ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1213503

ANALYSIS OF THE PROCESS OF VEHICLE STOPPING WITH THE USE OF EMERGENCY BRAKING SYSTEM

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Abstract

Road traffic poses high risk to human health and life and material objects. In an emergency situation, it is crucial for a driver to be able to reduce speed of the vehicle and pull up as quickly as possible. The braking distance of a vehicle depends on many factors including the surface condition and the braking system efficiency. During maintenance of a vehicle, the elements of a braking system undergo wear processes and failures. Therefore, producers equip vehicles with emergency braking systems, which can stop a car in the event of the main braking system failure. Cars in Poland are of diversified age therefore many different design solutions can be found.

In this study, the problems connected with stopping a car in case of the brakes failure has been discussed according to the type of brake actuation system. Simulation calculations were performed with the use of computer tool V-SIM4, and the obtained results allow to find a braking design with the highest efficiency in terms of braking distance and maintenance of the vehicle direction in case of the main system failure.

The research results make it possible to formulate a general conclusion that structures of emergency braking systems should be used in the following order: fully doubled, LL, HI whereas systems TT and X should be replaced by systems LL or possibly HI.

Keywords: *braking, braking simulation, road traffic safety*

1. Introduction

An analysis of the influence of a vehicle, as an element of R-T-U (road, traffic, user), on occurrence of an accident has been performed, in terms of its efficiency and the environmental impact. This is a human factor, which plays the crucial role in road traffic safety, and it exceeds 90%. However, an analysis of causes of accidents from the last two years indicates a change in the number of road accidents caused by the vehicle technical state though, the share of accidents caused by the vehicle technical state should not be neglected.

Efficiency of the braking system is of key importance in extreme situations when it is necessary to reduce speed immediately or pull up the car.

If the main braking system breaks down its function is taken over by an emergency braking system of the vehicle [2, 7, 8].

According to statistical data, in 2013 accidents caused by the vehicle technical state, failures of the braking system, accounted for 9.4% cases, whereas in 2014 failures of the braking system accounted for 27.3% of accidents [10].

The collision speed has a direct impact on the accident consequences [1, 3]. Therefore, a braking system belongs to the most important structural systems of a vehicle including both the main and the emergency systems.

The key role that is played by a braking system in road traffic safety involves a variety of requirements to be met concerning homologation rules approved by UNO and described in Regulations 1 no. 13 (series of amendments 06) and no. 78 (series of amendments 01) dividing vehicles into categories and groups – L_{1-5}, M_{1-3}, N_{1-3} and O_{1-4} [7, 8].

2. Braking systems

A braking system of a vehicle is supposed to produce a force acting on the vehicle, which is in motion whose direction is opposite to the vehicle driving direction, thanks to which the speed of a car is reduced or it is intentionally stopped.

It is possible due to creation of moments of braking forces (friction torques) whose direction is opposite to the direction of wheels rolling.

In order to provide passengers and other road users with safety, vehicles are equipped with braking circuits, which operate independently on each other allowing using brakes and stopping the car in case of the main braking system failure.

Emergency braking systems partly or fully can take over operation of the main braking system. Systems, which fully take over (acting on all the wheels), can be found in luxury vehicles. Cars of lower category, such that prevail on our roads, have braking systems that double partially.

The most frequently used systems are those, which take over the function of one of the vehicle rear axles or the front axle and one of the wheels of the rear axle. The cheapest solutions can be found in compact cars of older generations where the system operation is distributed diagonally in relation to wheels of both axles [6].

Figure 1 shows a split of braking systems used in passenger cars – front and rear and diagonal (also called crosswise), triangular split and four-two [6, 8].

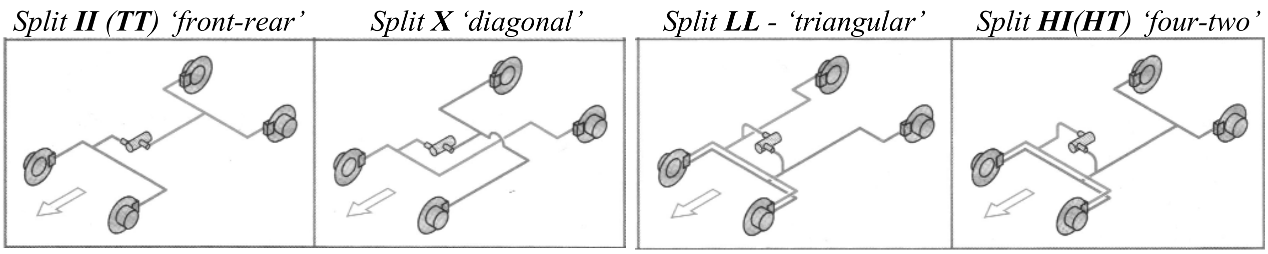

Fig. 1. Split of braking system of TT type and X as well as LL and HI (HT) [6]

Whereas, Fig. 2 shows the scheme of forces acting on a car while braking uphill.

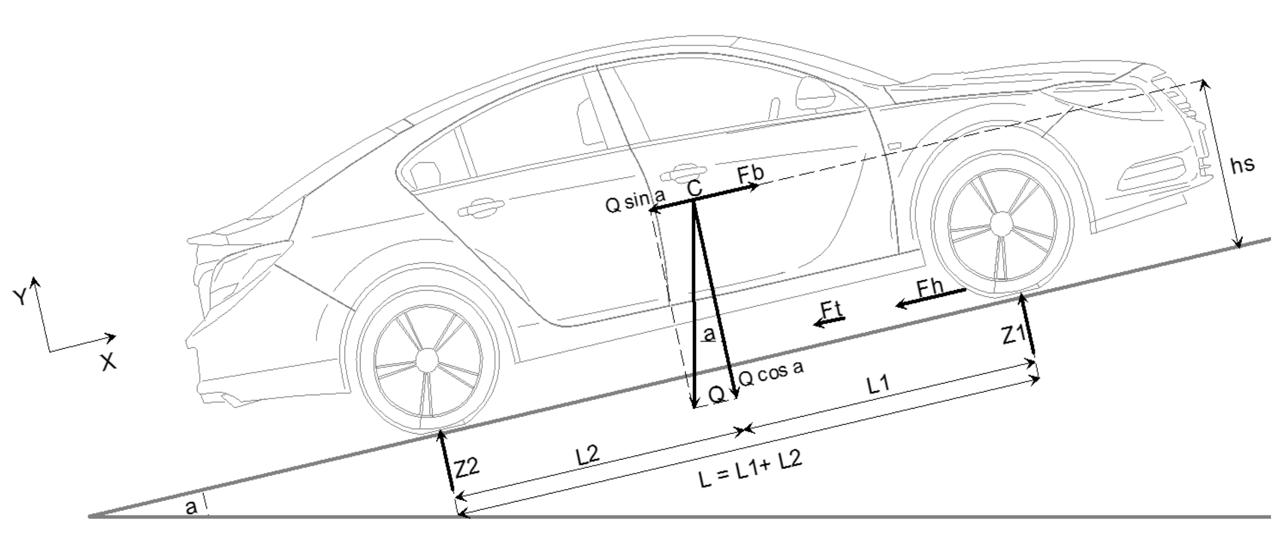

Fig. 2. Scheme of forces acting on a car

When one of the circuits of a two-circuit brake activation system is damaged, the vehicle is provided with the possibility of using the second system but the delay in braking is changed. For braking the front wheels of the front axle, it reaches the value described by formula (1), and for braking the back axle wheels, by formula (2).

$$A_{Hp} = \frac{g\left[\left(0.5 \cdot L \cdot f + \mu \cdot L_2\right)\cos\alpha + \left(L - \mu \cdot h_S\right)\sin\alpha\right]}{L - \mu \cdot h_S}, \quad (1)$$

$$A_{Ht} = \frac{g\left[\left(0.5 \cdot L \cdot f + \mu \cdot L_1\right)\cos\alpha + \left(L + \mu \cdot h_S\right)\sin\alpha\right]}{L + \mu \cdot h_S}, \quad (2)$$

where:
g – constant of inertia,
L – wheel space,
f – coefficient of rolling resistance,
$L_1 = L_2$ – distance of wheel axes from the vehicle centre of mass,
μ – coefficient of wheel adhesion to the road surface,
h_S – position of the vehicle centre of gravity height in relations to the road surface,
α – angle of elevation.

Whereas, in case of the diagonal system of brake actuation, when one of its circuits is out of order it is possible to brake the front right and the rear left wheel or conversely. Delayed braking in consequence of such a system failure is described by formula (3).

$$A_H = g\left(\frac{\mu}{2}\cos\alpha + 0.5 \cdot f \cdot \cos\alpha + \sin\alpha\right), \quad (3)$$

where:
g – constant of gravitation,
f – coefficient of rolling resistance,
μ – coefficient of wheel adhesion to the road surface,
α – angle of elevation.

3. Case study – own research

Performance of multi-variant calculations, depending on the kind of damage to the braking system in consequence of a decline of braking force in particular wheels, with the use of the above formulas is time consuming and does not allow continuing actual observation of results of these calculations depending on the parameter change. Moreover, an analysis of a change in the driving direction of a vehicle becomes problematic. Simulation programs using the above-discussed phenomena are free from such drawbacks thus they provide the possibility of actual verification of calculation results and their visualization. A method has been proposed for verification of efficiency of a braking system to be applied in a vehicle in the event of the main system failure with the use of a computer tool V-SIM4 [5, 9].

The research object

Below, there is the most important technical data of the research object:
- Skoda Fabia, vehicle curb weight 985 kg, driver's weight 75 kg,
- wheel space 2.462 m, wheel space of the front axle 1.436 m and rear axle 1.426 m,
- system equipped with ABS, tires of 165/70 R 14 size.

Accepted research conditions

The following research conditions and traffic environment have been included in calculations:
- alternative operation of a braking system for simulation of a failure in the form of wheel braking in arrangements presented in Fig. 2, as compared to the braking distance of a fully doubled braking system (braking all the wheels 100%),
- the calculation does not include the driver's reaction time [4],
- wheel grip coefficient – adhesive 0.8 and slip slide 0.75, coefficient of rolling resistance 0.015, initial speed 13.89 $m \cdot s^{-1}$.

4. Performance of research

Fully doubled split – efficiency of wheels and brakes of the front and rear axle 100%. Below, in Fig. 3, shows the vehicle delayed braking changes in the function of time, and in Fig. 4, there is a simulation of the vehicle stopping distance.

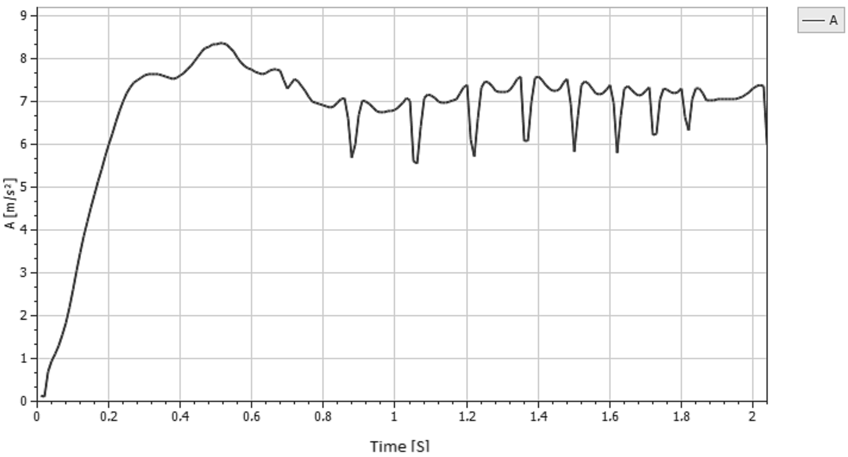

Fig. 3. The time histories of delayed braking changes of the research object

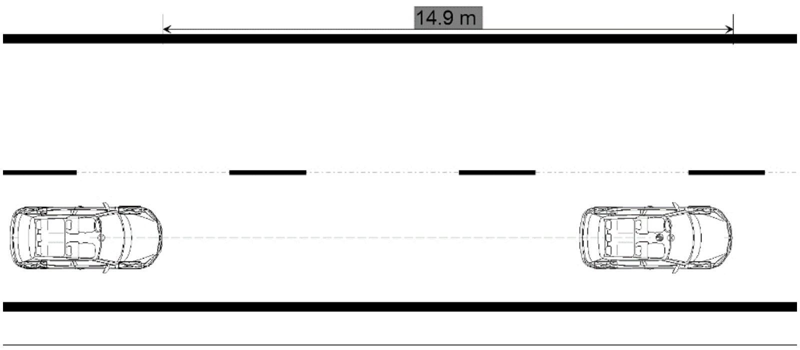

Fig. 4. Simulation of the research object stopping distance

TT split – efficiency of the front axle wheels 0% and rear axle wheels 100%**.** Fig. 5 shows changes in the delayed braking in the function of time whereas; Fig. 6 shows a simulation of the vehicle stopping distance.

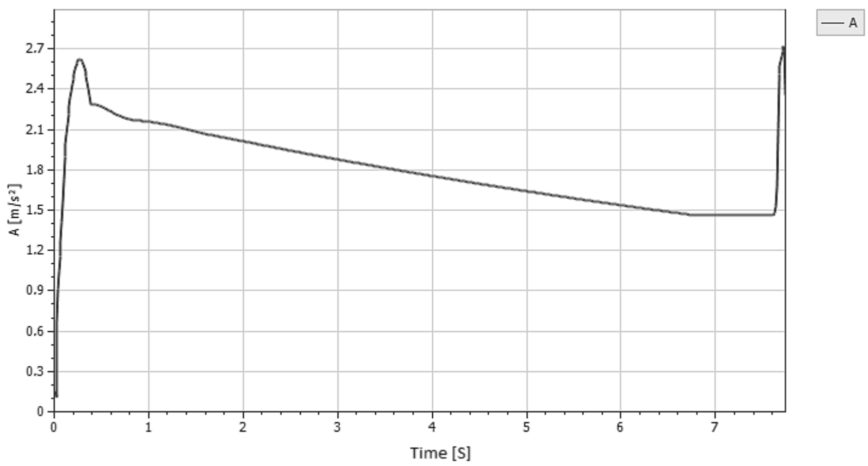

Fig. 5. Time histories of delayed braking changes of the research object

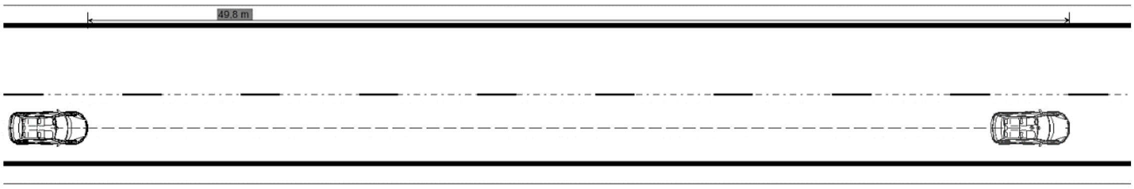

Fig. 6. Simulation of the research object stopping distance

Split X – efficiency of brakes of wheels front right and rear left after 100%, and of wheels front left and back right after 0%. Below, Fig. 7 there are changes in the delayed braking in the function of time, whereas, Fig. 8 depicts a simulation of the vehicle stopping.

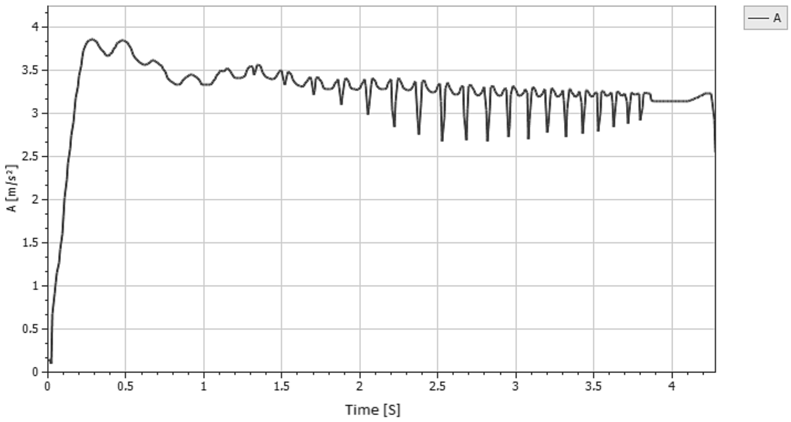

Fig. 7. Time histories of delayed braking changes of the research object

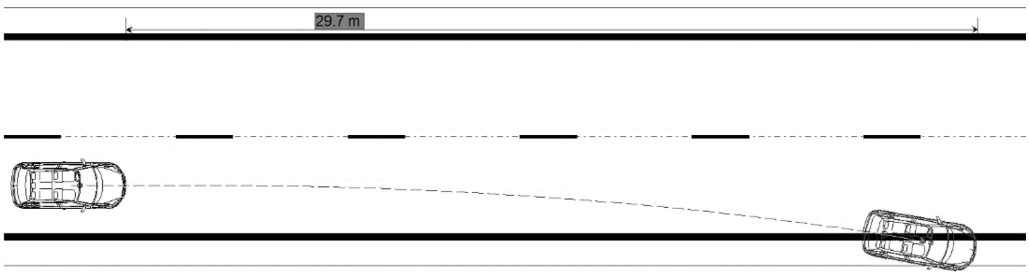

Fig. 8. Simulation of the research object stopping distance

Split LL – efficiency of brakes of the front axle wheels and the right rear wheel both 100% whereas the rear left wheel 0%. Below, Fig. 9 depicts a simulation of the vehicle stopping distance, in Fig. 10 there are changes in the delayed braking in the function of time.

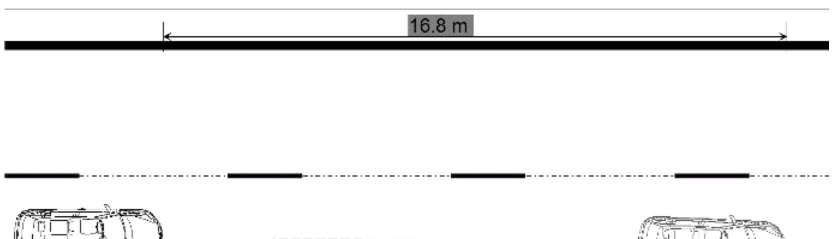

Fig. 9. Simulation of the research object stopping distance

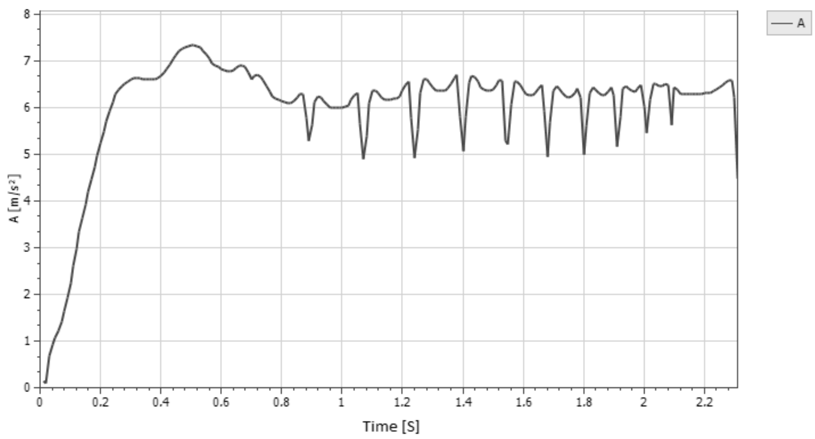

Fig. 10. Time histories of delayed braking changes of the vehicle

Split HI – efficiency of brakes of the front axle wheels 100% and the rear wheel 0%. Below in Fig. 11 there are changes in the delayed braking in the function of time, whereas Fig. 12 depicts a simulation of the vehicle stopping.

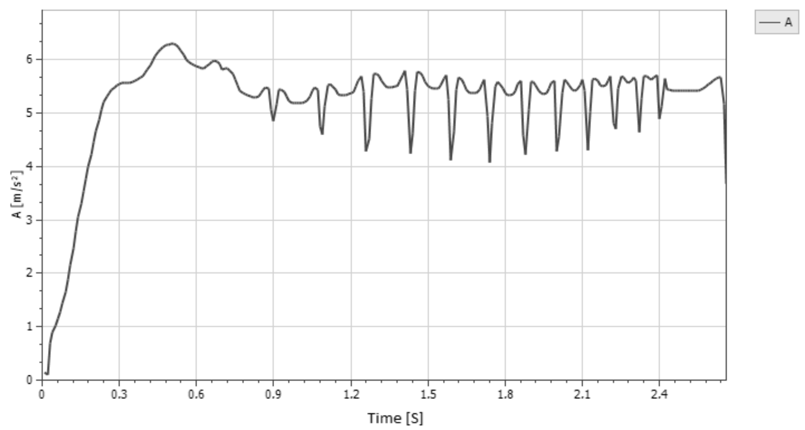

Fig. 11. Time histories of delayed braking changes of the vehicle

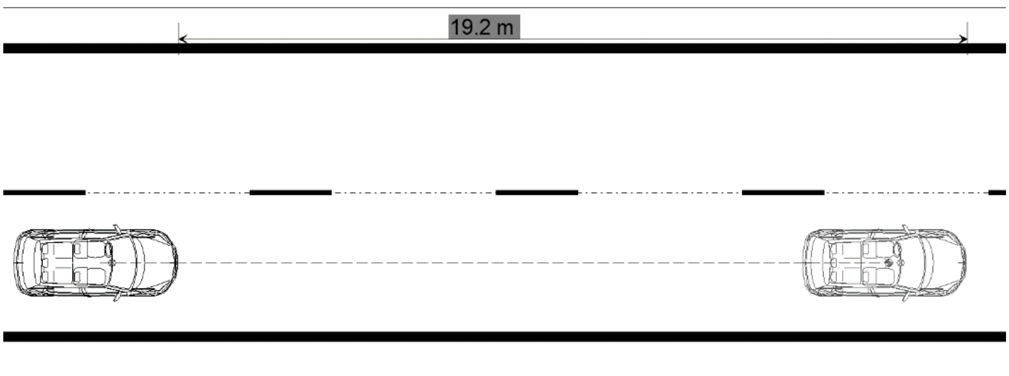

Fig. 12. Simulation of the research object stopping distance

Conclusions

The results of simulation calculations for the research objects are as follows:

– full doubling of systems S_z = 14.9 m without changing the vehicle driving direction during braking,
– TT system (front axis 0% and rear axis brakes efficient 100%) S_z = 49.8 m without changing the vehicle driving direction during braking,

- system X (front right and left rear wheels diagonally 100% efficient and the remaining 0%) S_z = 29.7 m during braking with significant change of driving direction during braking;
- system LL (wheels of the front axle and the rear right 100% efficient and the real left 0%) S_z = 16.8 m with a slight change of driving direction during braking,
- system HI (wheels of the front axle 100% efficiency and the wheel of rear axle 0% efficiency) S_z = 19.2 m without changing the direction of driving during braking.

The results of research have confirmed that the most effective emergency braking system is a fully doubled one acting on all the wheels of the vehicle. It provides the possibility of stopping the car over the shortest possible distance and without changing the direction of driving during braking. The worst result was recorded for TT system, that is, for braking wheels of only the rear axle. It is characterized by the longest braking distance; hence, it is the least safe.

Considering the remaining systems X, LL and HI the best result was found for system LL, which is characterized by the shortest braking distance and a slight change in the direction of driving during braking easy to be controlled by a driver. Right after this system there is a system with HI division, which provides a slightly longer braking system than LL with simultaneous maintenance of straight line driving during braking.

System X was found to be the least effective among the three ones in terms of both braking distance and straight line driving during braking.

The research results make it possible to formulate a general conclusion that structures of emergency braking systems should be used in the following order: fully doubled, LL, HI whereas systems TT and X should be replaced by systems LL or possibly HI.

Taking into consideration the economic factor, fully doubled braking systems find application in luxurious cars, whereas system LL should be recommended for popular vehicles (wheels of the front axle and one of the rear 100% efficiency) or possibly HI (wheels of the front axle 100% efficient and wheels of the rear axle unbraked).

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