New testing methods of automatic emergency braking systems and the experience of their application

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Abstract. This article offers testing methods of automatic emergency braking systems ("AEBS") for automobiles. Checking of the "AEBS" is carried out during the vehicle's moving towards different static "targets". It is estimated a possibility of the "AEBS" to recognize different "targets", the warning moment of collision situation and automatic braking effectiveness. The test drives are performed on different support surfaces. To avoid the damage of an automobile during the crash with the "target" or the "soft target" is used. This target is made of cardboard material. Besides, avoidance of crashing may be achieved by performing the maneuver "detour of obstacle". The method of synchronization of a collision warning signal with a parametric record of arrival is described also. There were performed tests of the "AEBS" of "Infiniti QX 60 Hi-tech" automobile model. Also there we analyzed reasons of the "AEBS" failures in various conditions. It was estimated that the technical vision units of the "AEBS of "Infiniti QX 60 Hi-tech" automobile model recognize the "soft target" as the obstacle.

Introduction

At present time a lot of car manufacturers offer driver assistance systems (DAS/ADAS) as an option on their automobiles, among them are: lane keeping systems, automatic emergency braking systems (AEBS), adaptive cruise control systems, automatic parking systems and many others. These systems, despite the additional cost, are very popular among customers. Thus, according to "Auto revue" magazine [1], a 15% increase of Subaru brand customers' amount in Europe was provided not by the all-wheel drive option or the boxer engine of these automobiles, but by the "EyeSight" brand security system. In turn, the customers expect safety of "DAS/ADAS" during the drive mode, which should be checked during the tests. Article [2] describes the possible problems during the operation of vehicles with similar systems and indicates the necessity for their testing.

As a part of the scientific work of the "Automobiles" chair of MADI, performed according to the State task of the Ministry of Education and Science of Russian Federation, it was decided to check the effectiveness of the "AEBS" of an automobile during various road situations. Test procedures were carried out to obtain information about the operation of a typical modern "AEBS".

The aims of the research works were:

1. Definition of terms and conditions (the speed of object, distance to the "target", type and offset of the "target") actuation or failure conditions of the "AEBS";

2. Determination of failure statistics of the "AEBS";
3. Evaluation of the moment in time receipt of the collision warning signal;
4. Evaluation of automobile's deceleration value, performed by the "AEBS";
5. Analysis of the "AEBS" adaptability due to changes of road surface conditions;
6. Determination of the "AEBS" resistance to false actuations.

Under the "AEBS Failure" it was considered the situation of non-response collision warning signal.

To perform experimental studies, a test program and a method of performing of run tests were developed, as well as a measuring complex was assembled to register the parameters of the test object (TO).

Test program and test procedure

To check the main functions of the "AEBS", which determine the overall efficiency of the system, various road situations were modeled in accordance to table1.

Table 1 Test program AEBS

Type test	**Man oeuvre**	**«Objective»**	**Test object speed, V, км/h**	**«objective» displacement Elat, %**	**Road surface**
1	Passing obstacle	Soft wall	40 60 80	0	Dry asphalt
2a	Braking; Steadiness on a straight course (driver brakes)	Soft wall	40 60 80	0	Dry asphalt Wet asphalt Wet basalt
2б	Braking; Steadiness on a straight course (AEBS brakes)	Soft wall	40 60 80	0	Dry asphalt Wet asphalt
3	Passing obstacle	Soft wall	40 60 80	50	Dry asphalt
4	Passing obstacle	Vehicle.	40 60 80	0	Dry asphalt
5	Passing obstacle	Motorbike model	40 60 80	0	Dry asphalt
6	Passing obstacle	Bicycle	40 60 80	0	Dry asphalt
7	Passing obstacle	Dummy	40 60 80	0	Dry asphalt
8	Birec troute	Vehicle	40 60 80	100	Dry asphalt

Test runs were carried out on dry and wet asphalt road, as well as on wet basalt road (for some types of test procedures), simulating a coating with a low adhesion coefficient.

Test types1-7 allow to define resources of "technical vision" of the "AEBS" detection methods of various types of static obstacles and the ability of the "AEBS" to reduce the speed automatically. When performing tests1-7, the vehicle moves in a straight line towards the "target".

In tests1, 3-7 after receiving a collision warning signal, the driver does not take measures to reduce the speed. Regardless the fact of operation of the "AEBS" during test procedures 1, 3-7, the test driver performs a maneuver of the bypass of the "target" to avoid a collision with it (Figure 1). This maneuver is performed with minimum safe distance from the "target". The maneuver of obstacles' detour allows to avoid a contact with the "target" much more exactly and it may be carried out later than the maneuver "braking in front of an obstacle" and allows to analyze the work of the "AEBS" almost to the obstacle itself.

Figure 1. The maneuver around an obstacle (soft wall)

During the test2a after the receipt of a collision warning signal, the test driver performs an emergency braking. The object during the slowdown remains in the lane until its stop in front of the "target" or before hitting the "target".

Test2b is identical to test2a and differs in a matter that after the receipt of collision warning signal the test driver does not perform braking and expects the object to slow down from the action of "AEBS".Test2a allows to estimate the timeliness of the collision warning signal.

Test2b allows to determine the slowdown value, performing by the "AEBS" of test object without driver participation.

Test8 allows to evaluate the stability operation of the "AEBS" to its false actuation are guarding a static vehicle.

During the test8 the vehicle moves rectilinearly in the direction of the "target" that is installed in the adjacent lane.

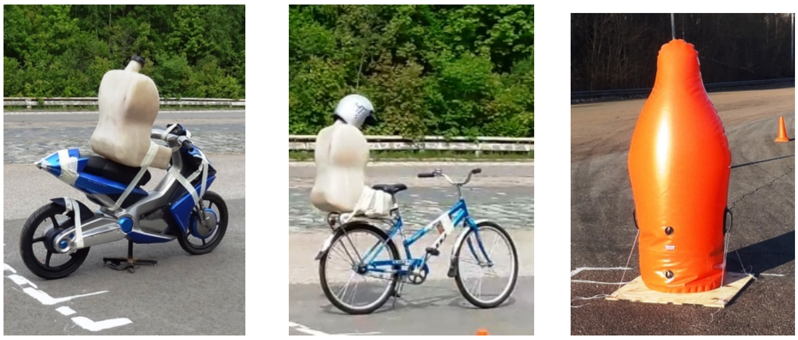
There were analyzed regulations during the development of the test program [3, 4, 5, 6]. Also the experience of other similar studies has been used [7, 8, 9].

Test runs were carried out on special roads of the NAMI’s Testing Centre (located in Dmitrov city).

The description of "targets":

As "targets" during the "AEBS" test procedures there were applied:

- "soft wall" (Figure 1);
- vehicle;
- motorbike model(Figure 2a);
- bicycle (Figure 2b);
- dummy (Figure 2c).



a b c

Figure 2. "Targets": a) motorbike model; b) bicycle; c) dummy

For the test runs with a probability of crashing situation of the "TO" with the "target" is used a "soft wall" made of a cardboard material. On the surface of the "soft wall" facing the approaching "TO" it is fixed a metalized coating necessary to improve the sensitivity of the "target" position. The main dimensions of the "target" are shown in figure 3.

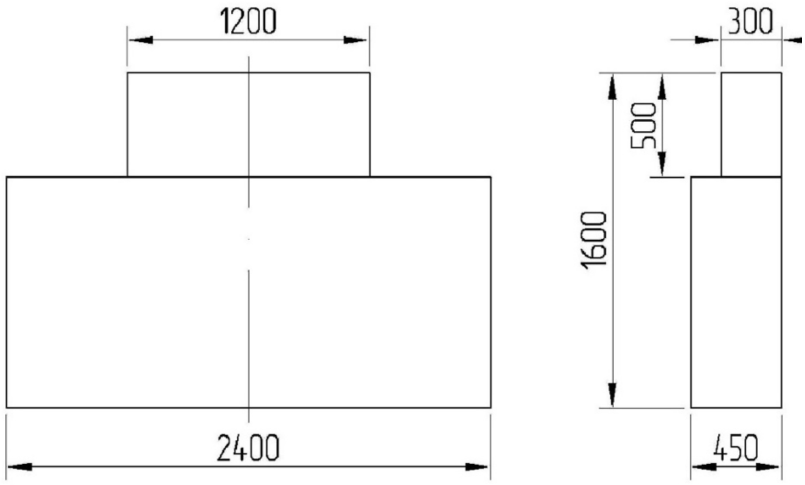


Figure 3. Main dimension features of the "soft wall target"

The main reason of the application of "soft target" is the safety improvement of test runs with the mandatory condition of adequate detection of such a "target" by the "AEBS" of tested object.

There was made a marking of test area and fixing of the geographical coordinates of the "goal" before the run tests.

Under the lateral displacement of the target Elat it is concerned the transverse distance between the longitudinal axes of the test object and the "target" measured as a percentage of the width of the "TO" (Figure 4). At Elat=100 % the "target" is located in the adjacent lane with the maximum offset from the side surface of the "TO" not more than 0.3 m along the outer rear-view mirrors.

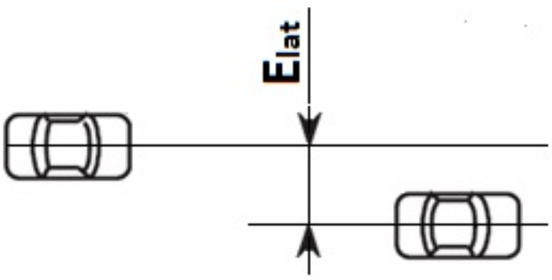


Figure 4. Elat lateral displacement between the "TO" and the "target"

Fixing method of the operation moment of the collision warning signal

To determine the parameters of the vehicle movement during the visual and/or acoustic warning signal of the collision situation it has been developed a method that allows to synchronize the time of the signal with the parametric record of the test run. The advantage of the proposed method is the ability to record any audio-visual signals regardless of origin: the appearance of an audio signal, the light control lamp on the instrument panel, the message on the screen of the on-Board computer, etc. Disadvantages of this method are the inability to fix the tactile signals (increased force on the accelerator pedal, belt tension, rapid failure of the brake pedal, etc.), the complexity and time of data processing. The fact of providing of the collision warning signal is fixed by the video camera. In the "field of view" of the camera there is a lamp (LED) of internal light indication, which lights up in a certain time after the start of parametric recording. In the processing and recording unit it also records the moment of filing and the duration of the digital signal, which controls the activation of light indication lamps. During the record procedure made by the camera, you can synchronize the time of the receipt of the collision warning signal with the parametric recording. The fact of presence of an external indicator lamp allows, in the presence of an external video, to synchronize with the parametric record all processes that occur with the automobile during the test run, for example, the moment of switching on the brake lights.

Test object ("TO")

It was submitted "Infiniti QX 60 Hi-tech" automobile model by "INFINITI Russia" Company for testing procedure. This automobile is equipped with the "FEB" system (Forward Emergency Braking), an emergency braking system with the detection option of pedestrians, is used in case of a frontal collision danger [10].

The "FEB" system uses radar (Figure5, POS. (a)) installed behind the lower grille of the front bumper to measure the distance to the vehicle moving in the same lane. A camera is provided to detect pedestrians (Figure5, Pos. b) [10]. This camera is installed on the top behind the windshield. The "FEB" system operates at speeds of more than 5 km/h (in the speed range from 10 km/h to 60 km/h when pedestrians are detected).

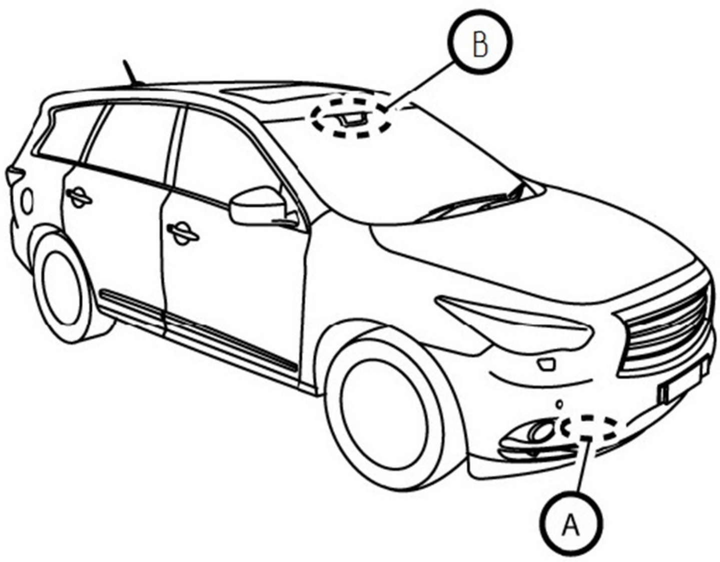


Figure 5. Means of "technical vision" of the driver assistance system's units: A-radar, B-camera [10]

Measuring and recording equipment

To solve the above mentioned problems of research work it was installed the following measuring and recording equipment on the automobile:

- torque measurement steering wheel MEASUREMENT STEERING WHEEL (MSW) produced by "KISTLER Company", Germany;
- brake pedal force sensor "CPFTA" produced by "KISTLER Company", Germany;
- remote angular velocity wheel sensor "WPT" produced by "KISTLER Company", Germany determines the circumferential speed of the left front wheel;
- acceleration and angular velocity sensor "Tri-Axial Navigational Sensor" (TANS) produced by "KISTLER Company", Germany;
- GPS antenna produced by "IMC" (Germany) and "JAVAD" (USA) Companies;
- universal measuring system for data collection and processing "CS 1016 FAMOS Online" produced by "IMC Company", Germany.

The power for the equipment was provided from an onboard power supply network of the vehicle via the power distribution unit "Small 12VPowerDistributorBox" produced by "KISTLER Company", Germany.

Registration of visual warning signal of the collision on the dashboard was performed by video camera mounted on the steering column cover.

Processing of test results

Time dependence diagrams were submitted for each test run (Fig. 6-8):

- movement speeds V;
- the longitudinal deceleration (jx);
- the angle of the steering wheel (α);
- distances from the "TO" to the " target "(D);
- the value of push effort on the brake pedal (Pbped).

The start point on the diagrams is concerned the warning moment of a possible collision situation. The distance between the "TO" and the "target" is determined by the coordinates of the global positioning system.

Examples of the diagrams for different types of tests are shown on figure 6.

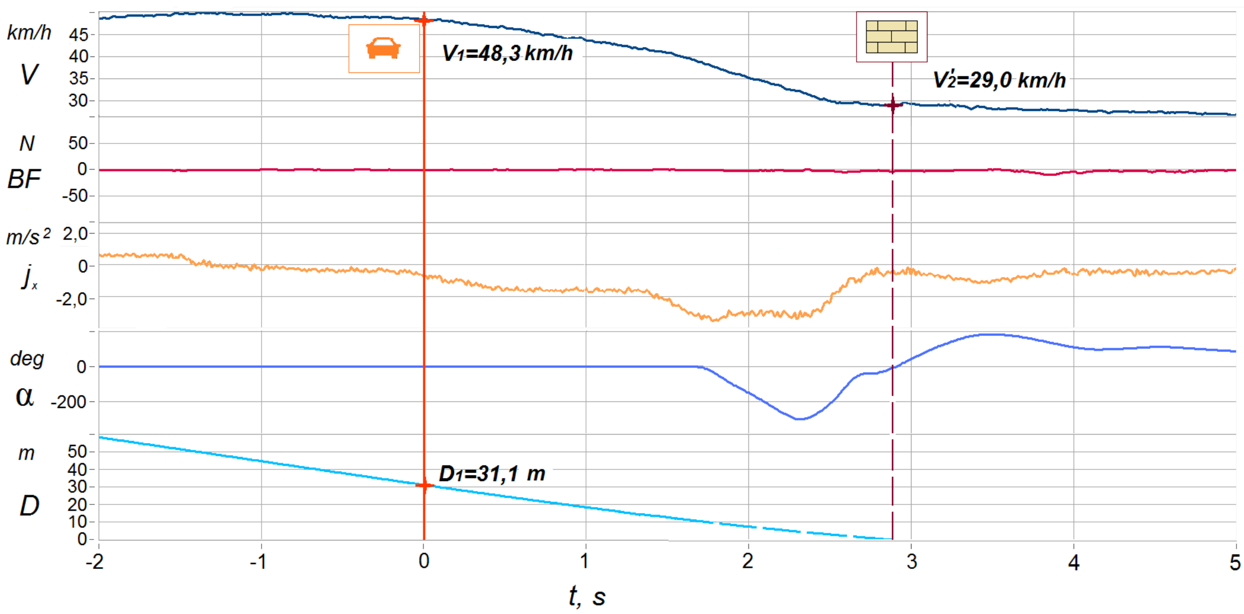


Figure 6a. Example of the diagram for tests 1, 3, 4, 5, 6, 7, 8

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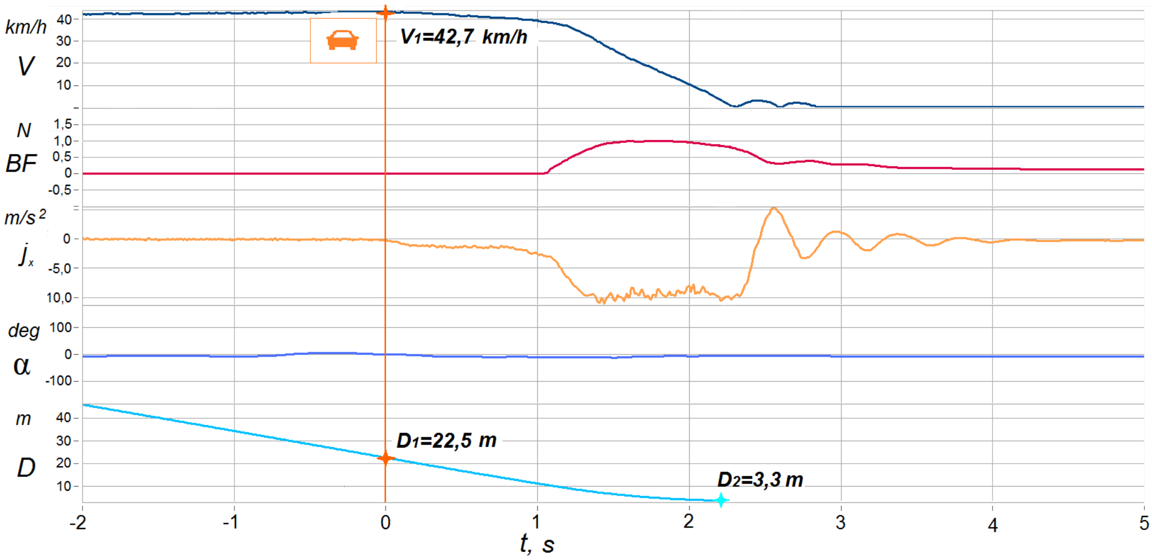


Figure 6b. Example of the diagram for test 2a

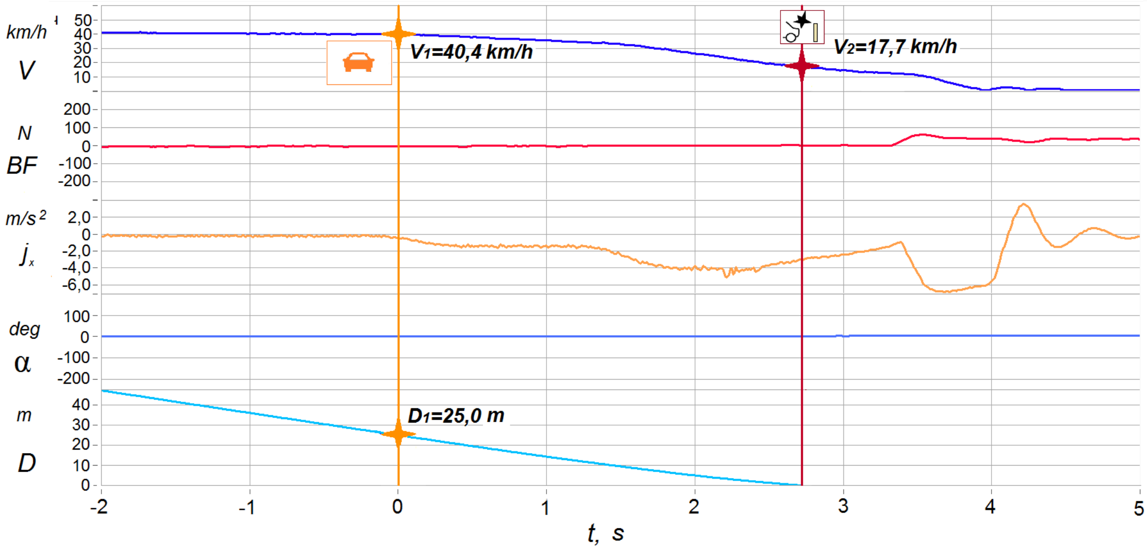


Figure 6c. Example of the diagram for test2B

Symbols on figure 6:

V1 is the longitudinal velocity of the "TO" during the warning signal moment of possible collision situation; D1 is the distance between the "TO" and the "target" during the warning signal moment of possible collision situation; D2 is the distance between the "TO" and the "target" in the case of its stop in front of the "target"; V2 is a longitudinal velocity of the "TO" during the collision with the "target"; V2 is hypothetical longitudinal velocity of the "TO" at during the collision with the "target" (when driving beside the "target") is the velocity of the "TO" during the collision with the "target", if there was no swerving;

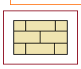
-  – the moment of the collision warning signal;
-  – the moment of suspended touch (when performing a detour of obstacles) of the "target" by the "TO";
-  – the moment of touch (only for soft wall) of the "target" by the "TO".

Figure 6. Example of diagrams for different types of tests

Analysis of test results

After the receipt of the collision warning signal an automatic braking action begins immediately by the "AEBS". Thus it is provided a constant value of deceleration on dry asphalt before the soft wall "targets" or the automobile at the rate 2-3 m/s ^{2} (at the speed rate from 40 km/h) and about 3-4 m/s ^{2} (at the speed rate from 60 km/h). But this efficiency of automatic braking action is not enough to stop in front of the "target".

During the test procedure 2a that was performed on dry bituminous concrete the "TO" had time to stop in front of the "target", but the collision had occurred on wet asphalt and basalt road. Thus, the "AEBS" system does not adapt to changes of adhesion coefficient value of support surface.

There were no false actions during the test procedure 8.

Failure statistics of the "AEBS" depending on different conditions is presented in table 2 and 3.

Table 2 System failures depending on the type of test

Type test	«Objective»	Number of tests		Number of system failures (%)	
1	Soft wall	34	Total: 59	2	Total: 4 (7 %)
2a, 2б		22		2	
3		3		0	
4	Vehicle	13		2 (15 %)	
5	Motorbike model	10		3 (30 %)	
6	Bicycle	9		3 (33 %)	
7	Dummy	18		5 (28 %)	

Table3 System failures depending on object speed

«Objective»	System failures depending on object speed, км/h		
	40	60	80
Soft wall	1	1	2
Vehicle	0	0	2
Motorbike model	1	0	2
Bicycle	0	0	3
Dummy	1	1	3
Total failures :	3	2	12
Total tests:	40	33	36

The analysis of table 2 shows that this "AEBS" system recognizes soft wall and the automobile "targets" in the best way.

It was also estimated the increase of the "AEBS" failures when the "TO" speed increased (see table 3).

Advance warning signal is estimated by the parameter "TTC" (Time to collision) - the time to the collision. Time to the collision is a time feature after which a collision of the "TO" and the "target" will occur as long as the current relative velocity of the "TO" and the "target" is constant.

The time to impact a stationary "target" is calculated by the following formula: TCS=D1/V1.

Table 4 shows a comparison of the average "TTC" values for different "targets" at speed rates of collision warning signal of 40 and 60 km/h.

Table 5 compares the average "TTC" values for different support surfaces.

Table 4 The TTC value for various "«Objectives»"

«Objective»	TTC, c	
	$V_{сраб}$=40 км/h	$V_{сраб}$=60 км/h
Soft wall	2,18	2,42
Vehicle	2,06	2,55
Bicycle	0,98	1,51

Table 5 The TTC value for various road surfaces (test 2a, 2б, «objective» – Soft wall, V=60 км/h)

Road surface	TTC, c
Dry asphalt	2,25
Wet asphalt	2,29

The proper response of the "AEBS" to a "soft target" is confirmed by a small percentage of failures (see table 2) and the identity of the "TTC" parameter for the "soft target" and the real automobile (see table 4).

The warning signal of a collision with a bicycle is received much later than with a soft wall or with an automobile. Therefore, automatic deceleration does not have time to start before the detour of obstacles.

The analysis of table5 confirms the previously made conclusion about the lack of adaptability of the "AEBS" algorithm to the change of the support surface state.

Conclusion

A new method is proposed to test automatic emergency braking systems. Features of the proposed test method are:

- tests are carried out on support surfaces with different grip value;
- investigation of the interaction with a large number of "targets";
- introduced maneuver "detour of obstacles";
- analyzed a larger number of motion parameters of the vehicle;
- new methods of processing test data are used.

The results of experimental studies of the "AEBS" of "Infiniti QX 60 Hi-tech" automobile model give us a possibility to make such conclusions:

1. Means of technical vision of the "AEBS" object recognize the type of the "target" – the "soft wall" as an obstacle. This "target" can be applied during future tests.

2. Means of technical vision of "AEBS" object recognize badly object type "target" – a "stationary bicycle". This aspect restricts the range of functional safety of the "AEBS".

3. The deceleration achieved by the object during the operation of the "AEBS" (without the driver) is not enough for the complete stop of the object in front of a static obstacle, which also reduces the effective range value of the system.

4. The collision warning signal algorithm does not depend on grip properties of the road surface. This fact reduces the functional safety of the "AEBS" on slippery surfaces.

5. A large number of the "AEBS" failures at a speed of 80 km/h indirectly indicate an insufficient distance value to detect the obstacle. This matter also reduces the range of application of the "AEBS".

6. There was not recorded an "AEBS" "false target" action.

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References

[1] Rastegaev O 2018 Outback in snow Autorewiev . № 6 (630) 36-37
[2] Prihodko V, Ivanov A, Borisevich V, Shadrin S 2017 Techniques for testing automated control systems Newsletter Moscow-State-Automobile-Road-Technical-University-MADI № 4(51) 10-15
[3] 2018 UNECE Regulation No. 131 (01). Uniform provisions concerning the approval of motor vehicles with regard to automatic emergency braking systems. (AEBS) - URL: https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2017/R131r1am1r.pdf
[4] Moscow: Standard inform 2017 GOST R ISO 22839-2017 Intelligent transport systems. Systems to reduce the severity of the consequences of a collision with a vehicle in front. Work, performance and verification requirements (ISO 22839: 2013, IDT). 29
[5] Moscow: Standard inform,2017. GOST R ISO 15623-2017 Intelligent transport systems. Collision avoidance systems with a vehicle in front. Performance requirements and test methods (ISO 15623: 2013, IDT). 28
[6] 2018 Safety Assist. – URL: https://www.euroncap.com/ru/для-инженеров/protocols/safety-assist/
[7] Sachkov M 2018 Top-Stop Za Rulem № 2 42-43
[8] 2016 OCAS-DRI-CIB-16-08 New car assessment program. Crash imminent braking system confirmation test. 2016 Nissan Rogue. Final Report. U. S. Department of transportation108.
[9] 2017 CAS-DRI-CIB-17-06 New car assessment program. Crash imminent braking system confirmation test. 2017 Mitsubishi Outlander. Final Report. U. S. Department of transportation, 120.
[10] 2017 Manual for infinity QX 60. - URL: https://www.infiniti.ru/content/dam/Infiniti/Russia/manuals/qx60.pdf