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## THE INFLUENCE OF VEHICLE PREPARATION ON THE RESULTS OF SUSPENSION KINEMATICS MEASUREMENT

### WPLYW PRZYGOTOWANIA POJAZDU NA WYNIKI POMIARU KINEMATYKI ZAWIESZENIA

#### Abstract

This paper concerns the assessment of the impact of tyre pressure and additional vehicle loading which is inconsistent with the manufacturer's requirements on the results of wheel alignment measurement. A sample of results from tests performed on a second generation Toyota Prius and a fifth generation Volkswagen Passat are presented. The tested vehicles differed in the types of front axle wheel suspension. An analysis of the obtained results was conducted. The analysis revealed differences between the results of reference tests performed in accordance with the requirements of vehicle manufacturers and those conducted for incorrectly prepared vehicles. The values of these differences depended, inter alia, on the type of suspension.

**Keywords:** car, suspension, wheel alignment, measurement, road safety

#### Streszczenie

Praca dotyczy oceny wpływu ciśnienia w ogumieniu oraz obciążenia pojazdu niezgodnego z wymaganiami producenta, na wyniki pomiaru geometrii zawieszenia. Przedstawione zostały przykładowe wyniki prób przeprowadzonych na samochodach Toyota Prius II generacji oraz Volkswagen Passat generacji piątej. Pojazdy różniły się rodzajami zawieszenia kół osi przedniej. Wykonana została analiza uzyskanych wyników, która wskazała różnice pomiędzy wynikami prób referencyjnych – przeprowadzonych zgodnie z wymaganiami producentów – a próbami dla pojazdów niewłaściwie obciążonych bądź z niewłaściwym ciśnieniem w ogumieniu. Wartości tych różnic uzależnione były między innymi od rodzaju zawieszenia.

**Słowa kluczowe:** samochód, zawieszenie, geometria zawieszenia, pomiar, bezpieczeństwo ruchu drogowego

## 1. Introduction

The suspension system is a significant part of a car which is responsible for transferring forces between the wheels and the body, as well as damping and reducing the dynamic forces acting on the wheels and the entire vehicle [14]. The front-wheel suspension systems of modern cars are usually independent systems; one of the most popular is the MacPherson strut, while the most complicated is multi-link suspension. Rear wheels are usually guided by a twist-beam or by independent suspension systems. Due to the significant impact of the suspension on vehicle handling and driving safety [1, 9, 15], a number of pieces of research and scientific works, including numerical simulations [16–20], have been conducted in order to improve and develop their construction and capabilities [4, 5, 7–10, 12, 14, 15]. As a result of appropriate suspension characteristics, it is possible to ensure adequate stability and steerability, which are the features that ensure the car's resistance to forces interfering with its movement [6, 11].

Regardless of the design and type of suspension, its proper maintenance is very important. Wheel alignment inspection and, if necessary, adjustment should be performed regularly [3]. Correct wheel geometry is very important in the context of road traffic safety; moreover, inaccurate alignment causes excessive tyre wear and has an influence upon fuel consumption [3]. To properly conduct measurements of wheel alignment, the vehicle should be in working order, any backlashes in suspension and steering systems should be removed and the tyre pressure should be correct. Additionally, measurement conditions such as proper vehicle load specified by the manufacturer must be provided.

## 2. Tested cars

Two cars with different types of suspension were used in the measurements of wheel alignment: a second generation Toyota Prius (XW20) and a fifth generation Volkswagen Passat Variant (B5). The Toyota was equipped with an independent MacPherson front wheel suspension system; the Volkswagen's front wheels were guided with a multi-link independent suspension system. The rear axles of both cars were equipped with semi-independent twist-beam suspensions. The basic parameters of the tested cars are presented in Table 1.

Table 1. The basic technical data of the tested cars

	Toyota Prius XW20	VW Passat Variant B5
Engine	1.5	1.9 TDi
Drive wheels	front	front
Front suspension	MacPherson	Multi-link
Rear suspension	twist-beam	twist-beam
Length [mm]	4450	4675
Wheelbase [mm]	2700	2705
Track front/rear [mm]	1505/1480	1515/1515
Curb weight [kg]	1317	1445
GVM* [kg]	1725	2010
* GVM – gross vehicle mass		

Figure 1 shows overviews of the examined vehicles on the test bench.

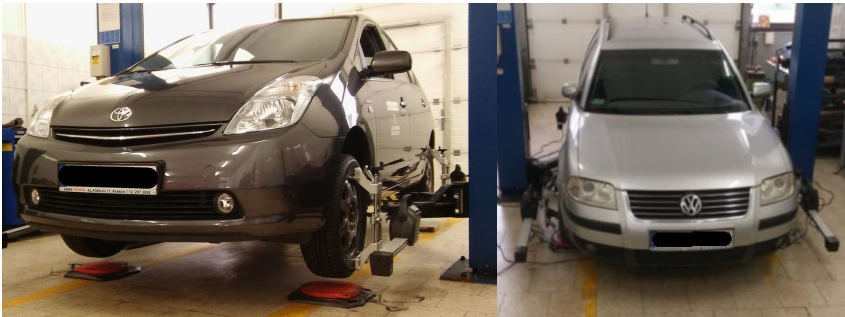


Fig. 1. Tested cars on the test bench: Toyota Prius (left); Volkswagen Passat (right)

Table 2 presents wheel alignment specification of tested vehicles.

Table 2. Wheel alignment specification of the tested cars

	Toyota Prius XW20	VW Passat Variant B5
Front wheels		
Caster angle	$+ 3^{\circ}10' \pm 45'$	n/n
Camber angle	$- 0^{\circ}35' \pm 45'$	$- 0^{\circ}35' \pm 25'$
Total toe	$0^{\circ}00' \pm 12'$	$0^{\circ}20' \pm 4'$
FL/FR* toe	$0^{\circ}00' \pm 6'$	$0^{\circ}10' \pm 2'$
SAI**	$+ 12^{\circ}35' \pm 45'$	n/n
Rear wheels		
Camber angle	$- 1^{\circ}30' \pm 30'$	$- 1^{\circ}30' \pm 20'$
Total toe	$+ 0^{\circ}18' \pm 15'$	$+ 0^{\circ}22' \pm 13'$
RL/RR*** toe	$+ 0^{\circ}09' \pm 7'$	$+ 0^{\circ}11' \pm 6'$
* FL/FR – front left/front right ** SAI – steering angle inclination *** RL/RR – rear left/rear right		

### 3. Used equipment

The measurements were conducted using a CUSTOR HWA G58 wheel alignment device [2]. The device is equipped with four heads with CCD cameras attached to the wheels using rim clamps.

Figure 2 shows an overview of a wheel alignment device used in the measurements and one of its heads fitted with CCD cameras; the basic technical specification of the device is presented in Table 3.



Fig. 2. An overview of the CUSTOR HWA G58 wheel alignment device and a close-up of a front left head attached to the wheel

Table 3. The basic technical specification of the CUSTOR HWA G58 wheel alignment device

	Parameter	Range	Accuracy
Front axle	Toe	$\pm 24^{\circ}$	$\pm 1'$
	Camber	$\pm 10^{\circ}$	$\pm 1'$
	Caster	$\pm 20^{\circ}$	$\pm 2'$
	SAI*	$\pm 20^{\circ}$	$\pm 2'$
	Setback	$\pm 10^{\circ}$	$\pm 1'$
Rear axle	Toe	$\pm 24^{\circ}$	$\pm 1'$
	Camber	$\pm 10^{\circ}$	$\pm 1'$
	Setback	$\pm 10^{\circ}$	$\pm 1'$
	Thrust angle	$\pm 10^{\circ}$	$\pm 1'$
* SAI – steering angle inclination			

#### 4. Measurements and their results

The aim of this study was the analysis of the influence of improper preparation of a car on results of wheel alignment measurement. A correctly prepared car must be free of defects or damage to suspension and steering systems; it should be loaded in accordance with the manufacturer's specifications and the tyre pressure should be correct. The presented work consists of multiple measurements of the wheel geometry of two cars: a second generation Toyota Prius and a fifth generation Volkswagen Passat Variant, with different loading of the tested cars which are noncompliant with the manufacturer's requirements. In the case of the Toyota Prius, the influence of tyre pressure was also taken into account. Before each measurement, a rims runout compensation was performed.

### 4.1. Impact of vehicle load

In accordance with the requirements of the manufacturers of both tested cars, the measurements should be performed without any additional load. However, in accordance with the aim of this study, vehicles were additionally loaded during the measurements. In the case of the Toyota Prius, the tests were conducted for 1, 2 and 3.5 kN of extra load placed in the boot; in the case of the Volkswagen, the extra load was 1, 2, 3.5 and 5 kN. The load was placed symmetrically in relation to the longitudinal axis. In addition to these measurements, the vehicles were also tested with only the curb weight in order to provide a control reference.

Figures 3 to 8 show sample results of the conducted measurements.

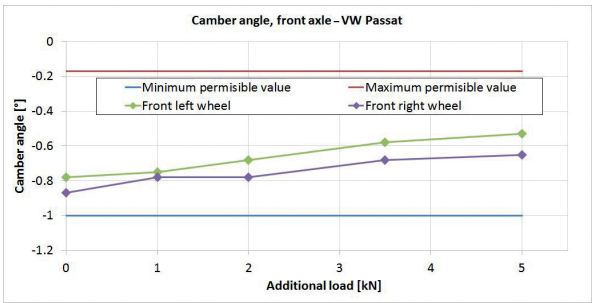


Fig. 3. Impact of additional vehicle load on front wheel camber angle value for VW Passat

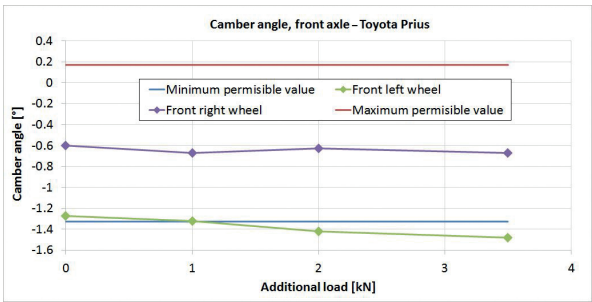


Fig. 4. Impact of additional vehicle load on front wheel camber angle value for Toyota Prius

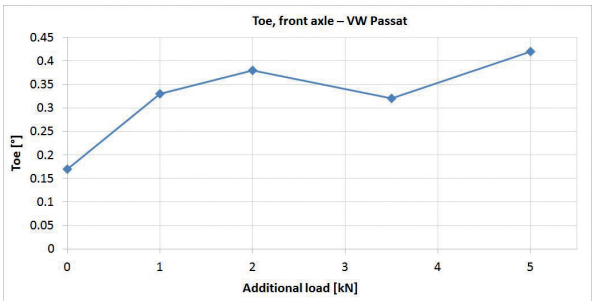


Fig. 5. Impact of additional vehicle load on front wheel toe value for VW Passat

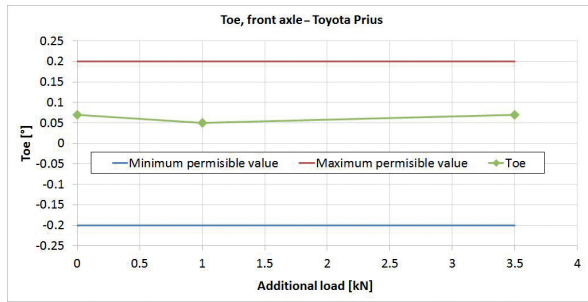


Fig. 6. Impact of additional vehicle load on front wheel toe value for Toyota Prius

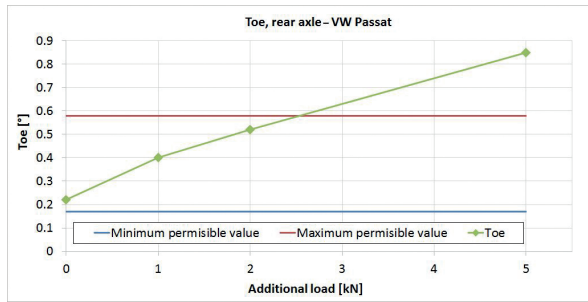


Fig. 7. Impact of additional vehicle load on rear wheel toe value for VW Passat

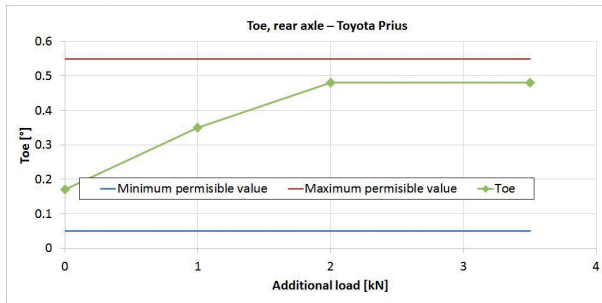


Fig. 8. Impact of additional vehicle load on rear wheel toe value for Toyota Prius

The obtained results of the measurements of the sample wheel alignment parameters are presented in Tables 4 to 7. The differences between the values obtained during the correct (referential) measurement and those obtained for the conditions with additional loading were calculated using Formula 1.

$$Difference = \left| \frac{A - B}{A} \right| \cdot 100\% \quad (1)$$

where

- A – the value obtained during correct measurement
- B – the value obtained for the car with additionally loading

Table 4. The results of the front wheel camber angle measurement for the VW Passat

Additional load [kN]	Camber front left [°]	Difference front left [%]	Camber front right [°]	Difference front right [%]
0	-0.78	—	-0.87	—
1	-0.75	4	-0.78	10
2	-0.68	13	-0.78	10
3.5	-0.58	26	-0.68	22
5	-0.53	32	-0.65	25

Table 5. The results of the front wheels camber angle measurement for the Toyota Prius

Additional load [kN]	Camber front left [°]	Difference front left [%]	Camber front right [°]	Difference front right [%]
0	-1.27	—	-0.6	—
1	-1.32	4	-0.67	12
2	-1.42	12	-0.63	5
3.5	-1.48	17	-0.67	12

Table 6. The results of the toe measurement for the VW Passat

Additional load [kN]	Toe front [°]	Difference [%]	Toe rear [°]	Difference [%]
0	0.17	—	0.22	—
1	0.33	94	0.4	82
2	0.38	124	0.52	136
3.5	0.32	88	—	—
5	0.42	147	0.85	286

Table 7. The results of the toe measurement for the Toyota Prius

Additional load [kN]	Toe front [°]	Difference [%]	Toe rear [°]	Difference [%]
0	0.07	—	0.17	—
1	0.05	29	0.35	106
2	—	—	0.48	182
3.5	0.07	0	0.48	182

## 4.2. Impact of tyre pressure

An additional area of interest was the impact of tyre pressure on the measurement results; this was tested for the Toyota Prius. Aside from the correct (referential) measurement with the correct tyre pressure of 0.2 MPa, two cases were considered: reduced front wheel tyre pressure to 0.14 MPa with normal rear wheel pressure and reduced pressure to 0.14 MPa in all four wheels.

Example results of conducted measurements are presented in Figs. 9 and 10.

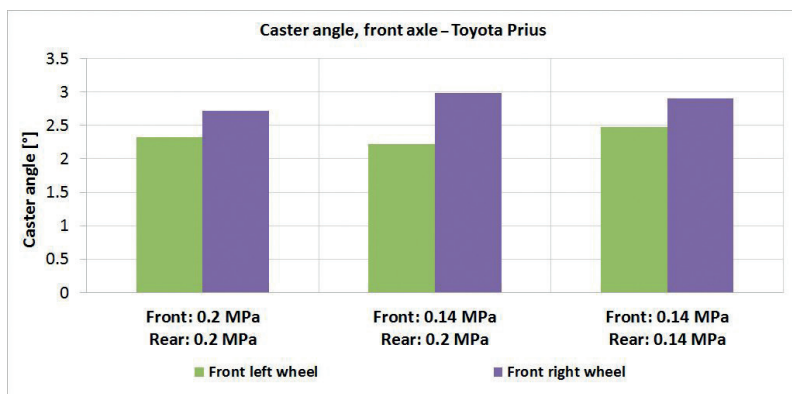


Fig. 9. Impact of tyre pressure on front wheel camber angle values for the Toyota Prius

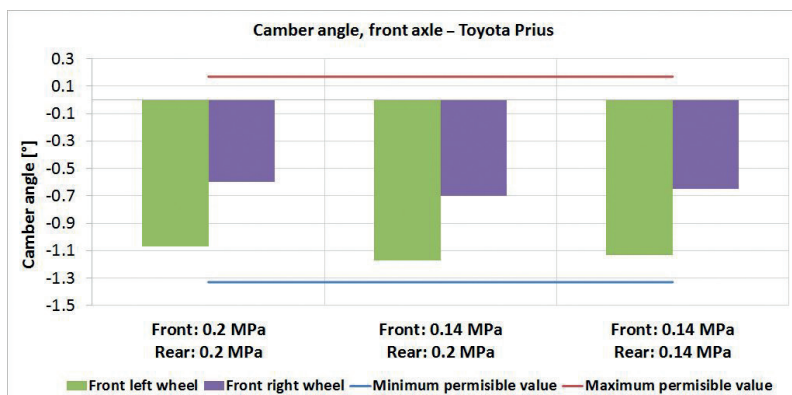


Fig. 10. Impact of tyre pressure on camber angle values for the Toyota Prius

Tables 8 and 9 show sample measurement results and differences between the correct measurement and the measurements performed for incorrect tyre pressures. The differences were calculated using Formula 1.

Table 8. The results of the camber angle measurement for the Toyota Prius

Tyre pressure [MPa]	Camber front left [°]	Difference front left [%]	Camber front right [°]	Difference front right [%]
front/rear: 0.2	-1.07	—	-0.60	—
front/rear: 0.14/0.2	-1.17	9	-0.70	17
front/rear: 0.14	-1.13	6	-0.65	8



Table 9. The results of the caster measurement for the Toyota Prius

Tyre pressure [MPa]	Caster front left [°]	Difference front left [%]	Caster front right [°]	Difference front right [%]
<b>front/rear: 0.2</b>	2.33	—	2.72	—
<b>front/rear: 0.14/0.2</b>	2.22	5	2.98	1
<b>front/rear: 0.14</b>	2.47	6	2.9	7

## 5. Summary

Analysis of the presented results shows that the preparation of the vehicle has an influence on the obtained values of the measured parameters. The incorrect tyre pressure and vehicle load resulted in changes to the results of the measurement compared to those conducted on properly prepared cars. These changes were dependent on the type of suspension, but in most cases, the obtained values were within the tolerance limits given by the manufacturer. The differences between the measured values and the result of the reference measurements ranged from a few to a dozen or so per cent, although in some cases, they exceeded one hundred percent.

The measured values of camber angle changed with the additional load, the changes were different for the MacPherson and multi-link suspension systems. In the case of Volkswagen, the additional load placed in the boot caused an increase in the measured value. In the case of the Toyota Prius, the camber angle slightly decreased with increases to the additional load (see Figs. 3 and 4).

Figures 5 and 6 present the impact of the additional load on the front axle toe measurements. The value of toe for the Volkswagen Passat increased by 147 % for 5 kN additional load; for the Toyota it did not significantly change.

Both cars were equipped with twist beam rear suspension; in both cases, the additional load caused growth of the measured values of the rear toe (see Figs. 7 and 8).

The influence of tyre pressure on wheel alignment measurement results was also analysed. The 30% reduction of tyre pressure caused a change in the values of the measured parameters by a few per cent.

The results obtained show that the correct preparation of a car for a wheel alignment measurement is crucial and must not be overlooked. This is especially true in the case of additional loading of a vehicle as this may distort the measurement and can lead to improper wheel alignment adjustment. In some cases, the additional load caused significant changes to the values of the measured parameters; however, these values exceeded the acceptable limits only for a load greater than 2 kN.

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