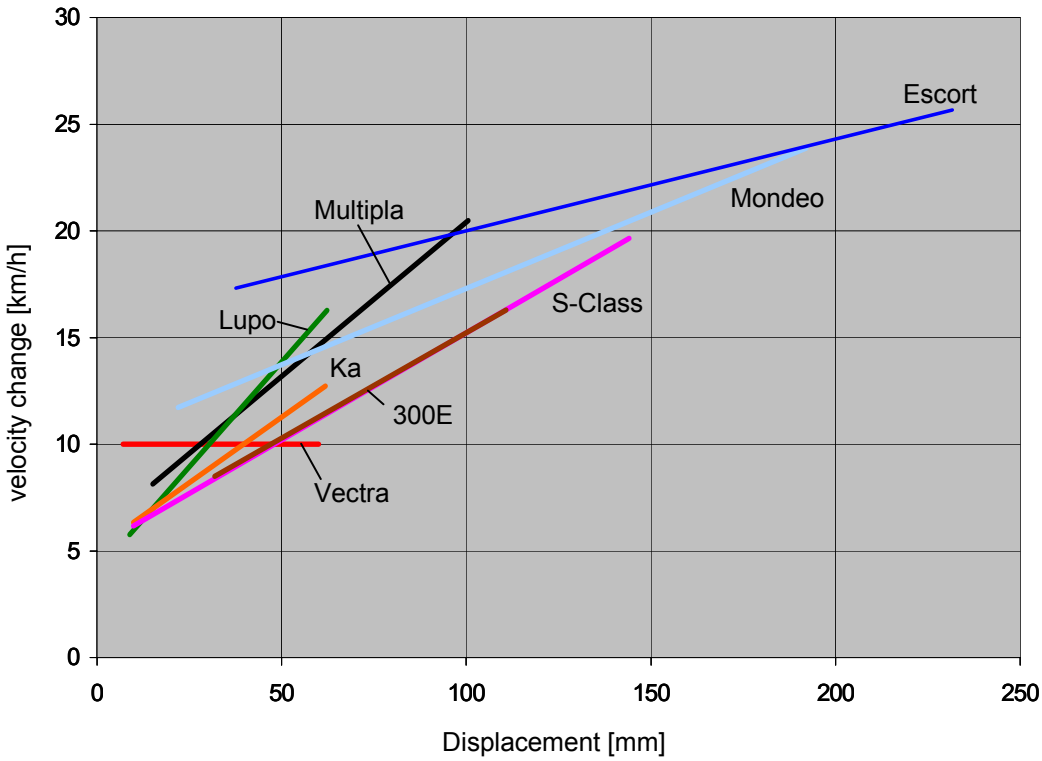


Fig. 8-2: Velocity change versus displacement for all systems

The airbag release can be depicted for all systems as a linear function of velocity change over the displacement. This approximation was significantly better for all vehicles.

The trend lines of the two Mercedes-Benz cars diverge only slightly from each other. Complicated adjustment to each of the front body section structures could not be detected.

In summary, the experimental work showed:

1. The release threshold with all airbags was recognised reliably by the ECU's. In addition, it was found that all airbag modules ignited without flaw. Any influence of ageing of airbag ECU's and modules caused by environmental conditions could not be found in the experiments carried out.

2. Contrary to the statements of vehicle manufacturers, the airbag ECU is able to emit an ignition impulse several times, even with the MIL (Malfunction Indication Lamp) turned on.

3. The release thresholds are mathematically quite simple trend lines. Even with two different vehicle types from one manufacturer, the trend lines diverge only slightly from each other. Complicated adjustment to each of the front body section structures could not be detected.

Although all airbag releases or decisions not to release were carried out correctly, it still makes sense to reflect on a test procedure for airbags since the number of systems studied was much too small to arrive at any statistically significant statements about reliability. Reports about improper release of airbags, recall actions precisely in regard to the airbag and the general issue of electronic system ageing underscore this necessity. With any type of test procedure one must be able to connect with the airbag electronic system via a diagnostic interface and here a standard diagnostic interface for all types of vehicle would be something to aim at.

The first step is to check that all system components are present and of the correct type. It is possible that after an accident not all airbags are renewed or components may be used which are not compatible with the original airbag system. A system check made at the very beginning of testing will detect such failure.

The next step in evaluating an airbag system should be the read out of the fault memory. It indicates to what extent the system itself has already recognised a malfunctioning or a disturbance.

The diagnosis routines are not only checking the components of the airbag-system permanently, but also the proper functioning of the ECU itself. This function is usually called "Watch-dog". The performance will be checked by a functionality test. Fig. 8-3 shows a procedure which was derived from the experiments that have been carried out.

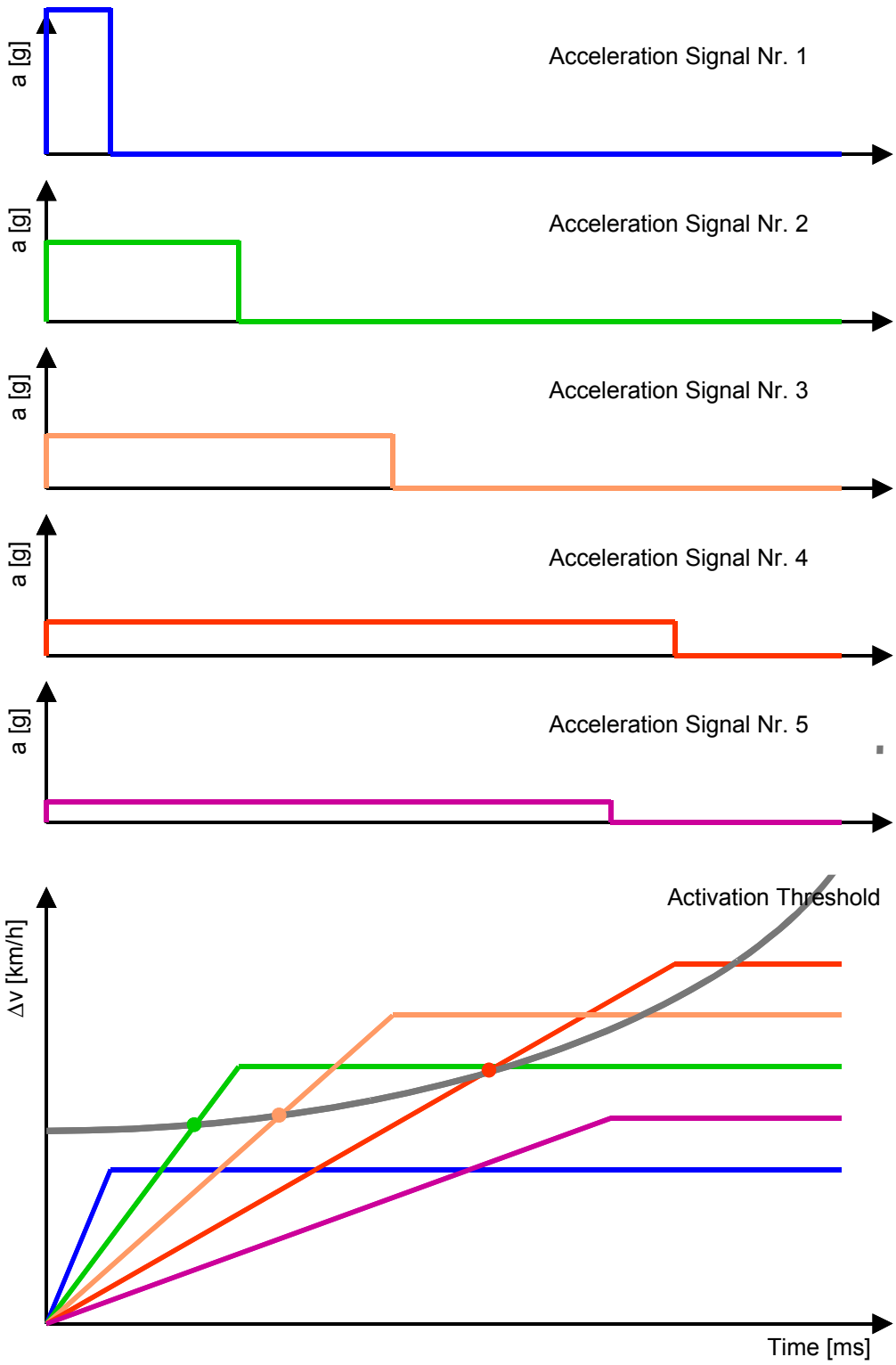


Fig. 8-3: Functionality test of airbag electronics

In order to be able to carry out a real functionality test of airbag electronic systems, acceleration signals would have to be fed to the evaluation unit which correspond to those of a real-life crash situation. In principle, acceleration graphs in the form of rectangular signals of varying size and duration would suffice. These rectangular signals would be integrated up by

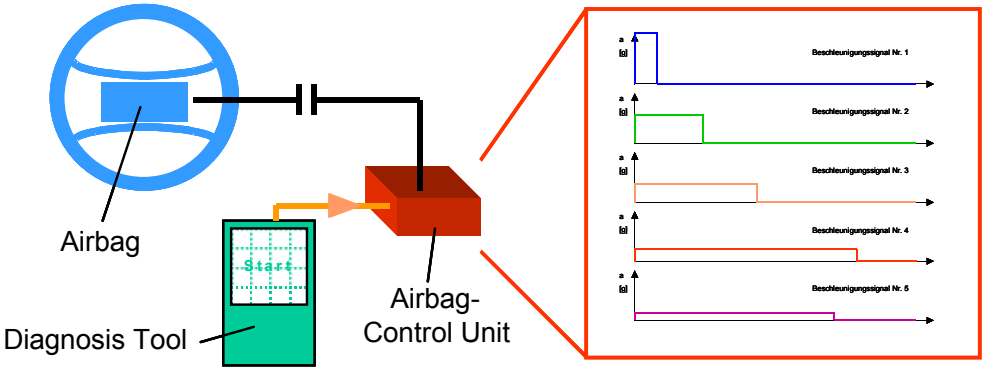
the airbag electronic system to straight lines of change in velocity. Depending on whether the changes in velocity thus calculated are large enough or not, the ECU will determine whether or not to emit an ignition impulse (Fig. 8-3). Signals No. 2, 3 and 4 will make the airbag fire, signal No. 1 is too short, the level of signal No. 5 is too low.

From the deceleration graphs which produce an ignition impulse, the characteristic release graph of the airbag electronic system can be reconstructed very simply. If the measured release threshold diverges very much from a basic shape, then the airbag is clearly malfunctioning. The test signals should be directly produced in the ECU to ensure that the airbag electronic system always uses appropriate signals. In addition, it will be certain that all relevant functions are actually tested. Moreover, manufacturers would not be forced to provide access to feed in the signals but may form the test signals in accordance with the characteristics of their systems. The ignition impulse must be picked up and evaluated. For this, access to the 'safeing' sensor would appear to be the most feasible option as this prevents inadvertent ignition of the airbag in the conditions of the test. As this procedure covers the complete signal path from entry of the deceleration signal up through emission of the ignition impulse, it constitutes a clear extension of the self diagnosis routines.

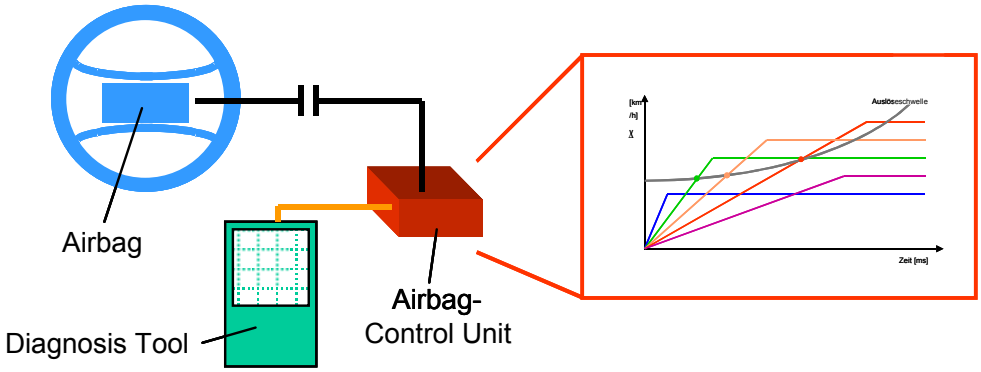
Fig. 8-4 gives an overview of the principles of the function test. The diagnose tool only takes care of the communication. All the required signals and the evaluation software is directly installed into the airbag-ECU.

This procedure will also support future airbag systems. They will be fitted out with a whole series of so-called “smart” features meant, on the one hand to improve determination of the right ignition moment and, on the other to release the appropriate airbag to protect the passengers. The features could include, for instance, extended recognition of seat occupancy with an estimate of passenger weight as well as of the passenger’s sex, “out-of-position” recognition to minimise passenger injuries by the airbag as well as a multistage ignition of the actual airbags. All of these “smart” features can be integrated in the test procedure relatively easily. Thus, as an example, the tester can change his seat position during testing. The system would have to recognise correctly the weight and sex of the passenger or, if the sitting position is too close to the airbag. In the latter case, the airbag would have to be deactivated. Likewise, different acceleration signals can be combined so that the airbag system is fooled into recognising various accident situations. Depending on the accident situation, ignition signals should be emitted only to the front or only to the side airbags.

1. Call test Signals



2. Function and Action Test Execution



3. Output Results on Diagnosis Tool

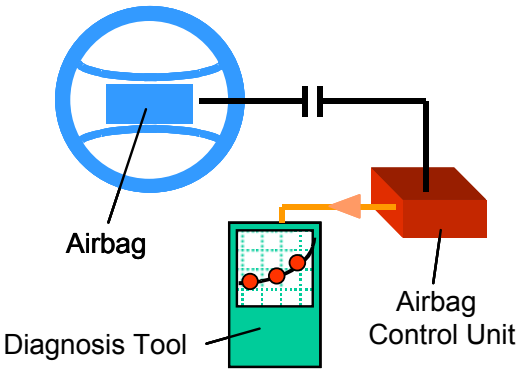


Fig. 8-4: Schematic Function Test

In summary, the recommended airbag test procedure can be described as follows:

I. System check

II. Read out of the fault memory

III. Check of the “Watch-dog”

IV. Functionality test

V. Testing of the “smart” features

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