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EXPERIMENTAL RESEARCH OF CAR ACCELERATION CHARACTERISTICS

BADANIA DOŚWIADCZALNE CHARAKTERYSTYK PRZYSPIESZENIA SAMOCHODU

Abstract

This paper describes an experimental research of car acceleration characteristics with evaluation of influence of traction control systems (further TCS). The main purpose of these experiments was to examine values of longitudinal car acceleration characteristics on different road pavements with efficiency evaluation of different TCS the "XL Meter Pro Gamma" accelerometer was used for the experiments. As an important active TCS was used in the experiments, the obtained results enable evaluation of influence of car wheel slip on car acceleration characteristics as well as on car control when such slip happens on different road pavements (dry asphalt-concrete, snow-covered asphalt-concrete). Analysis of car acceleration characteristics enables to research the controllability of front drive cars – the level of ability to pass by an obstacle with acceleration. The obtained and analysed results can be useful to experts and professionals analyzing road accidents. These results enable to found acceleration characteristics in some realistic situations and evaluate, had the driver a technical possibility to avoid the road accident.

Keywords: car, acceleration characteristics, longitudinal acceleration, racing, adhesion coefficient, accelerometer, experimental research, traction control system

Streszczenie

W artykule opisano badania doświadczalne charakterystyk przyspieszenia samochodu z oceną wpływu systemów sterowania trakcji (dalej zwanych TCS). Głównym celem doświadczeń było zbadanie wartości charakterystyk przyspieszenia wzdłużnego samochodu na różnych nawierzchniach drogowych wraz z oceną skuteczności różnych TCS. Do badań zastosowano przyspieszeniomierz „XL Meter Pro Gamma". Dzięki zastosowaniu do badań aktywnego TCS uzyskane wyniki pozwalają na ocenę wpływu poślizgu koła samochodu na charakterystyki przyspieszenia samochodu oraz na sterowanie samochodu podczas takiego poślizgu na różnych nawierzchniach drogowych (sucha asfaltowo-betonowa, asfaltowo-betonowa pokryta śniegiem). Analiza charakterystyk przyspieszenia samochodu pozwala na badanie sterowalności pojazdów z napędem przednim – poziom możliwości przejechania przez przeszkodę z przyspieszeniem. Uzyskane i przeanalizowane rezultaty mogą być wykorzystane przez rzeczoznawców i profesjonalistów badających wypadki drogowe. Wyniki te umożliwiają określenie charakterystyk przyspieszenia w pewnych realistycznych sytuacjach i ocenę, czy kierowca miał techniczną możliwość uniknięcia wypadku drogowego.

Słowa kluczowe: samochód, charakterystyki przyspieszenia, przyspieszenie wzdłużne, wyścigi, współczynnik przyczepności, przyspieszeniomierz, badania doświadczalne, system sterowania trakcji

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1. Introduction

The paper presents a brief survey of references, related to car acceleration characteristics and research of TCS. There are also presented the purpose and problems of this research, described the object of research and the used method of car testing on the different road pavements. The obtained results with their analysis are presented with recommendations and formulated conclusions.

During the experiments transversal accelerations were ignored as insignificant factors in analysis of cars longitudinal accelerations. The analysed found results can be useful for experts and professionals, investigating road accidents in cases, when one of the collision participant vehicles, in the accident initially standing, made attempts to get away the accident with acceleration. A similar occasion can happen if in a road cross a vehicle will enter too early. The obtained results enable to evaluate, if the driver had enough time to escape from the road accident by acceleration.

Often, avoiding road accidents at some conditions, cars ought not only brake efficiently, but as well and accelerate efficiently. In such case the car must have a sufficiently high controllability. Characteristics of car acceleration determine its manoeuvre ability, behavior in emergent conditions, when attempts are being made to prevent the road accident. Namely therefore research of car acceleration characteristics is of great importance. Having analysed car acceleration characteristics we obtain a possibility to analyse the controllability of front drive cars – ability to pass by an obstacle with acceleration.

2. Review of the references

Sangdon Lee in his paper [1] proposes information on car acceleration characteristics, evaluating the change of acceleration pedal, car speed and acceleration.

Authors Sangmin Kang, Maru Yoon and Myoungho Sunwoo in their paper [2] examined and described TCS working by designing TCS working model. The knowledge of this article has been used performing car acceleration experiments.

There are briefly descriptions of TCS working essentials in J.Y. Wong book "Theory of ground vehicles" [3].

Process analysis of the controlled car acceleration was analysed by R.S. Gan and V.B. Proskuryakov in their article [5].

By examining scientific articles, which are related to car acceleration with TCS [1–3, 5] and other references [4, 6–9], it have been ascertained that usually, although not in all senses, TCS improve car acceleration characteristics.

3. Aims and problems of the experimental research

The carried out experiments were tended to analysis of car acceleration processes going on different road pavements (with different adhesion coefficients) with evaluation of TCS influence on car dynamic characteristics. Such experiments allow learning of real characteristics of car acceleration when it accelerates at emergent mode.

For higher precision of the obtained results there were tested different cars (with petrol and diesel engines, with mechanical and different types of automatic gearboxes).

In car acceleration experiments we accepted transversal accelerations as insignificant, having unessential values. So the main attention was paid to longitudinal accelerations of cars. Also there were ignored some occasional parameters, such as wind, pavement inequalities in the entire road sector a. o. There were made attempts to carry out experiments with different cars at the same road conditions (closed experimental site, dry asphalt-concrete and snow-covered asphalt-concrete, see Fig. 1, 2).

4. The object and method of the experimental research

For acceleration measurement in the experimental research there was used the "XL Meter Pro Gamma" accelerometer [4]. During experiments the run up was being carried out from 0 to 60 km/h on a dry asphalt-concrete (see Fig. 1) and from 0 to 40 km/h on a snow-covered one (see Fig. 2).

Fig. 1. The experimental road sector with a dry asphalt-concrete pavement (the accelerometer installed in the car)

Rys. 1. Doświadczalny odcinek drogi z suchą nawierzchnią asfaltowo-betonową (przyspieszeniomierz zainstalowany w samochodzie)

Fig. 2. The experimental road sector with a snow-covered asphalt-concrete pavement (the accelerometer installed in the car)

Rys. 2. Doświadczalny odcinek drogi z nawierzchnią asfaltowo-betonową pokrytą śniegiem (przyspieszeniomierz zainstalowany w samochodzie)

During the experimental research the pattern of the tyres protectors' had a sufficient depth (4 to 8 mm).

It should be noted that all the experiments were carried out with car engines operating at normal working temperatures. Run up on a dry asphalt-concrete was being carried out at emergent manner by pressing the accelerator pedal home.

The experiments were carried out with cars having included traditional mechanical gearboxes as well as automatic gearboxes of different types (DSG – *Direct Shift Gearbox*, planetary, stepless CVT – *Continuously Variable Transmission*). These cars have the possibility to switch the TCS ON and OFF (see Tables 1, 2).

In winter conditions car acceleration experiments were carried out without emergent pressing the acceleration pedal home. Evaluating the pavement adhesion characteristics there were made attempts to proportion properly the accelerator pedal in order to limit car slide to a permissible level. So was treated with the "ON" and "OFF" TCS, because in other case the car driving wheels would constantly slide and the obtained results would be meaningless.

5. Results of the experimental research and their analysis

Experiments made on the dry asphalt-concrete pavement show that values of acceleration with the TCS ON are less than values when the TCS is OFF (see Table 1 and Figs. 3 to 5).

Table 1

Acceleration values of the cars, tested on dry asphalt-concrete paving

	TCS ON	TCS ON	TCS OFF	TCS OFF
Automobile	$a_{av.\,max}$ [m/s^2]	$a_{av.}$ [m/s^2]	$a_{av.\,max}$ [m/s^2]	$a_{av.}$ [m/s^2]
Volkswagen Golf 1.9 TDI 77 kW (DSG)	4.687	2.950	4.843	2.979
Mitsubishi Lancer 1.8 105 kW (CVT)	4.087	2.599	4.137	2.637
Volkswagen Golf 1.9 TDI *BlueMotion* 77 kW (manual gearbox)	5.260	3.056	5.810	3.162

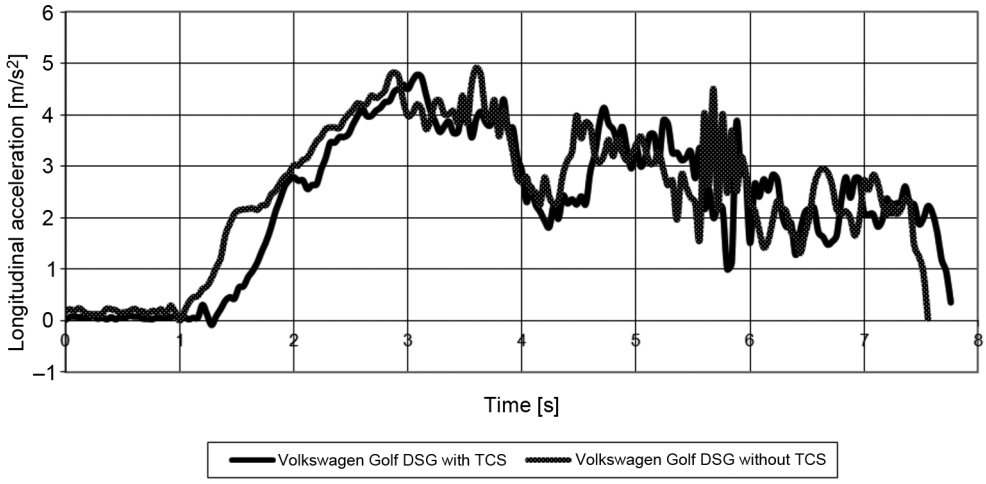

Fig. 3. Car Volkswagen Golf 1.9 TDI 77 kW (DSG) acceleration diagrams, when TCS is switched ON and OFF (dry asphalt-concrete)

Rys. 3. Samochód Volkswagen Golf 1.9 TDI 77 kW (DSG) – wykresy przyspieszenia przy TCS włączonym i wyłączonym (sucha nawierzchnia asfaltowo-betonowa)

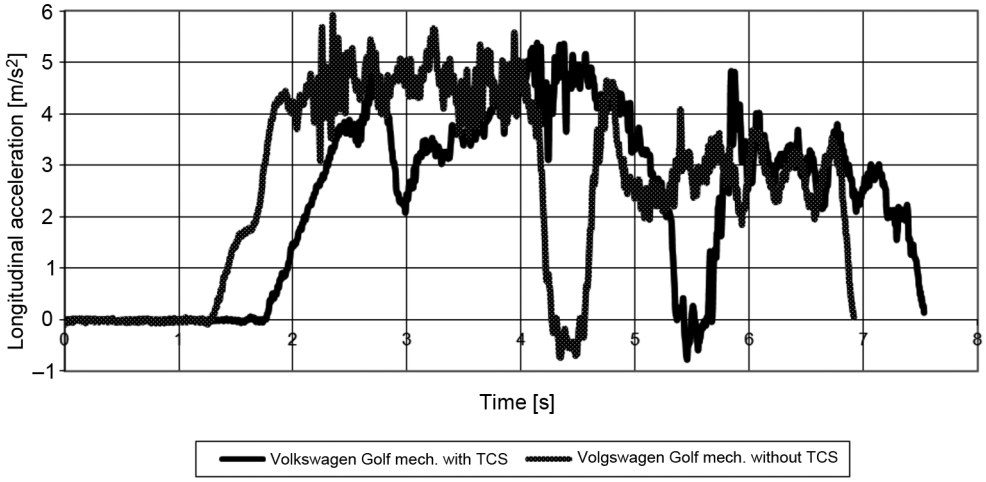

Fig. 4. Car Volkswagen Golf 1.9 TDI *BlueMotion* 77 kW (manual gearbox) acceleration diagrams, when TCS is switched ON and OFF (dry asphalt-concrete)

Rys. 4. Samochód Volkswagen Golf 1.9 TDI BlueMotion 77 kW (ręczna skrzynia biegów) – wykresy przyspieszenia przy TCS włączonym i wyłączonym (sucha nawierzchnia asfaltowo-betonowa)

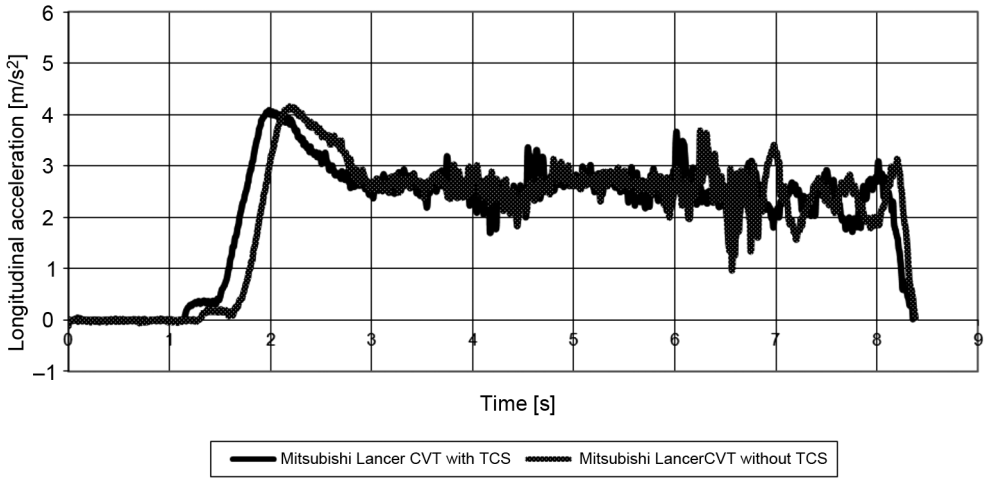

Fig. 5. Car Mitsubishi Lancer 1.8 105 kW (CVT) acceleration diagrams, when TCS is switched ON and OFF (dry asphalt-concrete)

Rys. 5. Samochód Mitsubishi Lancer 1.8 105 kW (CVT) – wykresy przyspieszenia przy TCS włączonym i wyłączonym (sucha nawierzchnia asfaltowo-betonowa)

It may be that such results were obtained because of possible precautions, installed in TCS with purpose of slip prevention of the driving wheels. Cars were tested on a dry asphalt--concrete, where the adhesion coefficient was sufficiently high and car driving wheels drove without slip. Because of these reasons acceleration values for cars with TCS ON are less than values for cars with TCS OFF. Would there has been a partial slip of the driving wheels, it would not be a deciding factor of car acceleration decrease.

The graph of car acceleration as time function for a car accelerating with the TCS ON in many cases seems more even, without clearly seen sharp increases and decreases of car acceleration, whereas for cars accelerating with TCS OFF they are clearly seen (see Figs. 3 to 5). Such results were obtained because for car acceleration with TCS ON slip of its driving wheels is under constant control by decrease of the rotation speed of the car engine at the necessary moment (when the slip is to begin). For this reason graphs of car acceleration with TCS ON seem more even, without significant jumps, whereas if a car accelerates with TCS OFF, slip of driving wheels is not controlled. When the traction power exceeds the adhesion power, a partial slip of driving wheels begins and adhesion between tyres and road pavement can be lost. Namely at such moments there occur sharp falls of car acceleration, as it is clearly seen on the graphs (see Figs. 3 to 5).When car acceleration further proceeds, adhesion renews and values on the graphs explodes up to a some value, when a partial slip of the driving wheels renews, a partial loss of adhesion occurs again.

Because of right proportioning of acceleration with the acceleration pedal (in winter conditions) adhesion of car wheels with road pavement was almost near to the limit of initialization of the driving wheels slip. So it was done with purpose to reach maximum possible acceleration driving on a slippery road pavement (see Figs. 6, 7). It should be noted that at some cases and moments values of acceleration with TCS OFF were obtained higher than for TCS ON (see Table 2 and Figs. 6, 7).This fact shows that with TCS OFF it is possible to reach higher maximum values of accelerations on a slippery pavement than with TCS ON but such problem is more difficult.

Also it should be noted that the obtained results in no shape do not indicates the inefficiency of the TCS, because there were analysed the most successfully accelerations. A part of experiments failed and were excluded from the research because of too high slip of driving wheels as erroneous.

Table 2

Acceleration values of cars tested on a snow-covered asphalt-concrete paving

	TCS ON	TCS ON	TCS OFF	TCS OFF
Automobile	$a_{av.\ max}$ [m/s^2]	$a_{av.}$ [m/s^2]	$a_{av.\ max}$ [m/s^2]	$a_{av.}$ [m/s^2]
Volkswagen Golf 1.9 TDI 77 kW (DSG)	2.317	1.338	2.197	1.391
Volkswagen Golf 1.9 TDI *BlueMotion* 77 kW (manual gearbox)	2.103	1.179	2.167	1.250

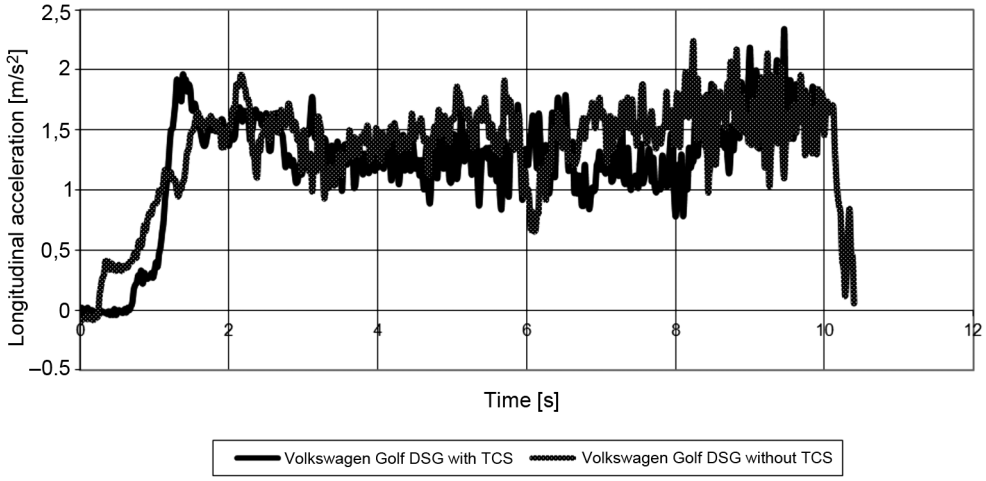

Fig. 6. Car Volkswagen Golf 1.9 TDI 77 kW (DSG) acceleration diagrams, when TCS is switched ON and OFF (snow-covered asphalt-concrete)

Rys. 6. Samochód Volkswagen Golf 1.9 TDI 77 kW (DSG) – wykresy przyspieszenia przy TCS włączonym i wyłączonym (nawierzchnia asfaltowo-betonowa pokryta śniegiem)

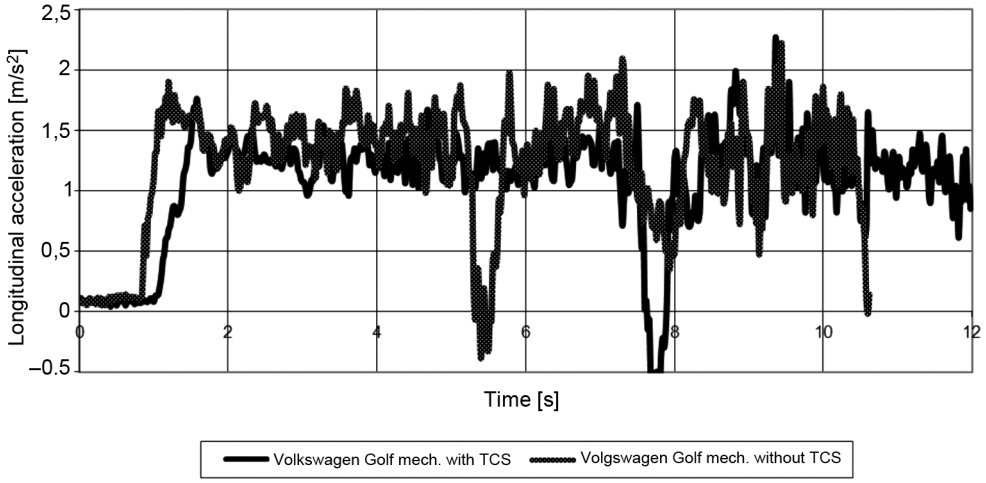

Fig. 7. Car Volkswagen Golf 1.9 TDI *BlueMotion* 77 kW (manual gearbox) acceleration diagrams, when TCS is switched ON and OFF (snow-covered asphalt-concrete)

Rys. 7. Samochód Volkswagen Golf 1.9 TDI BlueMotion 77 kW (ręczna skrzynia biegów) – wykresy przyspieszenia przy TCS włączonym i wyłączonym (nawierzchnia asfaltowo-betonowa pokryta śniegiem)

After experiments there became clear that in many cases the TCS determines even acceleration of cars without loss of adhesion with road pavement and it assists to drive the vehicle. But sometimes better car acceleration values can be obtained by the proper proportioning of the acceleration pedal (so that wheel slip would be near to its marginal value but because of a partial slip the possible maximum characteristics of acceleration would not decrease) and for cars without TCS (see Table 2 and Figs. 6, 7).

6. Conclusions

After experimental research of car acceleration for cars with and without the TCS the following conclusions are formulated:

1. It was established that car acceleration with the switched off TCS is not even if compared with the TCS switched on. As a car without the TCS intensively accelerates on a slippery road pavement, an improper proportioning of the acceleration pedal press will arouse loss of adhesion between the car driving wheels and road pavement and the car will slide at some time moments. This negatively influences the car acceleration characteristics. In such case the value of acceleration can significantly decrease and approach to zero. It should be noted that this do not happens if the TCS is switched on.
2. A proper proportioning of the accelerator pedal press on a slippery road paving with TCS switched off at some circumstances better acceleration characteristics can be obtained comparing with experiments with TCS switched on.
3. The results found in the experiments show that for cars with TCS switched off on a dry road pavement accelerations can be at 0.5 m/s^2 higher than accelerations with TCS switched on. This happens because of the constant control of wheel slip with some reserve; therefore acceleration of cars with TCS switched on can be less effective.
4. Average values of car accelerations, found in the experiments are:
   – for acceleration on a dry asphalt-concrete pavement, TCS ON, $a_{av.} = 2.868$ m/s^2;
   – for acceleration on a dry asphalt-concrete pavement, TCS OFF, $a_{av.} = 2.926$ m/s^2;
   – for acceleration on a snow-covered asphalt-concrete pavement, TCS ON, $a_{av.} = 1.259$ m/s^2;
   – for acceleration on a snow-covered asphalt-concrete pavement, TCS OFF, $a_{av.} = 1.321$ m/s^2.
5. It is seen from the obtained values that TCS can decrease insignificantly acceleration characteristics (2–5%). It should be noted that TCS does not allow any driving wheel slip; therefore car driving become easier and the car in parallel become much safer because the car preserves its stability and possibility of devious passing by an obstacle with acceleration. It means that there remains some continuous possibility to pass safely by the obstacle in emergent accidents.
6. The carried out research shows that if not in all cases but in many of them the TCS serve the purpose of improvement of car acceleration characteristics as well as car controllability – the possibility to pass by an obstacle by a devious trajectory without a road accident; it is important from the safety point of view.
7. Analysis of the research results indicates the conclusion that there would be purposeful to carry out a research of car acceleration characteristics driving car by a devious trajectory (e.g. by figure of eight/slalom) so creating a possibility to research the controllability

of cars with the front wheel drive – the ability of devious pass by of an obstacle with acceleration (presence or absence of such ability) together with operation and peculiarities of the ESP – *Electronic Stability Program*.

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