

## **PRACTICAL EXAMINATION OF LONGITUDAL ACCELERATION IN THE RACING CAR IN THE ASPECT OF GROUND ADHESION OF BITUMINOUS SURFACE**

© Krawiec P., Konrad J. Waluś, Polasik Ja., 2013

This work concerns problems connected with race car's behavior permitted to traffic motion on dry asphalt surface during braking and rapid acceleration . The characteristics of the vehicle is presented with particular reference to type of tires. Environmental characteristics and road surface were made. The result of the research and analysis are kinematic characteristics of the particular features of the vehicle enabling assessment the probable risk both for driver and other road users.

**Key words:** tire, Road, Acceleration, Deceleration, Acceleration Process, Breaking Process, Coefficient of Friction.

Ця робота стосується проблем, пов'язаних із поведінкою перегонного автомобіля, дозволеною під час руху по сухому асфальтовому покритті під час гальмування і раптового прискорення. Характеристики транспортного засобу було подано з відповідним посиланням на тип шин. Також було проаналізовано характеристики навколишнього середовища і дорожнього покриття. Результатом дослідження і аналізу є кінематичні характеристики особливостей транспортного засобу, які дають змогу оцінити ймовірний ризик як для водія, так і для інших учасників дорожнього руху.

**Ключові слова:** шини, дорога, прискорення, уповільнення, процес прискорення, процес гальмування, коефіцієнт тертя.

### **Introduction**

A small part of all the cars manufactured are race cars allowed to traffic. Unlike to standard vehicles they are equipped with components used, in general on racecourse which purpose is the fastest overcoming the racecourse. Sport tires, sport shock-absorbers and special elements in construction of car's suspension are helpful. Due to the fact that exchanged elements of the care are not commonly used in classic road vehicles there was necessary to make acceleration and rapid braking tests of the racing car. On the basis of previous experimental researches one can conclude that the efficiency of the components will be much higher than among other vehicles. Authors are aware of the fact that modifications made in the cars components will not influence the costs of its utilization.

Racing cars permitted to traffic motion thanks to used particular components give the driver more confident driving and perceptibly more tires adhesion. It results in obtaining a higher speed of the vehicle and enhancing the ability of transferring forces and moments on the road surface at the same time[1, 2]. The driver of such vehicle using the electronic system for Traction Control entrusts it in fact, not having sufficient driving skills after turning it off. Very important characteristic of such vehicles are both light weight and the relation of the power of the drive unit.

The article shows the behavior of the vehicle on the dry, asphalt surface during the rapid acceleration and breaking process.

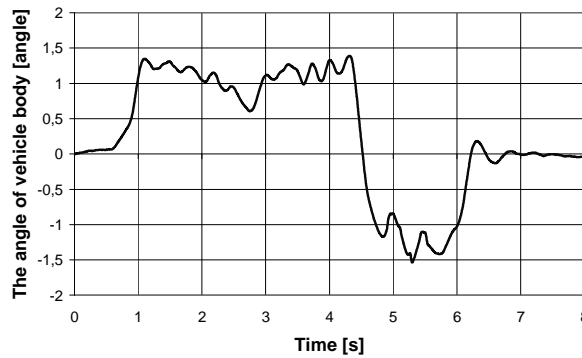
### **Characteristics Of The Vehicle**

Test vehicle was a sport car Renault Clio Sport, year of production 2012. Mileage car in the day of research did not exceed 24000 kilometers.

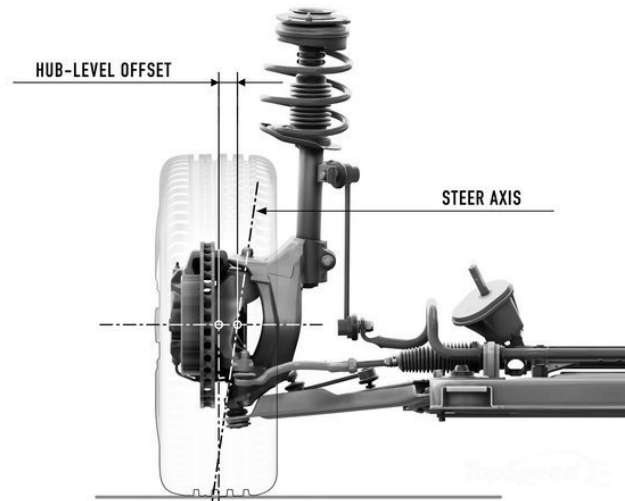


*Fig. 1. A view of the tested vehicle*

The car has manual six-speed transmission and sport suspension, which increases the precision of driving on the trajectory set by the driver. On the other hand it decreases the angular reaction movement of the body panel causing longitudinal roll during the breaking and accelerating process that are on similar level and limits within 1 to 1.5 degree (Fig.2).



*Fig. 2. Characteristic of the longitudinal tilt of the body panel obtained during the study*



*Fig. 3. View of the vehicle suspension system [www.topspeed.com]*

The suspension was applied to a vehicle's specially designed test switches and moved to the desired trajectory with the maximum rotations that enabled the entire width of the tire to remain in contact with the road. Most of the suspension elements eg. arms, switches and hubs in order to make the vehicle lighter are made from aluminum alloy. The vehicle was originally equipped with a sports Brembo 4 piston calipers on the front axle and the brake disc had a diameter of 320mm. On the rear axle, there were single-piston calipers with brake discs with a diameter of 280 mm.



Fig. 4. View of the front axle brake calipers and rear axle

### Characteristics Of Tyres

During tests, the vehicle was equipped with sport tires sized 215/45 R17 with light alloy rims. Tires for track racing have great softness (Tab.1), what ensure an increase of coefficient of cohesion. The usage of the allocated tires connected with sport suspension improves stability of the vehicle and enables gaining greater power of acceleration as well as delays in breaking process in relation with the vehicles that are not adapted to races and rallies [6-11]. The front axle was fit with Barum tires BRAVURIS 2 from 2013, with an asymmetric tread (Fig.4). The tire was marked with speed index “W”, which means that it can be driven to a speed of 270 km/h. Tires that are made from very soft rubber compound dedicated to races result in faster tread attrition. The manufacturer additionally applied silica in the center of the tread in order to hardness stabilization irrespective of temperature changes of the tire. The rear axle had mounted tires from Continental Conti Sport Contact 3 produced in 2011(Fig.4) The tires rear axle was also marked with speed symbol 'W' and as well as being on the previous axle which was characterized by the asymmetry of tread.



Fig.5 View of treads of tires used in road tests  
Barum BRAVURIS 2( on left) and Continental Conti Sport Contact 3( on right)

Table 1

### Hardness and tire temperature recorded during tests in 2013

Hardness of the side of tire	FL 54/54/54	FR 56/57/57
	RL 62/61/60	RR 61/62/60
Hardness of tread	FL 57/56/57	FR 57/56/59
	RL 60/63/61	RR 61/60/56
Temperature of the side of tire	FL +35,6 °C	FR +29,2 °C
	RL +22,6 °C	RR +16,6 °C
Temperature of tread	FL +38,4 °C	FR +36,8 °C
	RL +22,8 °C	RR +17,2 °C
Pressure inside the tire	FL 0,17 MPa	FR 0,19 MPa
	RL 0,16 MPa	RR 0,16 MPa

FL – Front left;    RL – Rear left  
FR – Front rear;    RR – Rear right

In order to define the tread depth three measurements were made in three cross-sections of each tyre. The measurement results are shown in table 2.

Table 2

**Averaged measurements of the tread depth of a particular tyres**

	LF	FR	LR	RR
External	6,17 mm	5,81 mm	5,94 mm	5,92 mm
Middle	7,37 mm	6,65 mm	5,86 mm	5,91 mm
Internal	6,22 mm	5,38 mm	5,29 mm	5,55 mm

### **Environmental characteristics and surface conditions**

Road tests were introduced in the year 2013 on a road with minimal traffic along the railway embankment between the times of 9:00 and 13:00. This location was chosen due to the safety of the study , the lack of pedestrians and other vehicles. A selected section of the road had a flat asphalt surface and a lack of latitudinal tilt( Fig.6,7). The lateral inclination on the road was below 1%. In the middle of the selected section of the road, there was little “hump” occurring all along the measured road section, which was about 150 meters in length. The occurrence of irregularities in the "hump" was caused by road use by moving vehicles. The road was about 2,5 meters wide what was the reason of significant limitations in its middle part. During the research the road surface was dry and clean. There were no defects and chunking in the selected section of the road however there were a few transverse cracks which did not have influence on the research results because they were not palpable by the steering wheel and was not detected by measuring system. The asphalt was clearly worn out however it maintained its roughness and there were not both worn out and smooth places (Fig.6).



Fig. 6. View of a road on which the tests were performed

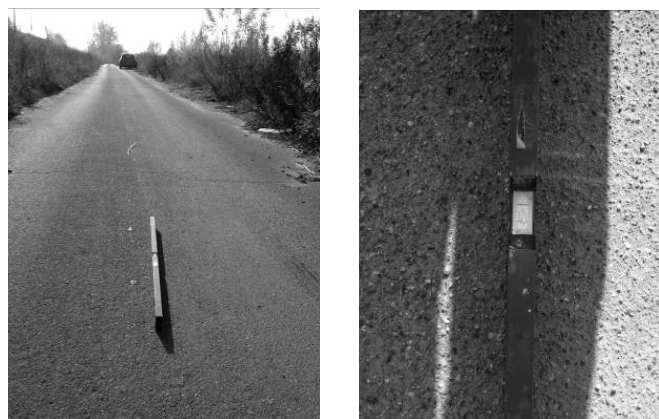


Fig. 7. Measurements of surface tilt

During the researches environmental conditions were tested three times: before , after five road tests and after the kinematic vehicle test. Results of these test are presented in table 3,4 and 5.

Table 3

**The results of measurements of environmental conditions before initiating tests of the kinematic characteristics of vehicle movement**

Air temperature	+11,3°C	
Humidity	68,3%	
Atmospheric pressure	1006,2 hPa	
Dew point temperature	+5,8°C	
Road surface temperature	+3,8°C	
Brake discs temperature	FL +27°C	FR +25°C
	RL +20°C	RR +17°C

Table 4

**The results of measurements of environmental conditions after five tests**

Air temperature	+16,7 °C	
Humidity	54%	
Atmospheric pressure	1005,9 hPa	
Dew point temperature	+7,3 °C	
Road surface temperature	6,6 °C	
Brake discs temperature	FL +38,4 °C	FR +34,8 °C
	RL +23,6 °C	RR +25,6 °C

Table 5

**The results of measurements of environmental conditions after termination of the kinematic characteristics vehicle's motion**

Air temperature	17,8°C	
Humidity	53,6%	
Atmospheric pressure	1005,7 hPa	
Dew point temperature	+7,2 °C	
Road surface temperature	+8,6°C	
Brake discs temperature	FL +73,2 °C	FR +71,6 °C
	RL +33,8 °C	RR +37,0 °C

**The methodology and the course of experimental research**

The aim of the researches was to measure the longitudinal accelerations of the sports car Renault CLIO Sport. The vehicle was equipped with Analog Devices type ADIS 16385 and test equipment type ADIS 16385 which consisted of three acceleration sensors and three piezo-gyroscopes integrated into one measuring system. The acquisition and data storage was made by a portable computer with dedicated software sensors (Fig.8) The measurement apparatus used in tests has about 2 % measurement uncertainty.[ 3,4,5]

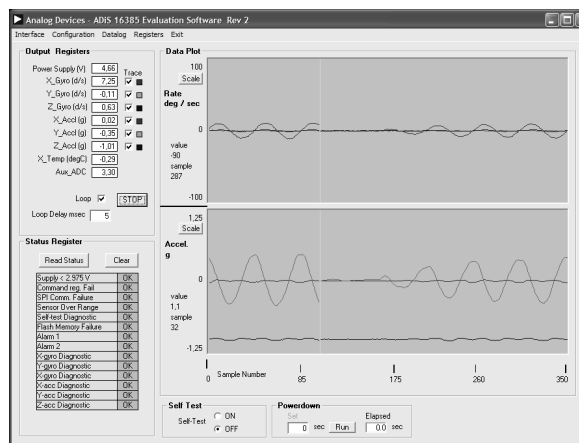


Fig. 8. View of vehicle with the test apparatus and a window to the acquisition and archiving of measurement data

### Results of measurement

During the experiment the racing car was dispersed on the first gear ( 5 trials) from a standing start to a speed of 50 km/h and next intensively braked to a stop. Next 5 trials were made with the change of gear and the achieved speed oscillated around 90km/h. All trials ended with intensive breaking of a vehicle and the drivers aim was constant pressing the brake pedal to stop the vehicle. Examples of the vehicle's accelerations characteristics obtained for the two measurement series are shown in Figure 9.

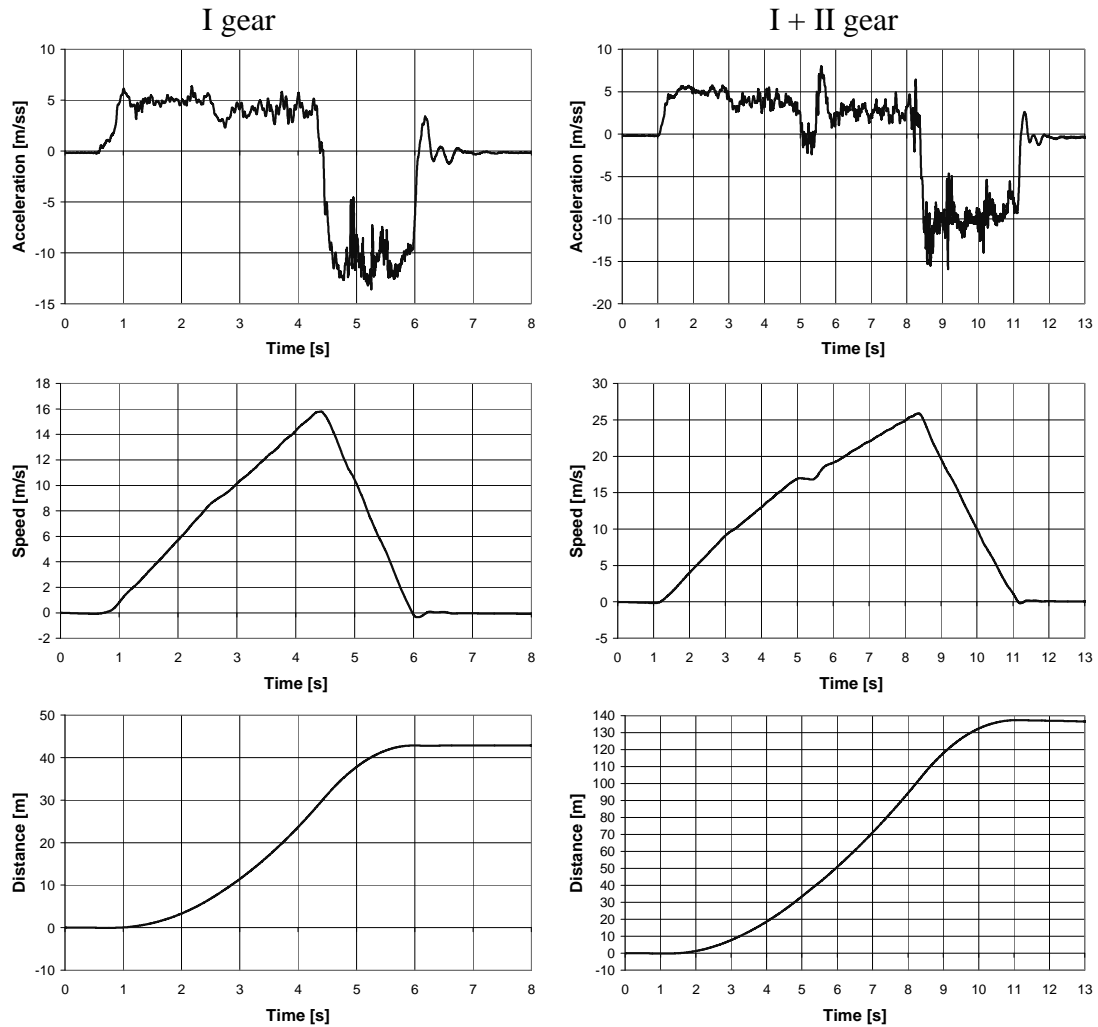


Fig. 9. Sample characteristics of the kinematic features of the vehicle movement

Table 6

### The results of measurements of the total distance traveled by the vehicle research

Trial number	Renault Clio Sport					
	Duration of test [s]	The total stopping distance measured by measuring tape [m]	The total length of the path determined from the value of the longitudinal accelerations [m]	Braking time [s]	Braking distance [m]	The initial speed of the braking [km/h]
1	6,59	42,5	42,38	2,34	12,74	55,73
2	6,39	42,1	42,65	2,45	12,34	57,66
3	6,38	42,0	42,27	2,55	12,23	56,84
4	6,46	41,2	41,85	2,53	11,69	56,58
5	6,34	36,8	37,07	2,72	10,80	53,25
6	10,33	117,4	118,37	3,73	35,12	83,74
7	10,86	126,8	127,10	3,58	29,42	90,69
8	10,81	132,0	133,75	3,59	30,95	92,89
9	11,02	124,4	125,24	3,51	27,44	85,68
10	11,20	135,6	136,25	3,79	32,38	93,31

### The analysis of results

During the experimental researches the drivers aim was impetuous acceleration and braking of the sports car. 5 acceleration trials only on first gear were made with the speed of 55km/h. Next five trials acceleration was made with the change of gears, and achieved speed was about 90km/h. After achieving planned speed the vehicle was braking intensively to stop. Obtained by car Renault CLIO Sport accelerations for first gear oscillate between  $4,05 \div 4,45 \text{ m/s}^2$ . Whereas for second gear range in  $2,89 \div 3,17 \text{ m/s}^2$ . During the measurement of braking process achieved by the racing car full of average decelerations (MFDD- Mean Fully Developed Deceleration) obtained from  $9,79 \text{ m/s}^2$  to  $10,69 \text{ m/s}^2$ . The results of experimental research of traveled distance were subjected to statistical analysis to determine standard declination of the a single measurement. For the calculation of the standard declination with normal distribution( method of measurement type A standard uncertainty[124, 139]) a following relation was used:

$$\sigma_x = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^n (x_i - \bar{x})^2}$$
 – the standard declination of the arithmetic mean of the measurements,

where n – the number of measurements, xi – the value of a single measurement,  $\bar{x}$  – the average value from measurements or expected value,  $(x_i - \bar{x})$  – measurement error or declination from the expected value.

Detailed results of the calculations are shown in Table 7 and 8.

Table 7

**Average value of longitudinal acceleration of the vehicle for first gear**

Trial number	Average acceleration on first gear [m/s <sup>2</sup> ]	MFDD (Mean Fully Developed Deceleration) [m/s <sup>2</sup> ]
1.	4,05	10,11
2.	4,41	10,69
3.	4,45	10,68
4.	4,42	10,13
5.	4,41	10,19
<b>Average measurement</b>	<b>4,35</b>	<b>10,36</b>
<b>Standard deviation</b>	<b>0,15</b>	<b>0,27</b>

Table 8

**Average value of longitudinal acceleration of the vehicle for gear shifting**

Trial number	Average acceleration on		MFDD (Mean Fully Developed Deceleration) [m/s <sup>2</sup> ]
	I gear [m/s <sup>2</sup> ]	II gear [m/s <sup>2</sup> ]	
6.	4,30	3,17	10,38
7.	4,25	3,12	10,58
8.	4,30	2,96	10,17
9.	4,29	3,05	10,53
10.	4,35	2,89	9,79
<b>Average measurement</b>	<b>4,30</b>	<b>3,04</b>	<b>10,29</b>
<b>Standard deviation</b>	<b>0,03</b>	<b>0,10</b>	<b>0,29</b>

Obtained by sports car values of acceleration are slightly higher for obtained by cars type Skoda Octavia II Tour combi or Peugeot 407SW combi (the article sent to print). A clear difference can be seen in the race car's MFDD delay. During the braking process, special sports tires in significantly greater the coefficient of adhesion using bigger energy than tyres not designed for sport competitions. The result of such state is the shortening of the braking way in dry asphalt surface condition.

## Summary

All the tests carried out are made of road safety measures. When measured by the test no common persons or other vehicles were present. Presented in the article values of acceleration during the trials of intense acceleration and braking can be the complementation of data consequent from previous experimental researches and literature sources. In order to preparing fuller description of examined phenomena in the area of vehicle dynamics is appropriate to conduct studies comparing sports cars and utility ones that are not designed for races.

The statistic analysis was made for all measurements which showed that none of gained results was not characterized as “fat” error. All obtained results did not exceeded the uncertainty scatter on the level of 1,6% and most of them ranged of uncertainty less than 1%.

This work has been supported by National Science Centre grant 5-53-5445.

1. Beckmann B., *The physics of racing*. Burlington, CA 91503, 1991-2002 ([http://phors.locost7.info/files/Beckman\\_-\\_The\\_Physics\\_of\\_Racing.pdf](http://phors.locost7.info/files/Beckman_-_The_Physics_of_Racing.pdf) 2013-10-04 12:35). 2. Gillespie T.D., *Fundamental of Vehicle Dynamics*, Warrendale, PA 15096-0001, 1992. 3. Kędziora Krzysztof, Lewandowski Andrzej, Waluś Konrad J., *Wykorzystanie czujników przyspieszeń do wyznaczania parametrów kinematycznego ruchu pojazdu, Projektowanie i badanie urządzeń mechatronicznych / pod red. M. Dudziak*, Wydaw. Politechnika Poznańska Katedra Podstaw Konstrukcji Maszyn, Poznań 2010, S. 235–244. 4. Waluś Konrad J., Lewandowski Andrzej, Kędziora Krzysztof, Dudziak Marian, *Charakterystyka i badanie cech kinematycznych trajektorii ruchu pojazdu za pomocą czujników przyspieszeń, Projektowanie i badanie urządzeń mechatronicznych / pod red. M. Dudziak*, Wydaw. Politechnika Poznańska Katedra Podstaw Konstrukcji Maszyn, Poznań 2010, S. 227–234. 5. Waluś Konrad J., Lewandowski Andrzej, Kędziora Krzysztof, Dudziak Marian, *Possibilities of vehicle movement trajectory characterizing with the use of acceleration sensors*, 7th International Scientific Conference on Production Engineering Development and modernization of production – RIM 2009, Cairo, Egypt, 2009, S. 25–26, full text on CD-ROM. 6. Waluś K. J., *Badania doświadczalne intensywnego przyspieszania ciągnika siodłowego w ujemnych temperaturach otoczenia (badania rozpoznawcze)*, *Autobusy* 3/2013, s. 2089–2096, CD-ROM, ISSN 1509-5878. 7. Waluś K. J., *Badania doświadczalne intensywnego hamowania ciągnika siodłowego w ujemnych temperaturach otoczenia (badania rozpoznawcze)*, *Autobusy* 3/2013, s. 2097–2102, CD-ROM, ISSN 1509-5878. 8. Waluś K. J., *Comparing the intensity of the acceleration of a passenger car equipped with summer and winter tires in sub-zero road surface temperatures*, *Technológ.* – 2013, nr 4, s. 262–264, ISSN 1337-8996. 9. Waluś K. J., *Comparing the intensity of the braking car equipped with summer and winter tires in sub-zero road surface temperatures*, *Technológ.* – 2013, nr 4, s. 265–267, ISSN 1337-8996. 10. Waluś K. J., *Comparison of the Maximum Acceleration of a Passenger Car on Selected Pavements in Wintertime*, abstract, proceedings of XX Ukrainian-Polish Conference on “CAD in Machinery Design. Implementation on Educational Issues.” CADMD’2012, October 11–13, 2012, Lviv, UKRAINE, p. 24–30, ISBN 978-617-607-332-1. 11. Waluś K. J., Olszewski Z., *Analysis of Tire-road contact under Winter conditions*, *Lecture Notes in Engineering and Computer Science, Volume 2192, proceedings World Congress on Engineering 2011, Volume III, London, U.K. 6-8 July, 2011, p. 2381–2384*, ISBN 978-988-19251-5-2, ISSN 2078-0958. 12. EA-4/02 – *Wyrażanie niepewności pomiaru przy wzorcowaniu*, wydanie elektroniczne, 1999, <http://www.gum.gov.pl/>. 13. PN – ISO 3534-1:2002, *Statystyka, Terminologia i symbole – Część 1: Ogólne terminy z zakresu rachunku prawdopodobieństwa i statystyki*.