# Crash Pulse Recorder (CPR) - validation in full scale crash tests

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## Abstract

The importance of estimating the accident severity in accident reconstruction and analysis is fundamental. Accident severity can be measured in many different ways, but in frontal collisions the change of velocity ($\Delta V$) , EBS or EES are most often used.
The severity of a collision is most often estimated from vehicle deformations. It is however known, that these estimates are poor if compared to laboratory test conditions. To be able to have almost the same measurement accuracy in real life accidents as in laboratories, on board measurement technique is necessary.
In this presentation, a low cost device measuring the crash pulse for a car in an accident is tested both concerning accuracy and precision as well as reliability. The device called Crash Pulse Recorder (CPR) is based on measuring the movement of the mass in a spring mass system in a collision.
In the study the results of several full scale crash tests are presented. The crash tests are made in a large range of different collision types where both offset and angled collisions were included. Most of the tests were car to car collisions but barrier tests were also performed. A brief description of its construction is also included.

## Background

To be able to make an accident reconstruction several important parameters must be known (1, 8). Table 1 shows a model for accident data useful for understanding the connection between different accident parameters in order to link the accident severity to the injury outcome.

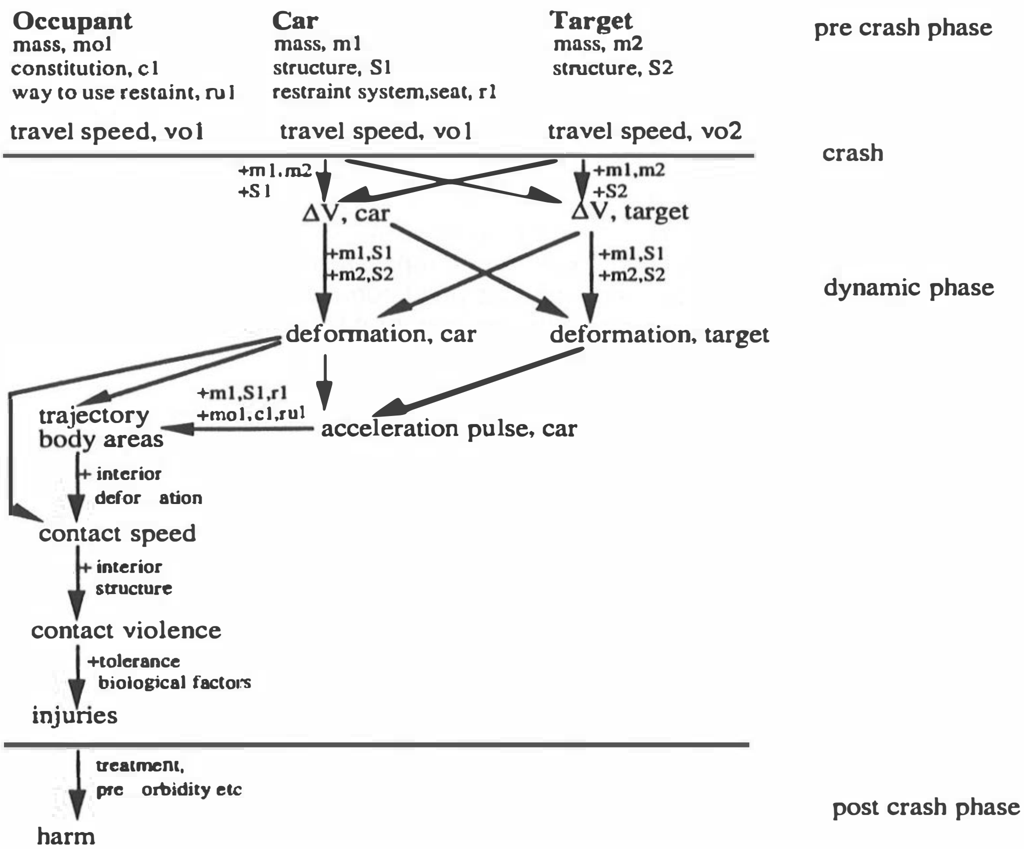


*Table 1, Schematic model for understanding the relation between given parameters and the outcome of an accident (from(8)).*

One parameter of certain interest is the severity of an accident. Often is the accident severity calculated by accident reconstructions where ΔV, change of velocity, is the most often used parameter. Such calculations gives a random error which is too high (around 15% (2)). Another way to take care of the accident severity is by indirect statistical methods (paired comparisons (3)).
The accident severity is essential for several reasons, especially when calculating accident severity distribution and injury risk as a function of accident severity.

The relation between risk of injury and severity can be seen as a dose-response problem where the dose is the severity of the crash and the response is the injury of the occupant in that accident, see fig 1.

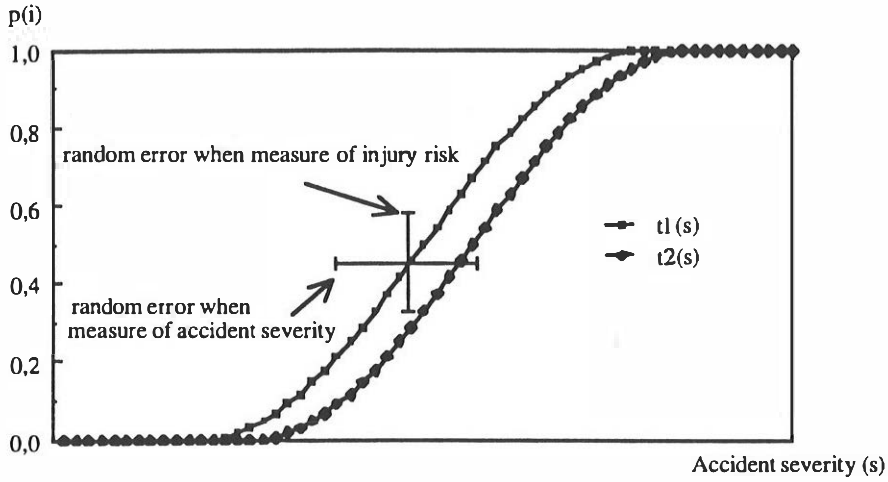


*Fig 1. Schematic probability functions for injury risk for different accident severity. $t_1(s)$ refers to construction (1) and $t_2(s)$ to construction (2).*

At low severities no injuries occur and at a certain level the risk is 100 %. Figure 1 also shows error estimates both concerning biological variation, vertical axis, and variation concerning the severity measurements, horisontal axis. For measurements of the severity of injuries many systems are excisting (AIS etc).

In most cases the accuracy of accident severity is too low to be able to detect changes in safety levels. The measurement errors are greater than the changes in safety levels. One major problem is that data with low accuracy can not be replaced with more data, but will only lead to an answer that is wrong, but with a better precision.(1)
The ultimate data available would of course be the acceleration time history for the crash with identical measurement accuracy as in laboratories.

In this paper an analysis of the results of crash tests with a low cost one dimensional accelerometer aimed at field accident studies is presented. The presented accelerometer has already been tested in several crash tests on a sled (4). In this study the accuracy and precision as well as the reliability has been studied in 14 full scale crash tests with 21 cars involved. Included are also a brief description of the CPR and the mathematics behind the calculations of the crash pulse from the registration.

The obective of the study was

- to verify the accuracy of the accelerometer in several crash modes and velocities.

- to verify the precision under similar circumstances.

## Material and methods

### General description

The presented accelerometer, called Crash Pulse Recorder (CPR) see fig 2, is based on a spring mass system where the movements of the mass in a collision is measured. It includes mechanical, electronical and optical features. The quote spring coefficient over the mass, is choosen in a way that the displacement of the mass covers the time for a normal crash. It means that around 120 ms will be registered depending of the shape of the crash pulse.

The displacement of the mass is registered on a photographic film, fig 3, where light emitting diods (LED) registers its location. The LED is driven by a crystall oscillator circuit which gives a modified square pulse with a frequency of 1000 Hz. The circuit has its' own power cell and does not need an external power unit. The circuit is activated via a micro switch when the mass starts to move in a crash. The trigger level is choosen to be approximately 1 g to avoid registration of manouvre decelleration.

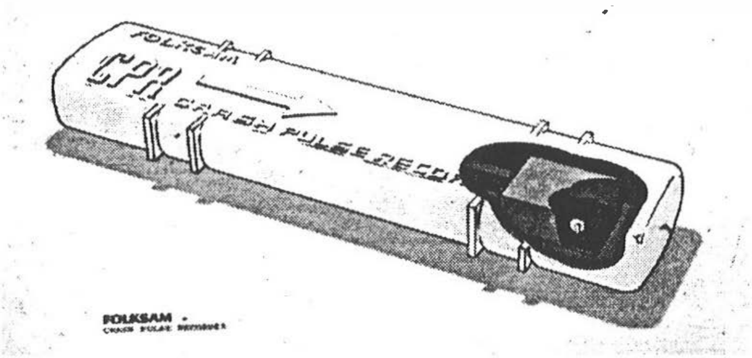


*Fig 2, CPR*

### Analysis of the registration

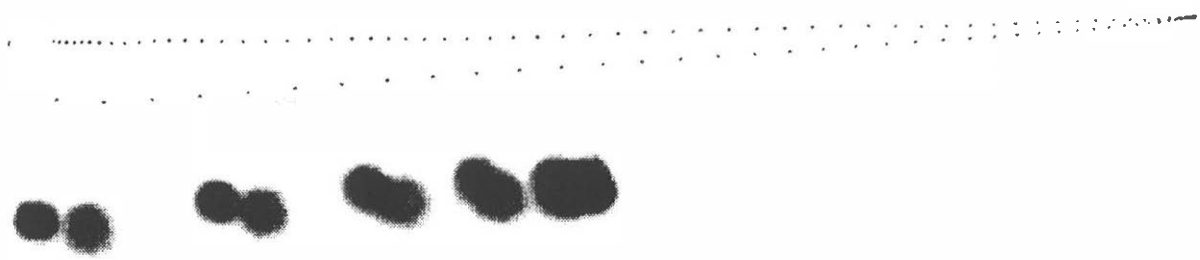

*Fig 3. Displacement registration of the CPR on a photographic film (upper), zoom in of the area where the mass turns (lower).*

After an impact the registrations on the photographic film, fig 3, is scanned into a computer as a digital image. The computer finds the greylevel center of gravity for each mark. From these measurements it is possible to get the displacement of the mass as a function of time. With all characteristic parameters for the CPR measured and with the displacement time history, the acceleration time history can be calculated with the mathematics presented below.

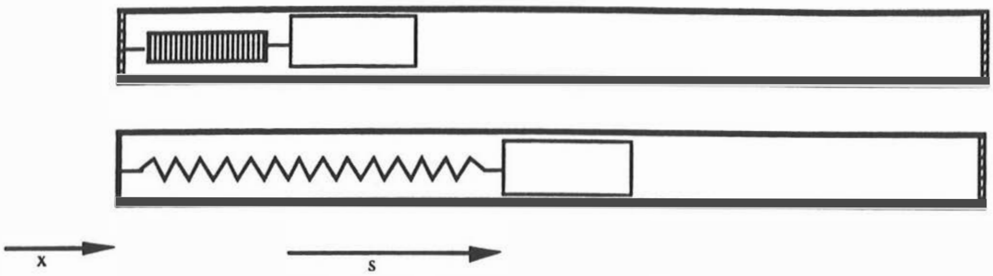

*Fig 4, schematic picture of coordinate system for the mathematic model of the CPR*

$x$ = displacement of the tube relatively a fixed point
$s$ = relative displacement of the mass
$m$ = $m_{mass} + m_{spring}/2$ = equivalent mass for the system
$c$ = damping coefficient for the system
$k$ = constant for the spring
$F_0$ = prestress force of the spring
$F_\mu$ = frictional drag

The coordinate system choosen for the calculations is described in fig 4 where x and s are described above.
The relation between the force of inertia and the external forces acting on the mass is shown in equation 1. Included are terms for spring force, viscous damping, prestress force and frictional drag.

$$m(s''+x'') = -cs' - ks - F_0 - F_\mu \qquad \text{eq 1}$$

$$x'' = -s'' - c/m\, s' - k/m\, s - (F_0 - F_\mu)/m \qquad \text{eq 2}$$

$$s' = ds/dt \qquad \text{eq 3}$$

$$s'' = ds'/dt = d^2s/dt^2 \qquad \text{eq 4}$$

x" is the acceleration pulse for the tube and by that the acceleration pulse for the car if the tube is fixed to the car.

The initial conditions in this case are

$$x(0) = s(0) = 0,\ x'(0) = s'(0) = \Delta V$$

**Full scale comparison tests between accelerometer for laboratory use and CPR**

After several tests on sled testing track a large test series of 14 full scale tests was conducted to conclude the precision and accuracy of the CPR in collisions with cars in different crash situations. An essential part is to study how accurate it measures the crash pulse for different shapes of the pulse, long or short time duration, angled crashes, offset crashes etc. Angled and offset crashes were performed, both car to car collisions as well as barrier tests. Also three lateral impacts were conducted. In total 21 cars in 14 tests were involved. The test configurations are presented in table 2.

Totally 72 CPRs were involved in the tests. To study the precision of the CPR several CPR´s in the same car were installed.

The CPR´s were mounted on a metal sheet where a standard laboratory accelerometer was mounted on the same sheet as a reference accelerometer.

| | | |
|---|---|---|
| test1 | AUDI 80, fullfront barrier test 70 km/h | 2 CPR |
| test2 | MAZDA 2000E, full front barrier test 50 km/h | 5 CPR |
| test3 | Nissan Prairie, full front barrier test 50 km/h | 1 CPR |
| test4 | Nissan Prairie - Volvo 245, rear end collision 50 km/h | 3+5 CPR |
| test5 | Volvo 745 - Volvo 245, lateral impact 50 km/h | 3+7 CPR |
| test6 | Volvo 245 - Volvo 245, lateral impact 50 km/h | 6+4 CPR |
| test7 | Opel Corsa - Volvo 145, 40% overlap 70 km/h | 6+4 CPR |
| test8 | Daihatsu Charade - Volvo 245, 30 ° angled full front 70 km/h | 5+2 CPR |
| test9 | Toyota Corolla, 50% overlap barrier test 56 km/h | 3 CPR |
| test10 | Volvo 245, 50% overlap barrier test 58 km/h | 3 CPR |
| test11 | SAAB 9000 - Opposite vehicle, 40% overlap 56 km/h | 1+1 CPR |
| test12 | Opel Omega - Audi 100, lateral impact 50 km/h | 3+2 CPR |
| test13 | SAAB 900, 50 % overlap, 72 km/h | 2 CPR |
| test14 | Opel Kadett, full frontal collision, 57 km/h | 6 CPR |

*Table 2*

## Results

In all following figures presenting acceleration measurements the measurements, both from CPR and laboratory accelerometers, were filtered with approximately 100 Hz.
In the following 6 figures CPR versus laboratory acceleration measurements are plotted. The figures also includes the velocity. Fig 5 and 6 shows results from barrier tests, fig 5 a full frontal impact in 50 km/h and fig 6 a 50 % overlap in 58 kmph. Fig 7, 8, 9 and 10 presents the results from four car to car collisions. The first is an offset test with 40 % overlap with a relative velocity of 70 kmph. The second is an angled fullfrontal test also in 70 kmph. Fig 9 shows the results from an offset test with 50 % overlap with a relative velocity of 113 kmph. Fig 10 shows the pulse from the opposite vehicle (Volvo 245) in the Daihatsu/Volvo test. That represents a low velocity impact with a ΔV of around 25 km/h.

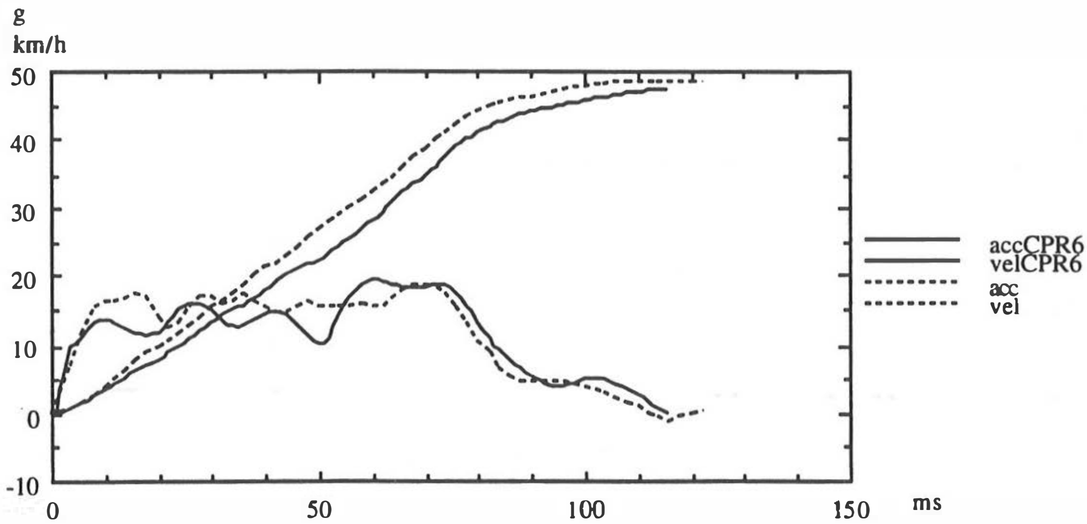


*Fig 5, Accelerometer and CPR measurements from the Mazda in test 2, 50 km/h barrier test.*

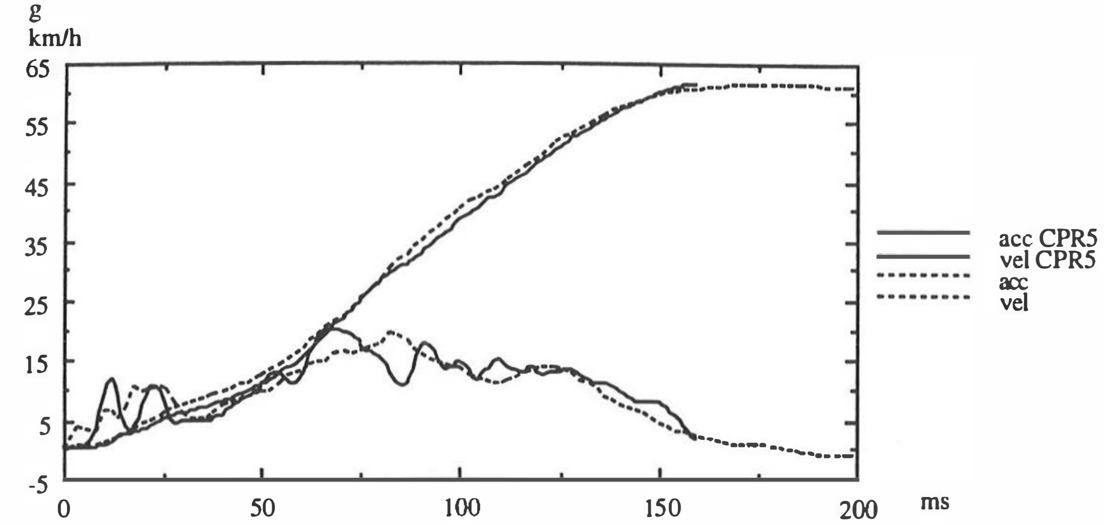


*Fig 6, Accelerometer and CPR measurements from the Volvo in test 10, 50% overlap in 58 km/h, barrier test.*

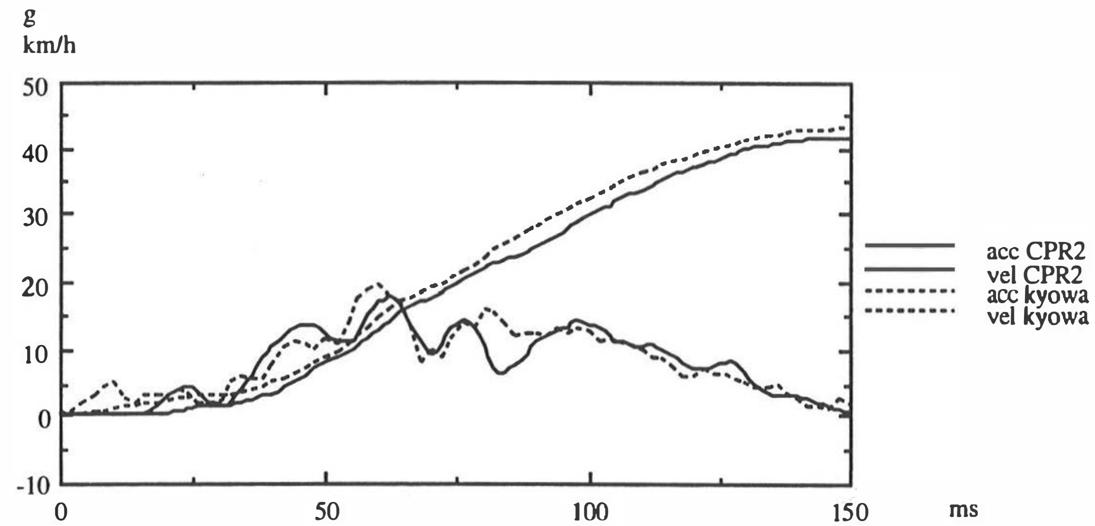


*Fig 7, Accelerometer and CPR measurements from the Opel Corsa in test 7.*

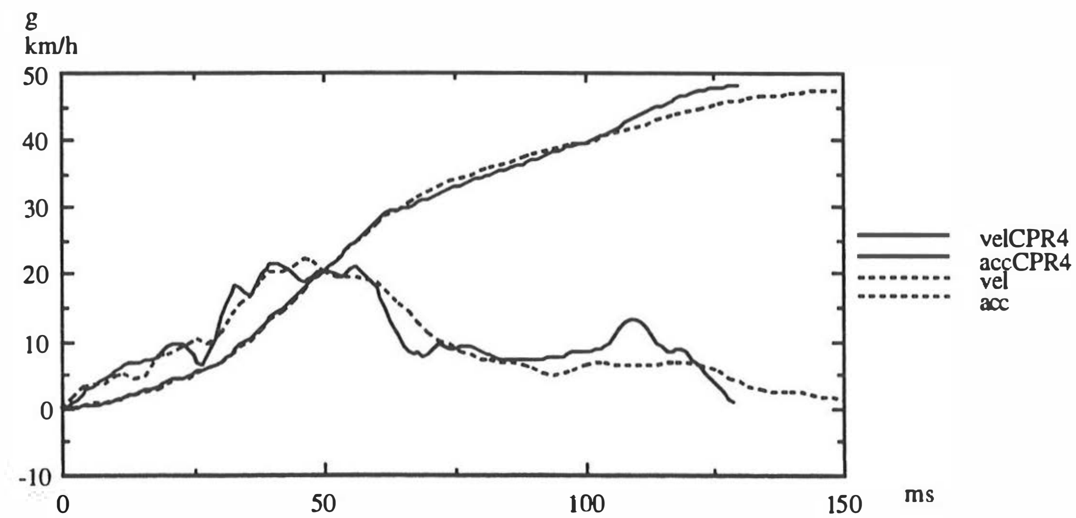


*Fig 8, Accelerometer and CPR measurements from the Daihatsu Charade in test 8.*

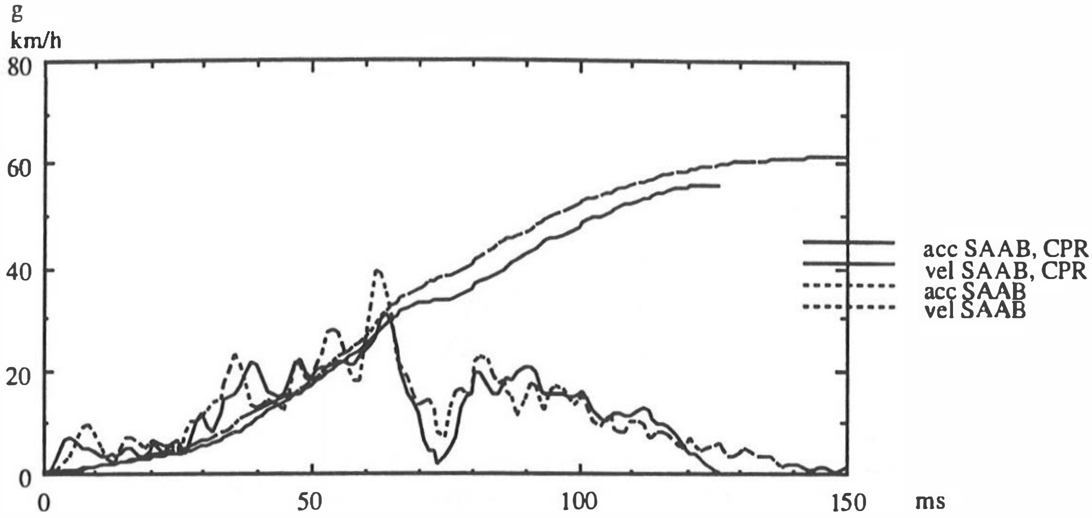


*Fig 9, Accelerometer and CPR measurements from the SAAB in test 11, 50 % overlap car to car collision in 56 km/h.*

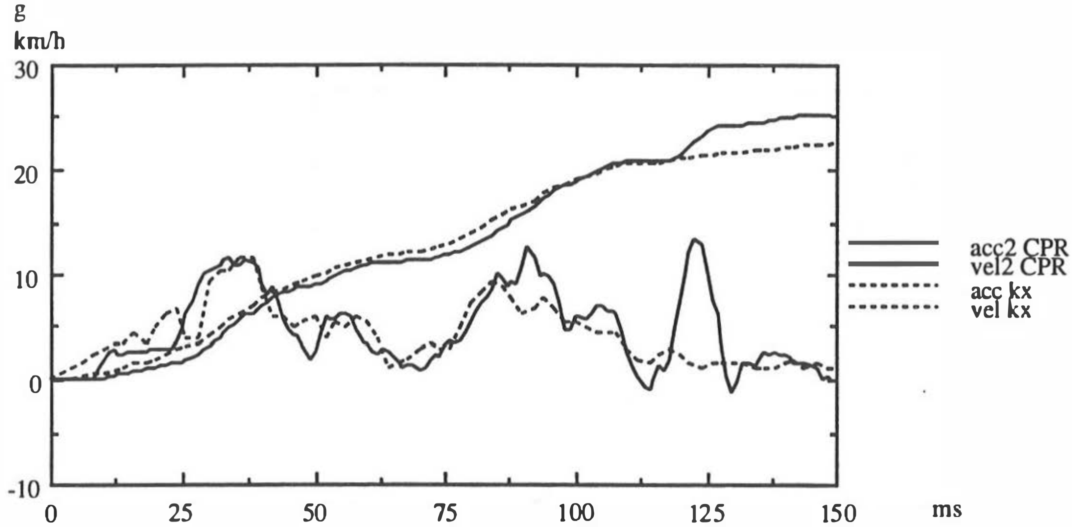


*Fig 10, Accelerometer and CPR measurements from the Volvo 245 in test 8.*

In fig 11, 12 and 13 CPR acceleration measurements are plotted for several CPR´s in the same test. The measurements in fig 12 and 13 are from the same test, the Volvo and the Corsa in test 7.

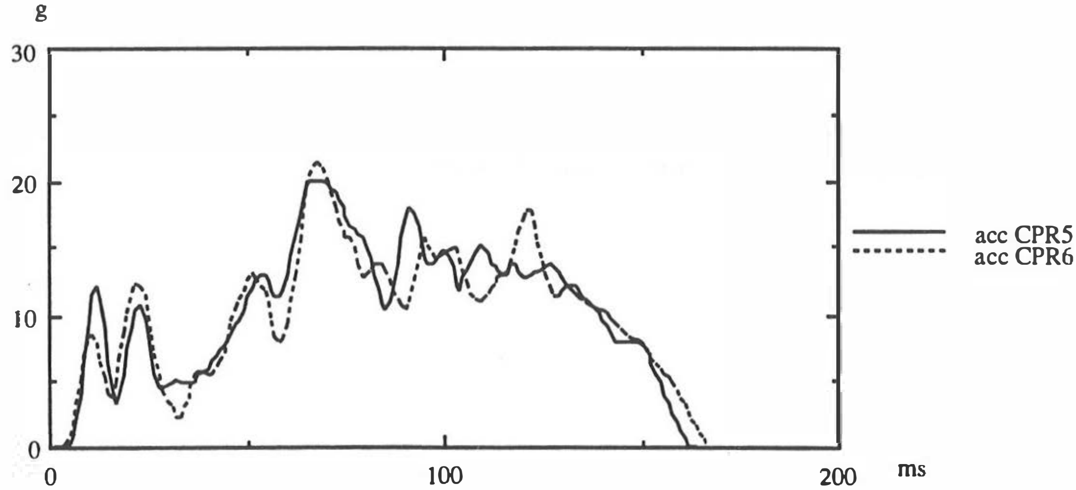


*Fig 11, CPR measurements from two CPR´s in the Volvo in test 10, 50% overlap 58 km/h.*

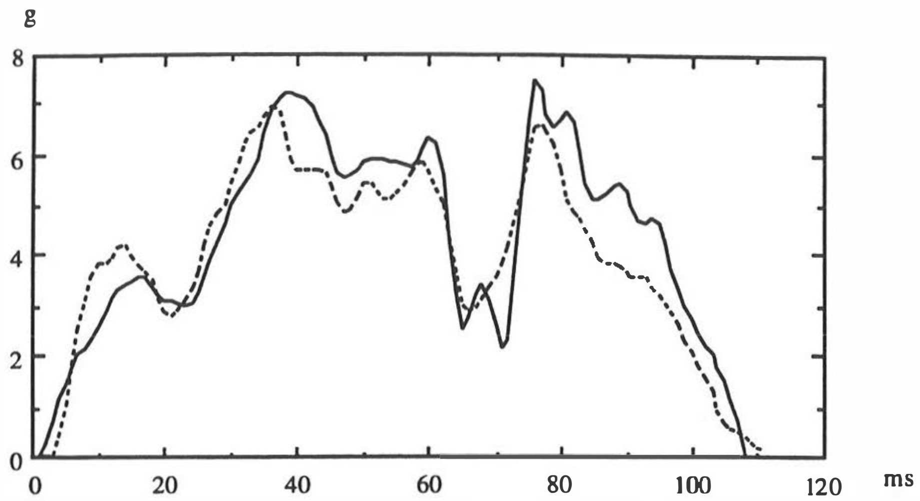


*Fig 12, CPR measurements from two CPR's in the Volvo in test 7, the Volvo experienced a ΔV of around 20 km/h.*

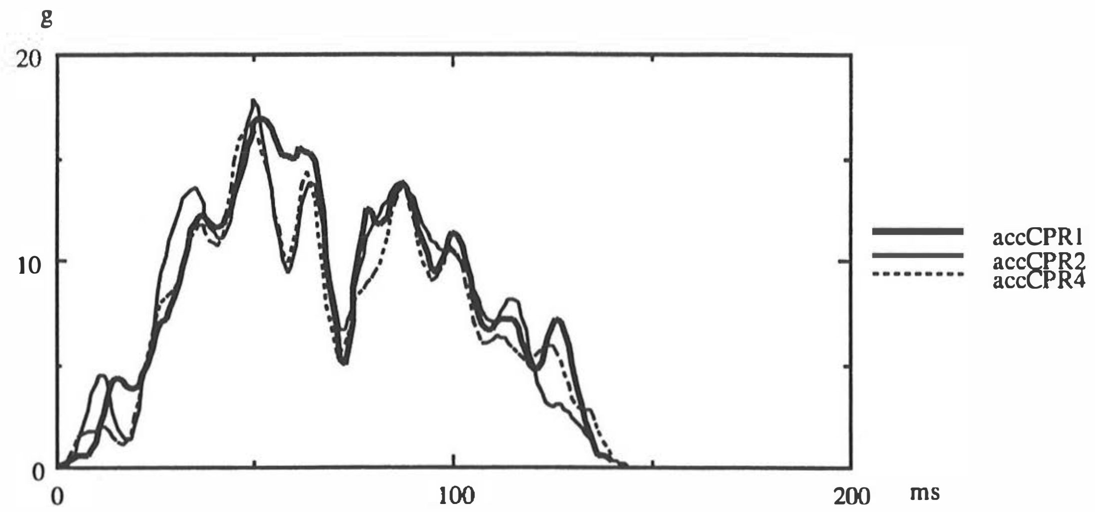


*Fig 13, CPR measurements from three CPR's in the Opel Corsa in test 7, the Corsa experienced a ΔV of around 43 km/h.*

The following figures showes tests where the measurement failed of different reasons. In fig 14 the mass had a too long displacement and it is clear where it hit the wall in the box.
In fig 15 the angle of the collision was too high, around 20°, and the mass turned in to the edge of the box too heavily.
Fig 16 shows the results from the test with the SAAB 900 in 72 kmph with 50 % overlap. In that test the crash time duration was too long so the CPR made two registrations on the film, see fig 17. Fig 16 shows the measurements from the first registration.

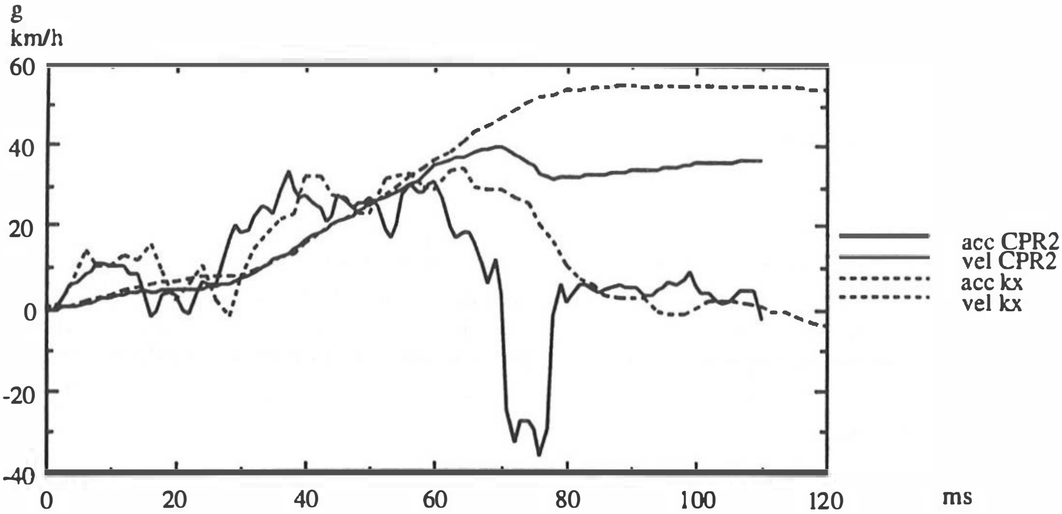


*Fig14, Accelerometer and CPR measurements from the Nissan in test 3, full fron tbarrier test in 50 km/h.*

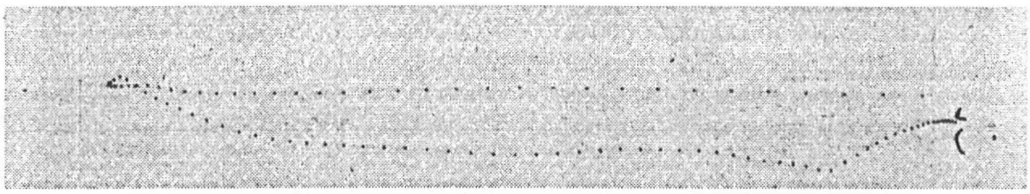

*Fig 15, Registration of a too angled impact .*

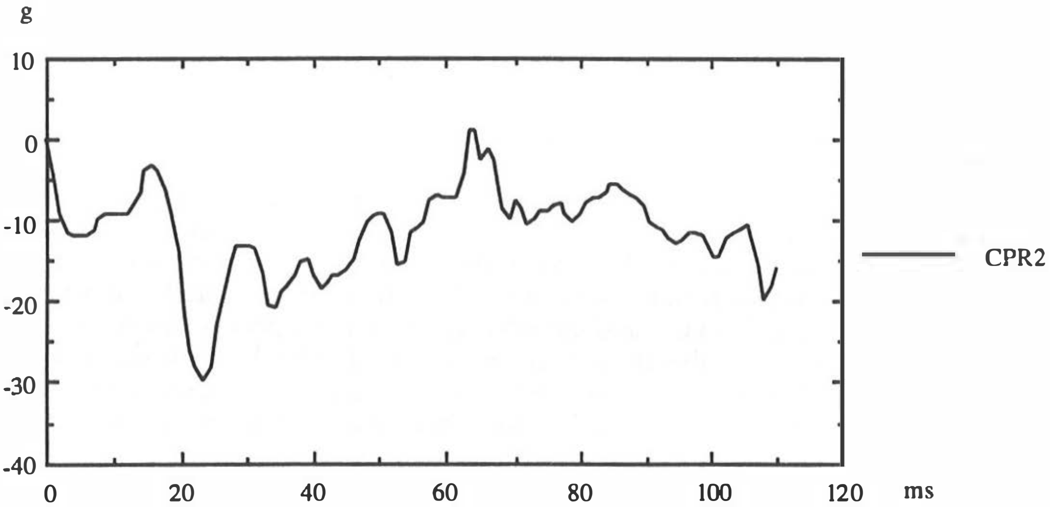


*Fig 16, Measurements from the longest displacement in the registration in fig 17.*

*Fig 17, Registration of two displacements from a CPR in the SAAB in test 13, 50 % overlap in 72 km/h, barrier test.*

## Discussion

The understanding of injury production and effectivness of new safety technology is fundamental in injury epidemiology. To what extent injuries can be explained reduces the number of accidents that are nessesary for such understanding and analysis of i e restraint effectiveness. One way to reduce the number of accidents under study is to increase the validity and reliability of important accident parameters such as accident severity.
In table 1 it is possible to study the complexibility concerning the link between different accident data parameters. To better understand the link between the crash severity and the injury outcome, is it not enough with only a ΔV measurement. A study made by Hartemann et al (5) showed that intrusion affects the injury and fatality rate to a large amount. To measure only ΔV or other parameters as mean acceleration is not enough to relate to injury and fatality rates. Acceleration time history and deformation measurements, especially interior, are therefore essential.

The two possible ways to get the accident severity is either by accident reconstruction or by crash recorder technique where either ΔV or the acceleration time history is measured. Accident severity estimations based on accident reconstruction will almost always give a result with to low accuracy. Reconstructions based on deformations of the car, mass, stiffness, direction of force in the crash etc, has too many parameters which are either unknown or are measured with low accuracy in large accident data bases. Studies has been made concerning the accuracy in accident reconstructions based on manual measurements. In ref (2) it can be seen that deformation measurements made by hand gives an accuracy of ± 7,5 cm. The estimations of the angle of the crash is done with an accuracy of ±20 degrees (2). This leads to an average accuracy of around ± 15 % of the ΔV computation (2) in an idealized case with collisions made in laboratory. It can be expected that the error in real life is even larger, up to 20 - 30 %.

A problem is that poor accident data will result in an inaccurate answer even if a large data material is collected. Measurements with low accuracy can not be replaced with more data (1), but will only lead to an answer that is wrong, with a better precision (biased).

Several times crash recorders have been developed and tried out. Most of the time for legal purposes, but also for research purposes in the interior safety field. The presented crash recorder will in relation to other proposed recorders (6,7), only measure parameters that are fairly insensitive to the integrity of the driver. Most of the crash recorders measures many parameters in the pre crash, crash as well as the post crash phase which gives good possibilities for research and accident reconstruction. Their major problem is that they are to expensive. In order to make large fleet field experience with crash recorders it is essential that the cost for each unit and its installation is low. With the CPR presented in this paper it is possible to, in retrospect, calibrate it and measure all the parameters necessary for the analysis. The production cost can therefore be reduced dramatically. It measures only the acceleration time history during the crash phase in one dimension. The requirement concerning accuracy and precision are less than for laboratory accelerometers. The production cost for each unit will therefore be around 5 USD.

Several sled tests has already been performed with good results (4). A final construction and analysis method has been developed. After the tests on sled a large test series of 14 full scale tests were conducted to conclude the precision and accuracy of the CPR in collisions with cars in different crash situations. An essential part is to study how accurate it measures the crash pulse for different shapes of the pulse, long or short time duration, angled crashes and offset crashes. The presented CPR measures mainly frontal collisions, but it is possible to measure also angled collisions in at least ± 15 degrees range. Offset collisions were performed for both car to car collisions as well as barrier tests to study the CPR measurements in that type of collisions with rotations involved. One angled car to car collision was also performed with an angle of 30 degrees. Fig 18 shows the registration of an offset collision where the mass turned into the edge of the box in an early stage of the crash. The result, see fig 9, shows that the shape of the pulse is not affected by that fact. If the impact angle is too high the crash pulse of course will be affected. The impact angle is clearly visible on the film, so it is no problem to sort out these types of impacts from the collected material. The film in fig 15 shows an impact where the angle was too high, around 20°.

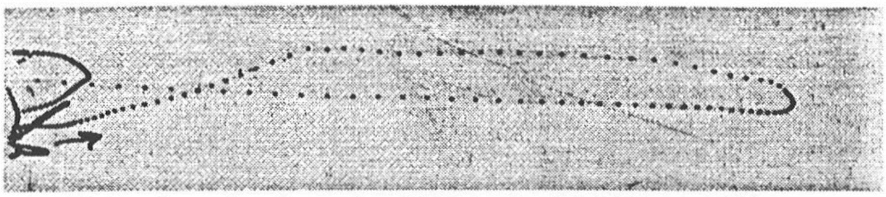

*Fig 18, Registration from the CPR in the SAAB in test 11.*

The CPR is optimized for measuring collisions with a ΔV of around 50 km/h. The longer displacement of the mass in the box, the higher accuracy of the measurement. The limit is the length of the box which in turn depends on the space available in the car. One problem that can occur is then that the CPR gives a measurement with low accuracy for the low speed impacts and in the high speed impacts the mass turns into the top of the box.
Fig 10 and 12 shows results from low velocity impacts under ΔV 30 km/h. The accuracy was slightly lower than for the severe impacts as in fig 6, 9 and 16. Fig 14 shows the results from a test where the constant for the spring was low for the CPR. In that case the mass turned into the top of the box. Fig 19 shows the registration from the CPR in that test.

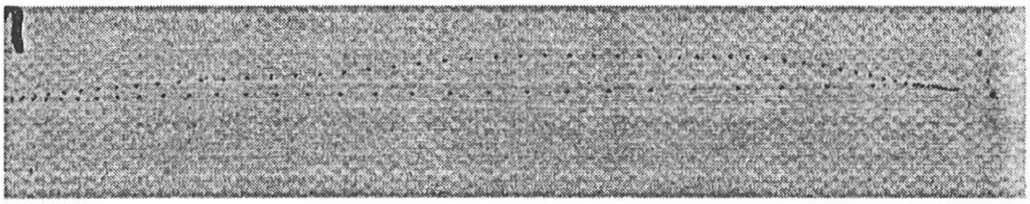

*Fig 19, Registration from the CPR in the Nissan in test 3.*

The problem with pulses with long time duration can be studied in fig 17. On that film 2 registrations has been made from the same impact. The time duration was so long that the mass made to displacements. Fig 12 shows the acceleration time history for the longest registration on the film in that test. The acceleration pulse from the CPR ends up at a g-level of 20 g. The measurements from the reference laboratory accelerometers shows how the real pulse continues. In fig 7, 8 and 9 acceleration pulses with long time duration is measured. In fig 9 the CPR measures the pulse even in 150 ms while in fig 8 and 9 only until 125 ms. How long time duration the CPR can measure depends on the shape of the pulse.

It is obvious, that in most situations where the CPR will fail to give an adequate registration, it is possible to detect the failure from the registration.

To study the precision of the CPR several CPR´s were installed in the same car. In fig 11, 12 and 13 measurements from CPR´s in the same car is presented. In fig 12 and 13 low velocity impacts is shown. Even in low velocity impacts where the accuracy is a little bit lower than for the severe ones the precision is very good. The different CPR´s in the same test shows almost the same shape of the accelerasion pulse.

The presented Crash Pulse Recorder has been produced in more than 20.000 units. Over 15.000 are on mounted in cars in Sweden. So far around 25 of these cars have been involved in accidents.

## Conclusions

With accident severity measurements made by Crash Pulse Recorders it is possible to make large field experience studies.

The accuracy and precsion is high enough for accident severity measurements in term of acceleration time history.

**References**

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