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New Crash Discrimination Algorithms and Locations of Accelerometers

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Two new algorithms for frontal crash discrimination were proposed; one used the deceleration change multiplied by the velocity change as a metric, and the other used the deceleration squared multiplied by the velocity change. For all the frontal crash modes studied in this paper, the first algorithm resulted in the time-to-fires of frontal air bags less than the required time-to-fires, and the second algorithm resulted in the time-to-fires less than the required time-to-fires except only for underride crashes. Moreover, it was proposed that an accelerometer be installed at each side of the rails, rockers or pillars to assess the crash severity of each side especially during an asymmetric crash such as oblique and offset crashes. As an example, the deceleration pulses measured at the left and right B-pillar • rocker locations were processed through the first algorithm, and appropriate but different time-to-fires of the driver air bag and the passenger air bag were obtained.

Keywords: Crash Discrimination Algorithm, Safety ECU, Advanced Air Bag

INTRODUCTION

From 1986 to June 1, 1998, air bag deployment saved about 3150 lives but it claimed about 105 lives in the United States (1)**. Most of the people who died from the deployment were small adults or children close to the air bag module at time of deployment. In order to minimize the risks posed by air bags and improve the protection for occupants, many researchers are involved in the development of advanced air bag technologies. The technologies enable air bags to inflate with different levels of power, based on information on the vehicle and the occupants just before and during a crash such as the crash severity, occupant position and weight (1,2). NHTSA (National Highway Traffic Safety Administra-tion) has announced an NPRM and an SNPRM to upgrade FMVSS208 which require some new passenger cars and light trucks to be equipped with advanced air bags beginning September 1, 2002, and require all new cars and light trucks beginning September 1, 2005 (1,3).

In addition to the advanced air bag technologies, many researches have been done on crash discrimination algorithms and sensing methodologies in order to improve the reliability of air bags (4-12). In most of vehicles currently manufactured air bag deployment is controlled by a safety ECU (Electronic Control Unit) which is installed at the tunnel. The safety ECU consists of an accelerometer, a microprocessor, an energy reservoir, and some peripheries. The accelerometer measures deceleration during a crash, and the microprocessor processes the signal of deceleration to determine whether and when air bag deployment is required. An algorithm the microprocessor uses to determine whether and when air bag deployment is required is called a crash discrimination algorithm. In such an algorithm the velocity change has mostly been used as a metric, and air bag deployment is requested when the velocity change becomes larger than a certain threshold. Instead of the velocity change, the deceleration, deceleration squared, power, rate of power or the summation of deceleration squared has also been used (4-7). However, the algorithms using one of these metrics could not result in TTF's (time-to-fires) of frontal air bags less than RTTF's (required time-to-fires) especially for pole, offset, oblique, and underride crashes. This means that the air bags would deploy later than required. In addition, during an asymmetric crash such as oblique and offset crashes, the occupants do not move straight forward, but they usually move inclined to one side. If TTF is larger than RTTF especially for an asymmetric crash, it is likely for the occupants to slip over the air bags and to impact the vehicle interior. Therefore, it is necessary to reduce TTF's below RTTF's, and two new algorithms were proposed in this paper; one used the deceleration change multiplied by the velocity change as a metric, and the other used the deceleration squared multiplied by the velocity change. In order to evaluate the applicability of these algorithms, TTF's of frontal air bags of two different types of vehicles were determined by processing the deceleration pulses measured at the tunnel during several frontal crash modes, and they were compared to RTTF's. The first algorithm resulted in TTF's less than RTTF's for all the crash modes, and the second algorithm resulted in TTF's less than RTTF's except only for the underride crashes.

It is noteworthy that according to NASS (National Accident Sampling System) data more than 50% of frontal crashes are non-head-on crashes such as offset and oblique crashes (8). During these crashes, the struck side has more intrusion, and it is more likely for the occupant at the struck side to get injured. By a conventional safety ECU which has an accelerometer at the tunnel, it is difficult to differentiate the crash severity of each side because the deceleration pulse is similar whether the driver side or the passenger side of the vehicle is engaged. However, if an accelerometer were installed at each side of the rails, rockers or pillars, it would be possible to assess the crash severity of each side and to determine the TTF of the driver air bag and that of the passenger air bag separately. This would be necessary especially in an advanced air bag system because an advanced air bag is supposed to inflate with different levels of power depending on the crash severity. Therefore, in this paper the deceleration pulse obtained at each side of the B-pillar • rocker location was processed, and the TTF's of the driver air bag and the passenger air bag were determined. As expected, the TTF's for the air bag at the struck side were less than those for the air bag at the other side during asymmetric crashes.

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** Numbers in parentheses designate references at the end of paper

SIGNAL PROCESSING

A conventional safety ECU consists of an accelerometer, a microprocessor, an energy reservoir, a safing sensor, and some peripheries. The accelerometer measures and sends the deceleration signal to the microprocessor through a built-in anti-aliasing low pass filter (13). The sampling and the cut-off frequencies for the anti-aliasing filter were determined, based on the frequency and amplitude information about 35 *mph* barrier crash pulses obtained through the FFT (Fast Fourier Transformation). The microprocessor samples the deceleration signal and filters it through a software to remove undesirable noises, which prevents air bags from deploying at a low speed crash. As an example, an unfiltered signal and the corresponding filtered signal are shown in Fig. 1.

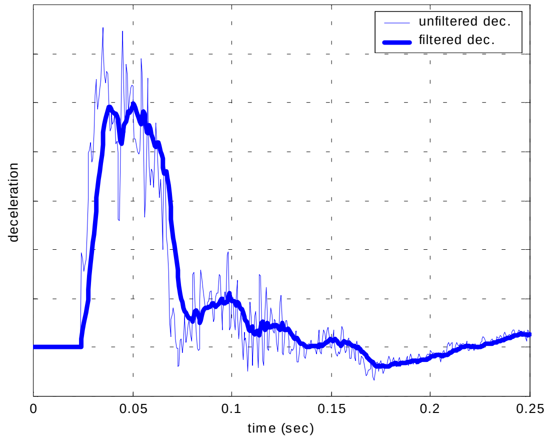

Figure 1 – Deceleration signals before and after the digital filtering

NEW CRASH DISCRIMINATION ALGORITHMS

In this paper two algorithms were proposed for crash discrimination. The first one used the deceleration change multiplied by the velocity change as a metric, and the second one used the deceleration squared multiplied by the velocity change. The deceleration is related to the impact force occurring during a crash, and the deceleration change is related to the impact force change. In addition, the velocity change is related to the summation of the impact force from the beginning of a crash because the velocity change is equal to the integral of the deceleration. Therefore, both the impact force change (or the impact force) and the accumulation of the impact force can be monitored simultaneously through the metrics. Moreover, the noises in the deceleration signal can be effectively eliminated, being multiplied by the velocity change because the velocity change signal is very smooth.

It is well known that a "hard" pulse occurs during a crash with the full front engaged with a hard structure, and the impact force or the impact force change is high. In contrast, a "soft" pulse occurs during a crash with only a portion of the front engaged such as pole, offset, oblique, and underride crashes, and the accumulation of the impact force is high. Therefore, through the algorithms proposed in this paper a crash can be detected adequately whether it entails a "hard" pulse or a "soft" pulse.

RTTF's of frontal air bags can be determined by so call the 5 *in* – 30 *msec* rule (14). That is, RTTF is equal to the time for the occupant to move forward by 5 *in* minus the time for the air bag to inflate more than 80%, which is about 30 *msec*. The time for the 5 *in* movement can be determined by two methods. The first method is to integrate twice the deceleration signal measured at any point in the uncrushed zone such as at the tunnel or at the B-pillar • rocker location. The second method is to measure the time by the analysis of the crash film.

The TTF's and RTTF's for the frontal air bags of a medium size passenger car currently manufactured in Korea were obtained, and the ratios of TTF's to RTTF's are shown in Table 1 and 2. Here TTF's were determined by the algorithms proposed in this paper and other algorithms published in the literature which use the deceleration, deceleration squared, power, power rate, or the summation of deceleration squared as a metric (4-7). A metric can be processed as a function of the time from the beginning of a crash, but it can also be processed as a function of the velocity change. The ratios shown in Table 1 were obtained when the metrics were processed as a function of the time, and the ratios shown in Table 2 were obtained when the metrics were processed as a function of the velocity change. In Table 1 and 2, NF (no fire) means that the air bag deployment is not needed.

The results shown in Table 1 indicate that the first algorithm proposed in this paper resulted in TTF's less than RTTF's except only for the 20 *mph* underride crash, but the other algorithms including the second algorithm proposed in this paper resulted in TTF's larger than RTTF's for the 19 *mph* pole, 20 *mph* underride, and 30 *mph* pole crashes. The results shown in Table 2 indicate that the first algorithm resulted in TTF's less than RTTF's for all the crash modes, and the second algorithm resulted in TTF's less than RTTF's except only for the 20 *mph* underride crash. However, the other algorithms resulted in TTF's larger than RTTF's for the frontal, pole, oblique, offset and underride crashes.

Table 1 – TTF/RTTF obtained when the metric is represented as a function of the time

Units : %

Crash mode	$\lvert\Delta$dec.$\rvert$ x vel	dec.^{2} x vel	dec.	dec.^{2}	power	power rate	Σdec.^{2}
8mph frontal	NF	NF	NF	NF	NF	NF	NF
15km/h ffset	NF	NF	NF	NF	NF	NF	NF
14mph frontal	58	58	55	62	62	60	68
30mph frontal	60	47	45	50	50	50	55
35mph frontal	83	83	63	89	94	73	89
19mph pole	98	127	125	132	128	128	173
20mph underride	120	123	111	131	130	124	162
22mph left oblique	40	33	30	34	38	33	37
22mph right oblique	43	36	31	37	44	36	39
30mph pole	95	110	108	163	158	160	183
30mph right oblique	41	39	38	43	43	41	50
35mph offset	27	22	39	25	32	24	27

Table 2 – TTF/RTTF obtained when the metric is represented as a function of the velocity change

Units : %

Crash mode	$\|\Delta$dec.$\|$ x vel	dec.^{2} x vel	dec.	dec.^{2}	power	power rate	Σdec.^{2}
8mph frontal	NF	NF	NF	NF	NF	NF	NF
15km/h ffset	NF	NF	NF	NF	NF	NF	NF
14mph frontal	58	60	58	67	72	62	95
30mph frontal	47	47	45	53	53	50	76
35mph frontal	83	89	57	99	104	94	140
19mph pole	88	89	142	155	89	90	165
20mph underride	90	108	110	116	110	111	164
22mph left oblique	40	37	30	195	185	193	44
22mph right oblique	42	43	31	183	170	46	59
30mph pole	37	97	107	108	97	98	127
30mph right oblique	39	39	39	46	70	43	57
35mph offset	27	24	19	178	154	34	47

The TTF's and RTTF's for the frontal air bags of a sports utility vehicle currently manufactured in Korea were also obtained with the metrics processed as a function of the velocity change, and the ratios of TTF's to RTTF's are shown in Table 3. Once again, the first algorithm resulted in TTF's less than RTTF's for all the crash modes, and the second algorithm resulted in TTF's less than RTTF's except only for the 20 *mph* underride crash although the other algorithms resulted in TTF's larger than RTTF's for pole, oblique, offset, and underride crashes.

Table 3 – TTF/RTTF obtained when the metric is represented as a function of the velocity change

Units : %

Crash mode	$\|\Delta$dec.$\|$ x vel	dec.^{2} x vel	dec.	dec.^{2}	power	power rate	Σdec.^{2}
8mph frontal	NF	NF	NF	NF	NF	NF	NF
15km/h ffset	NF	NF	NF	NF	NF	NF	NF
14mph frontal	58	60	58	67	72	62	100
30mph frontal	60	60	57	67	67	63	100
35mph frontal	83	89	57	99	104	94	146
19mph pole	89	89	142	155	89	90	165
20mph underride	90	121	116	127	121	122	180
22mph left oblique	40	37	30	195	185	193	67
22mph right oblique	43	43	31	183	170	46	67
30mph pole	37	97	107	108	97	98	132
30mph right oblique	39	39	39	46	70	43	138
35mph offset	27	24	20	183	159	35	103

NEW LOCATIONS OF ACCELEROMETERS

In most of vehicles a safety ECU is located at the tunnel, i.e. at the middle of the vehicle from each side, and it has an accelerometer. Therefore, a similar deceleration pulse is measured by the accelerometer whether the driver side or the passenger side is engaged during an asymmetric crash. However, there occurs more intrusion at the struck side, and it is more likely for the occupant at the struck side to get injured. Deceleration pulses measured by the accelerometer during a left oblique crash and a right oblique crash are shown in Fig. 2, and they are slightly different due to asymmetric arrangement of components under the hood. This implies that the safety ECU would not discern which side is engaged during an asymmetric crash. This would be a serious problem especially for an advanced air bag system because an advanced air bag system is supposed to modulate the air bag power based on the crash severity.

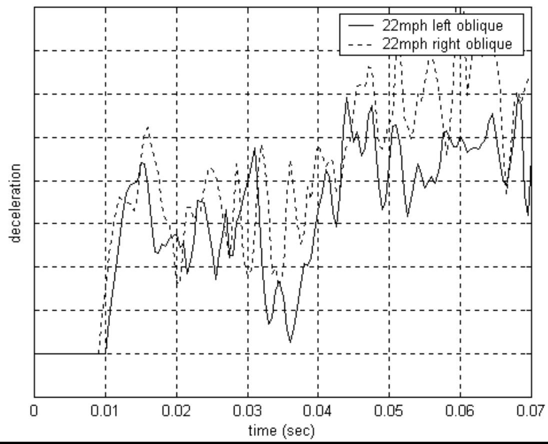

Figure 2 – Deceleration pulses measured at the tunnel during the left and right oblique crashes

However, if an accelerometer were installed at each side of the rails, rockers or pillars, the accelerometer installed at the side closer to the struck point would sense a severer deceleration pulse during an asymmetric crash. Figure 3(a) shows the deceleration pulses measured at the left and right B-pillar • rocker locations during a left oblique crash of the medium size passenger car. It is clear that the pulse measured at the left location is severer at the early stage of the event. Figure 3(b) shows the deceleration pulses measured during a right oblique crash, and the pulse measured at the right location is severer. Since the deceleration change multiplied by the velocity change turned out to be the best metric, the metric was plotted as a function of the velocity change for the left oblique crash and the right oblique crash in Fig. 4(a) and (b), respectively. Once again, the pulse measured at the side closer to the struck point is severer at the early stage of the event. In Table 4, the ratios of TTF to RTTF were shown for oblique and offset crashes. Here RTTF's were obtained by integrating twice the deceleration pulses measured at the tunnel because they were almost the same as RTTF's obtained from the deceleration pulse measured at either the left B-pillar • rocker location or the right B-pillar • rocker location. It is noteworthy that TTF's were less than RTTF's for all the asymmetric crashes studied here, and TTF's for the struck side were quite less than those for the other side. This implies that the air bag at the struck side would deploy earlier and/or more powerfully than the air bag at the other side. In Table 5, the ratios were also shown for symmetric crashes. All the ratios were less than 1, and TTF's for both sides were almost the same.

CONCLUSION

In this paper, two crash discrimination algorithms were

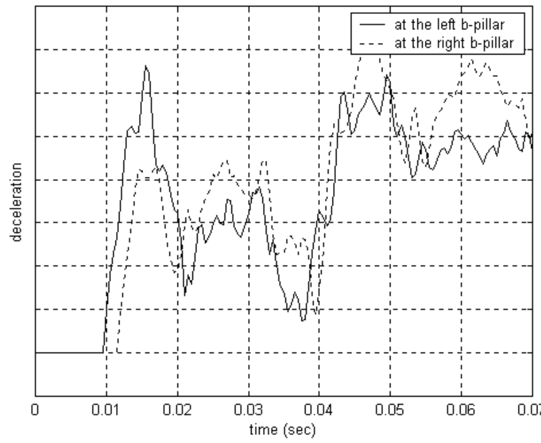

Figure 3(a) – Deceleration pulses obtained at the B-pillar-rocker locations during the left oblique crash

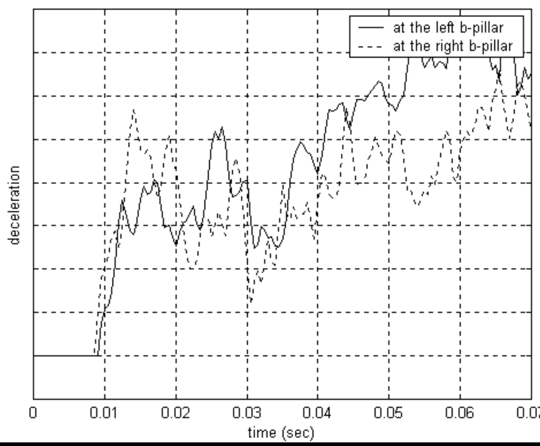

Figure 3(b) – Deceleration pulses obtained at the B-pillar-rocker locations during the right oblique crash

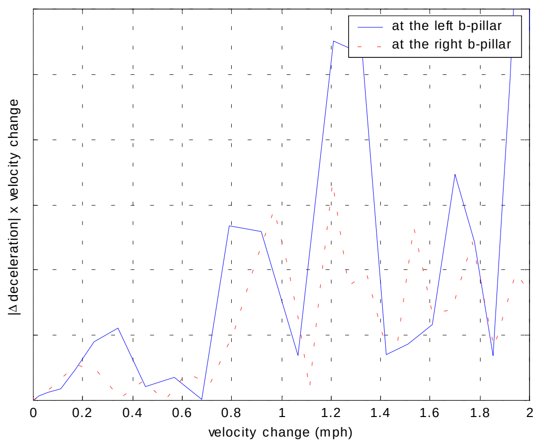

Figure 4(a) - |Δdecel.| x velocity change signals for the left oblique crash

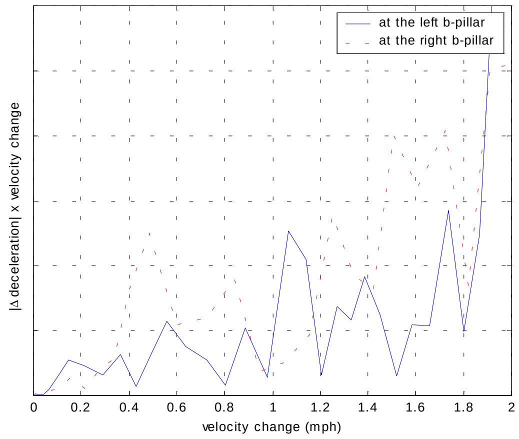

Figure 4(b) - |Δdecel.| x velocity change signals for the left oblique crash

Table 4 – TTF/RTTF obtained from the deceleration pulses measured at the B-pillar-rocker locations

Crash mode	**Sensor location**	**TTF / RTTF**
15km/h offset	left b-pillar	NF
	right b-pillar	NF
22mph left oblique	left b-pillar	32%
	right b-pillar	80%
22mph right oblique	left b-pillar	51%
	right b-pillar	37%
35mph offset	left b-pillar	28%
	right b-pillar	40%

Table 5 – TTF/RTTF obtained from the deceleration pulses measured at the B-pillar-rocker locations during symmetric crashes

Crash mode	**Seosor location**	**TTF / RTTF**
14mph frontal	left b-pillar	57%
	right b-pillar	57%
30mph frontal	left b-pillar	60%
	right b-pillar	63%
35mph frontal	left b-pillar	83%
	right b-pillar	83%
20mph underride	left b-pillar	82%
	right b-pillar	95%
30mph pole	left b-pillar	95%
	right b-pillar	83%

proposed, and they were evaluated for several frontal crash modes of two different types of vehicles. The algorithm in which the metric of the deceleration change multiplied by velocity change was processed as a function of the velocity change resulted in TTF's less than RTTF's for all the frontal crash modes considered in this paper. The algorithm in which the metric of the deceleration squared multiplied by the velocity change was processed as a function of the velocity change also resulted in TTF's less than RTTF's except only for the underride crashes. Through the metrics both the impact force change (or the impact force) and the accumulation of the impact force can be monitored simultaneously. That is, both a “hard” pulse occurring during a full-barrier-type crash and a “soft” pulse occurring during a pole, underride, oblique or offset crash can be detected early enough.

Moreover, the deceleration pulses measured at left and right B-pillar • rocker locations were processed to determine TTF’s for the driver air bag and passenger air bag separately, utilizing the metric of the deceleration change multiplied by the velocity change. The TTF’s for the driver air bag were smaller than those for the passenger air bags under left oblique crashes and offset crashes with the driver side engaged, but vise versa under right oblique crashes. However, TTF’s for both air bags were almost the same during symmetric crashes. This implies that it would be possible to assess the crash severity of each side adequately during an asymmetric crash or a symmetric crash if an accelerometer were installed at each side of the rails, rockers or pillars. It is common to install the sensing device for the side impact crashes at the B-pillar • rocker locations. Therefore, it would be possible to pack together the sensing devices both for the frontal crashes and the side impact crashes.

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