PERFORMANCE OF AN IMPROVED ABS AND EXPECTED SAFETY BENEFITS

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ABSTRACT

ESC efficiency to reduce accident is now well proven. But ESC has a significant cost and to install it as a standard equipment on small cars will make them more expensive and then slow down the modernisation of the car in the street which is the most efficient way to improve safety.

On the other hand ABS is already standard equipment on all cars in many countries. Then if an ABS can significantly improve the stability of the cars in real world accident cases, one can expect major safety benefits without this cost problem.

As ABS can be efficient only when drivers brake, accident statistics obtained in France and studies of drivers' reactions are shown to establish in which cases the driver has an action on the brakes. Important cases like accident in a curve, in a straight line or at an intersection are addressed. It is shown that a significant accident reduction can be expected with an improved ABS.

We made measurements of car behaviour during tests reproducing such accident situations. Results of these measurements are produced to compare the stability of a car equipped with the sensors of a state of the art ESC and the improved ABS. As a reference performance of a car fitted with a current ABS are also provided.
The special algorithms of ABS used to obtain these improvements are introduced.

INTRODUCTION

In [1] we can find an evaluation of the efficiency of ESC to avoid accident.
This study is interesting as it distinguishes the different accident scenarios. Then it identifies accident situations for which the ESC is pertinent or not. For example ESC is pertinent for loss of control accidents whilst it is not for cars pulling out of a junction. According to this paper, the accidents for which the ESC is pertinent are related to loss of control or guidance problems. The given list is :

- Single car accident. Loss of control or guidance problem on a straight road outside junction
- Loss of control or guidance problem on a straight road outside junction. Collision with an opponent
- Single car accident. Loss of control or guidance problem in a bend outside junction
- Loss of control or guidance problem in a bend. Collision with an opponent
- Single car accident. Loss of control or guidance problem at a junction.

For these accident scenarios we assume that an enhancement of vehicle stability is possible via ABS when the driver brakes. To estimate the possible accident reduction possible this way, we need to determine the proportion of cases with a driver's action on the brakes. Of course when the driver does not brake the ESC will be the only way to avoid these kinds of accidents.
Several studies based on real world accidents give indications. With [2] we learn that there is a rate of 40-50% braking actions in fatal accidents in France. This study is not precise enough and we cannot make a distinction between the accident for which an ESP is pertinent or not.
For this purpose specific studies are more efficient. During such studies an accident situation is simulated to study the driver behaviour. The LAB Laboratory of Accidentology, Biomechanics and studies of human behaviour carried out such studies for accident scenarios in a straight line and accident scenarios in a curve. These studies are realized on the field and not in a simulator. The details of these experiments methodology and accident simulation can be found in [3] for straight line and [4] for a curve. The chosen scenarios are pertinent for the study of guidance or loss of control problems as they may lead to severe steering wheel manoeuvre.

The main advantage of a specific study is that the driver's actions are measured. Then we can see that:

- 68 % of drivers began by braking before steering in the straight line case
- 57 % of the drivers brake before or during the steering manoeuvre in the curve case

With this figures, we see that an improvement of vehicle stability obtain via ABS will address a significant proportion of ESC pertinent accidents.

PROPOSED IMPROVEMENT

Existing systems

During a curve, when the driver brakes the ABS tries two obtain the same slip or the same braking effort on the two wheels of an axle. When a difference exists it is a small one. It is obtained only via a reduction of the inside wheel braking effort due to a sooner ABS regulation as the vertical load is smaller.
These small differences in the braking effort produce only a small yaw torque that will not be sufficient to counter an oversteer tendency of the car. That is true even when the driver brakes strongly.

This is illustrated in figure 1 and figure 2. The desired slip level corresponding to the black horizontal lines in the small graphs are kept constant during the manoeuvres. The values are the same for the two wheels of an axle and are the same as during a straight line.

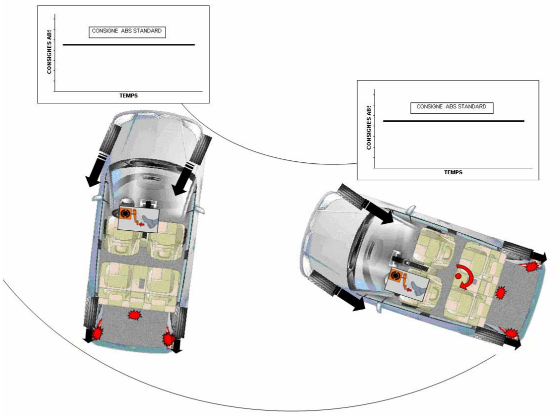

Figure 1. The desired slip level is kept constant during the curve

Description of the new algorithm

The system employed is an ABS 8 from Bosh only equipped with the four wheel speed sensors. The aim of this study is to avoid side slip angle increase or at least to limit it.
This is obtained with a new algorithm of ABS developed during this study.
The inputs are:

- an estimation of lateral acceleration a_y based on the wheel speeds.
- An ABS instability regulation criteria for each wheel

The estimation of a_y is used in a function to recognize

- a curve in ABS
- a lane change with ABS

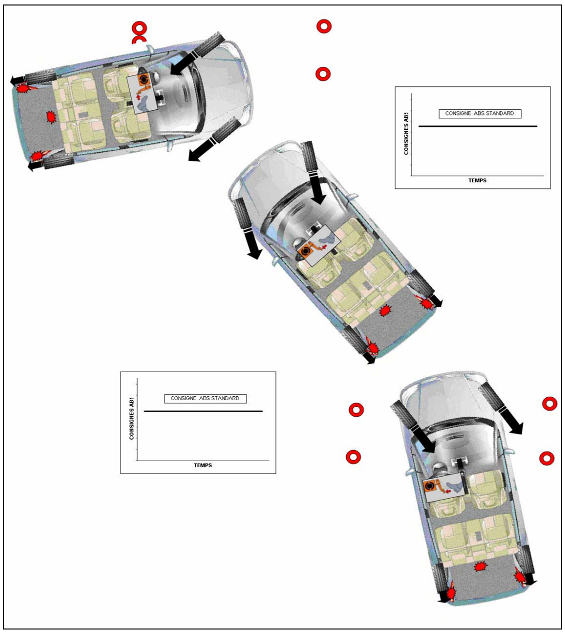

Figure 2. The desired slip level is kept constant during a sever lane change manoeuvre

Depending on these inputs the ABS instability regulation criteria is modified. In ABS this criteria is here to avoid a sudden increase of the tyre skid. So it is related to the desired longitudinal slip of the tyre. This criteria is modified in order to increase the drag of the wheels outside the curve and to reduce it for the wheels inside the curve. With these modifications the tyre braking efforts generate a yaw torque that big enough to improve the stability of the car.

Is important to note that during a severe lateral solicitation when a stability problem may occur, the vertical load of the inside wheels will be small. As a consequence this wheel begins to skid with a small longitudinal effort. This explains why the described algorithms are efficient with moderate braking orders and not only during emergency braking.
The modifications made during a braking in a curve and a lane change manoeuvre are now detailed.

BRAKING IN A CURVE

The observed lateral acceleration is symbolised by the blue curve of figure three.
When this estimate becomes higher than a given threshold, the instability criteria of the wheels outside the curve is modified in order the pressure release in the brakes come latter. This leads to an increase of braking force produced by these wheels.
In figure three, the nominal value of the instability criteria corresponds to the black line it is the same as in figure 1. When the increased of estimates lateral acceleration is detected, the value is

modified to a higher value corresponding to the red line.
On the opposite, the instability criteria of the wheels inside the curve is modified in order the pressure release in the brakes is initiated sooner. This leads to a decrease of braking force produced by these wheels. When the increased of estimates lateral acceleration is detected, the value is modified to a smaller value corresponding to the green line in figure 3.
The modification on the instability criteria is possible on the two wheels of one side of the car or only on one wheel depending on the desired behaviour of the car.

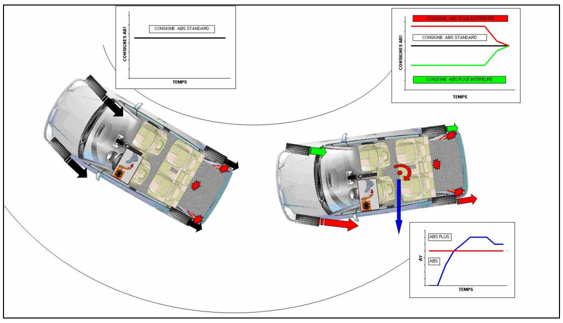

Figure 3. Illustration of the brake forces modifications during a braking in a curve

To increase the robustness, these modifications of the instability criteria are only kept for a limited time interval. The magnitude of the duration is tuned to produce a desired yaw speed change. Then the desired slip values of the two wheels of the axle go back to the default values i.e. the straight line values.

LANE CHANGE MANOEUVRE

With such a manoeuvre the oversteer tendency appears during the second manoeuvre i.e. when the driver wants the car to stabilize in the left corridor.
The time when this second manoeuvre is done by the driver is detected with the a_y estimation. Then modifications similar to those employed during the braking in a curve are realized. The magnitudes of these modifications are more important to obtain a greater effect as the vehicle tends to be more instable during this manoeuvre.

The corresponding brake forces modifications are illustrated in figure 4.

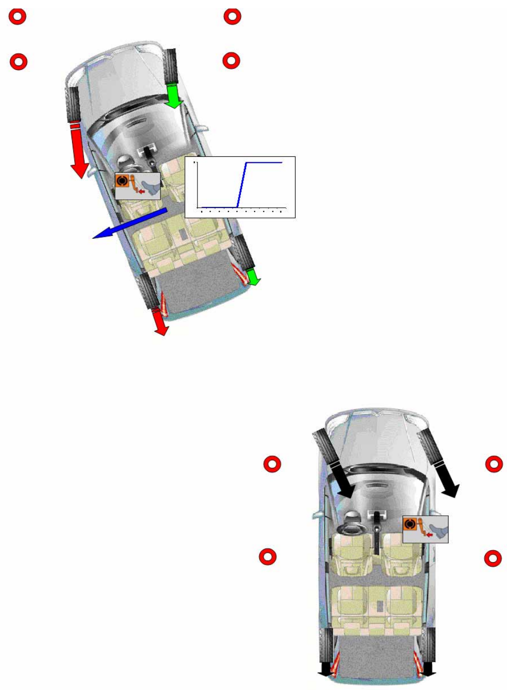

Figure 4. Illustration of the brake forces modifications during a lane change manoeuvre

VALIDATION

The proposed algorithm was tested for both manoeuvres on roads with different levels of adhesion and with various braking efforts. The detail of the test matrix is given in table 1.
In this table l.c. means lane change and b.i.c. means braking in a curve.

Table 1.
Test matrix

		Master cylinder pressure						
surface	test	10	20	30	40	50	60	70
snow	l.c.	•	•	•	•	•	•	•
	b.i.c.	•	•	•	•	•	•	•
wet	l.c.	•	•	•	•	•	•	•
	b.i.c.	•	•	•	•	•	•	•
dry	l.c.	•	•	•	•	•	•	•
	b.i.c.	•	•	•	•	•	•	•

The corresponding results on snow are shown in figure 5. In this figure green means the stability is good, yellow means the stability is satisfactory for an experienced driver and red means the stability should be improved.

In this figure the left part gives the results for the braking in a curve and the right part for the lane change manoeuvre.
In addition for each test a comparison is made with the same car equipped with a state of the art ABS (noted ABS), the ABS with the proposed

modification (noted ABS plus) and an ESC (noted ESP).

With no surprise we can see that the stability is always good with the ESC and almost never at the desired level with the ABS.
With the ABS plus the stability should be improved only in the case of very low brake pressure (10 bars) for the braking in a curve and for 10 bars and 20 bars for the lane change.
The improvement is very significant.

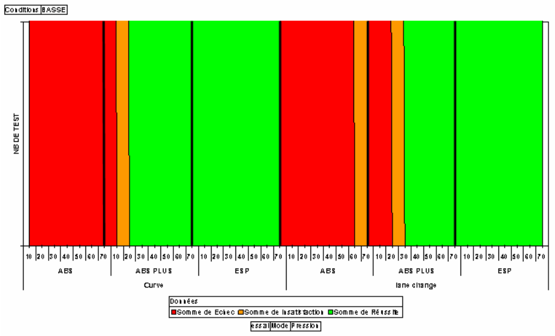

Figure 5. Tests results on the snow.

Figure 6 illustrates this improvement with a plot of the side slip angle (noted with the french word “derive” in the legend). The case tested here is a lane change at 80 km/h with a pressure of 40 bars measured in the master cylinder. The side slip angle obtained with the state of the art ABS means the vehicle is not stable. The time histories of side slip are very similar with ABS plus and with the ESC. We can see a small oscillation of side slip angle with ABS plus around t = 6 s. This is because we only have an open loop correction so it is difficult to terminate it without any oscillation.

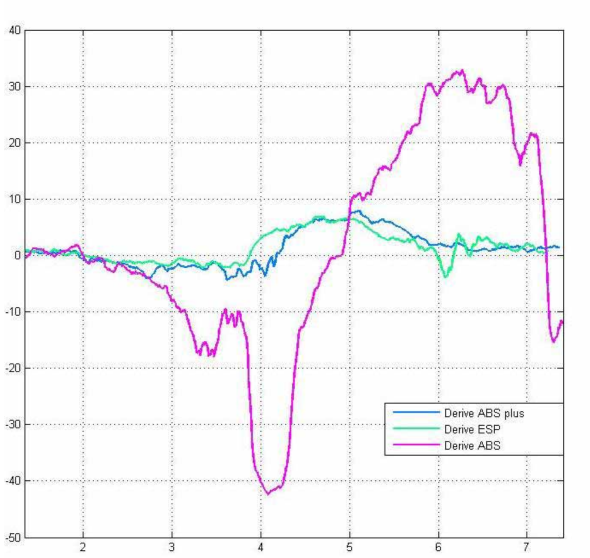

Figure 6. Time history of the Side slip angle during a lane change manoeuvre

CONCLUSIONS

It has been established that ESC are efficient to avoid accidents. When going into deeper analysis ESC is pertinent for loos of control or guidance problems. Theses problem my occur in a straight line or in a curve.
Specific studies with accident situations simulated to study the driver behaviour show that :

- 68 % of drivers began by braking before steering in the straight line case
- 57 % of the drivers brake before or during the steering manoeuvre in the curve case

Then we can see that the drivers brakes for a very significant part of these loss of control or guidance problem.
When the driver brakes an improvement of the car stability can be obtained via an ABS equipped only with the wheel speed sensors.

The principle of the algorithm for such an improvement of car stability is introduced for the braking in a curve and lane change manoeuvre.

Results of tests showing the improvement are produced.

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