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ASSESSMENT OF VEHICLE DYNAMIC PROPERTIES

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Abstract
This article deals with the assessment and subsequent comparison of the acceleration and deceleration characteristics of a selected vehicle with data from manufacturers. Dynamics is a complex concept, including many elements that somehow contribute to changing the dynamics of movement, i.e. to acceleration and deceleration, from engine power, gearbox sizing to tires and, in the case of braking, brake components and tires. All the parameters given by the manufacturers guarantee certain properties, and the aim of the article is to determine the performance of the combustion engine and the efficiency of the tires determined from the acceleration achieved, without financially demanding operations and disassembly of individual elements. The tested vehicle was a Mercedes S500 Coupe (335 kW). The tests show the correlation of dynamic tests performed on the engine and the entire transmission from braking to acceleration, while tests performed on the roller test bench prove that the vehicle has greater performance, which corresponds to the acceleration and deceleration test.

Key words: *acceleration, deceleration, braking distance, speed characteristics, automobile, XL Meter.*

INTRODUCTION
Vehicle traffic on roads is becoming increasingly dense. This is why vehicle manufacturers are trying to ensure the greatest possible safety for the crew with various safety features. There are many factors that affect road safety and vehicle driving dynamics. The basic dynamic properties of motor vehicles include acceleration capability, which is also an important parameter in terms of smoothness and road safety *(Vlk, 2003; Rievaj et al., 2013; Waluš, 2016)*. Acceleration capability is influenced by several factors, such as engine parameters, transmission or driving resistance. In addition to the drive system, the driving dynamics are also influenced by the braking system, for which the requirements in various parameters are also constantly increasing. Currently, various electronic systems are increasingly being used in vehicles to help the driver manage limit situations on various surfaces. In passenger cars, these are mainly ABS, EBD, ESP, BA and ASR *(Jablonický et al., 2015; Rill & Castro, 2020; Alamdari et al., 2024)*. In addition, tires also play a significant role, as they have a huge impact on the vehicle's driving dynamics. They form the contact points between the vehicle and the ground. They must transmit all transverse, normal and longitudinal forces. Tires have different properties depending on the design, inflation pressure, type and size. The acceleration time from a certain speed to the desired speed cannot answer all the questions. The acceleration time value may seem satisfactory or unsatisfactory, but to clearly determine this parameter it is necessary to know the entire course of dynamic events. These dynamic events can be determined after a detailed analysis of the chassis, tires and transmission mechanisms. Given the relatively large number of elements that affect the final result, the characteristics of individual components can be determined from a complex measurement of acceleration or deceleration. The measurement of dynamic properties is therefore not only about time *(Maurya & Bokare, 2012; Guiggiani, 2018; Omar et al., 2018; Synák, F. & Synák, J., 2020)*. In order to exclude the influence of tires and climatic conditions, it is necessary to determine the quality of the adhesion properties of the tires. In general, with a more powerful engine and the use of lower quality or poor-quality tires on a less adhesive surface, the guaranteed time given by the manufacturers will not be achieved. As for determining the quality of tires, it is determined using a braking test, where the average deceleration is determined. If the tires are suitable *(they achieve a deceleration of at least 8 - 10 $m.s^{-2}$)* and the test is carried out in suitable conditions, it is assumed that the tires will also work well during acceleration. Subsequently, an acceleration test is carried out and the dynamic times obtained by the test, and the engine power obtained on a dynamometer are cross-compared *(Waluš, 2013; Ivanov et al., 2017; Žuraulis et*

al., 2018; Gillespie, 2021; Reński et al., 2024). The aim of this article was to assess and subsequently compare the dynamic characteristics of the selected vehicle with data from the manufacturer.

MATERIALS AND METHODS

Characteristics of the used material

The vehicle tested in the research was a Mercedes S500 Coupe with an automatic 7-speed transmission and 4x4 drive. The parameters of this vehicle are given in Tab. 1. The tested vehicle is shown in Fig. 1 and in Fig. 2 the measuring devices on the vehicle's windshield can be seen.

Fig. 1 Tested vehicle Mercedes S500 Coupe

Fig. 2 XL Meter and GPS VBox measuring instruments on the vehicle windshield

Tab. 1 Technical specifications of the Mercedes S500 Coupe according to the manufacturer's data

Parameter	Value
Cylinder displacement [cm^3]	4663
Type of engine	8 cylinder, petrol turbocharged
Vehicle operating weight [kg]	2090
Acceleration from 0 to 100 km.h^{-1}, stated by the manufacturer [s]	4.5
Maximum speed [km.h^{-1}]	250
Number of kilometres driven [km]	100600
Length - Width - Height - Wheelbase of the vehicle [mm]	5027 – 1899 – 1411 - 2945
Manufacturer of tires / Type / Size	Pirelli / Sottozero / 255/40 R20
Load and Speed Index	101 V
Tire tread depth	all tires: 8

Characteristics of the used instruments devices

The MAHA MSR 500 power roller test bench is used to measure maximum power and torque. The bench is also suitable for measuring 4x4 vehicles. A rollmeter is used to measure ground distances, which is mainly used by the police in investigating traffic accidents and measuring vehicle braking distances. We will use the XL Meter and GPS VBox to measure acceleration and deceleration values. XL Meter is for measuring the vehicle's braking distance, braking time and deceleration. It consists of an electronic part, an articulated arm *(for adjustable mounting)* and a vacuum suction cup *(for mounting on the glass)*. This data can then be uploaded to a computer, where the appropriate software *(XL Vision)* evaluates and graphically plots the measurement progress.

Characteristics of work procedures

Methodology of measuring performance parameters on a selected vehicle

- Positioning, fixing and preparing the vehicle on a performance cylinder test bench in accordance with technical instructions
- Warming up the engine to operating temperature
- Switching off the electronic stabilization system *(ESP)* on the vehicle
- Performing three measurements on the tested vehicle

- Processing and averaging the measured data

The following Tab. 2 shows the temperature conditions for measurement

Tab. 2 Conditions during measurements of performance parameters

Parameter	Value
Air temperature	20,6 – 22,3 °C
The temperature of the intake air	17,6 – 22,6 °C
Relative humidity	25,6 %
Air pressure	1003,9 – 1004,1 hPa

Methodology of measuring acceleration and deceleration on a selected vehicle

- Selecting a suitable location with suitable parameters for carrying out measurements: a sufficiently long and wide road with a quality surface without irregularities and other obstacles with zero slope.
- Determination of speeds for vehicle testing: 60 km.h^{-1}, 100 km.h^{-1}, 150 km.h^{-1}
- The measurement is carried out with winter tires on a dry surface at an air temperature of 15 °C.
- Warming up the engine to operating temperature
- Installation and adjustment of XL Meter and GPS VBox measuring instruments
- Experimental measurement of acceleration from a speed of 0 km.h^{-1} to predetermined speeds
- Experimental measurement of deceleration from predetermined speeds to a speed of 0 km.h^{-1}
- Measurement of the vehicle's braking distances after each deceleration
- Determination of the adhesion coefficient μ:

$$\mu = \frac{a}{g} \tag{1}$$

where: a is the measured braking deceleration [m.s^{-2}],
g is the gravitational acceleration [m.s^{-2}]

- Processing and evaluation of the measured data

RESULTS AND DISCUSSION

1) Testing the Mercedes S500 Coupe – measuring the vehicle’s speed characteristics

Fig. 3 shows a graphical representation of the power at the wheels, power loss, corrected engine power and torque depending on the revolutions. The maximum power at the wheels was achieved at a speed of 5295 min^{-1} and amounted to 278.5 kW. The maximum power loss of 80.2 kW was achieved at a speed of 5295 min^{-1}. The measured power value is not identical to the value stated by the manufacturer. Differences can be caused by several factors such as a different measurement methodology by the manufacturer, a 2% permissible measurement error on the dynamometer, a faulty dynamometer, unauthorized intervention in the engine, and entry of lower power in the technical certificate in order to save money on insurance and vehicle registration. In Tab. 3 shows other power and torque values from the manufacturer and measured by Maha. During the measurement, the engine reached a torque of only M_k = 480 Nm at a speed of 1800 min^{-1}, which the manufacturer states as the lower limit of maximum torque, while the value of 700 Nm, which the manufacturer states as the maximum torque, was reached by the engine at a speed of 3365 min^{-1}.

Tab. 3 Power and torque values with corresponding rpm on a Mercedes S500

Parameters	Corrected engine power [kW] / revolutions [min^{-1}]	Maximum torque [Nm] / revolutions [min^{-1}]
Manufacturer	335/ 5200 - 5500	700 / 1800 - 3500
Measured values of Maha	352,13 / 5340	706,8 / 3835

As for the power, the manufacturer indicates on the vehicle a corrected power P_{norm} = 335 kW at a revolutions of n = 5250 – 5500 min^{-1}. By measuring, we found the maximum engine power P_{norm} = 352.13 kW at a revolutions of n = 5340 min^{-1}. The maximum measured power exceeds the power parameter specified by the manufacturer by more than 17 kW, while this deviation is no longer consistent with the 2% measurement error on the roller test bench.

1000

800

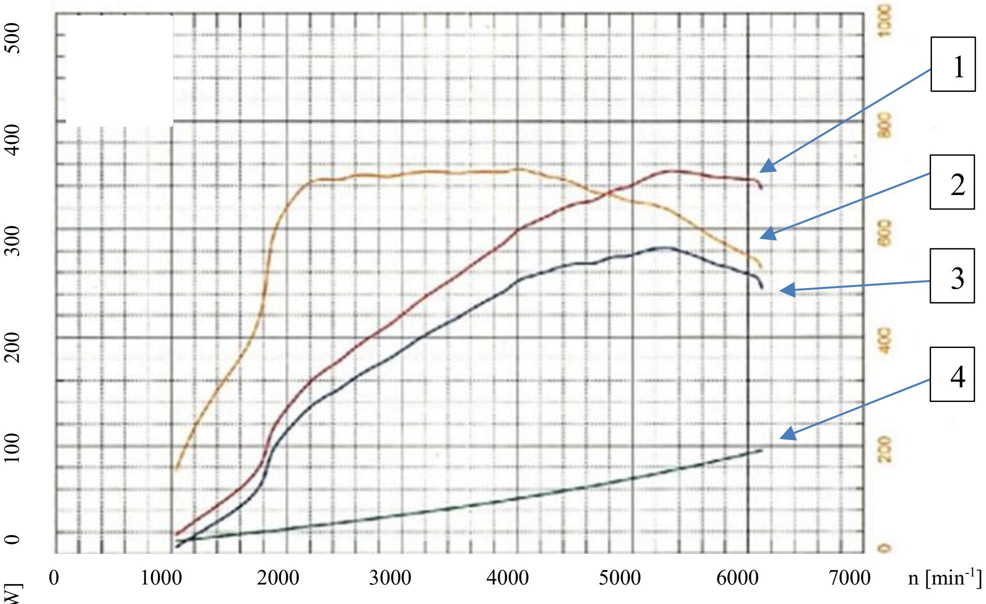

Fig. 3 Measured speed characteristics of the Mercedes S500 Coupe where 1: Corrected engine power [kW]; 2: Torque [Nm]; 3: Engine power on wheels [kW]; 4: Engine power loss [kW])

2) Testing the Mercedes S500 Coupe – Acceleration and Deceleration Measurement

Acceleration

Fig. 4 shows the acceleration measurement process to a speed of 100 km.h^{-1} and Tab. 4 lists selected acceleration parameters.

Tab. 4 Resulting acceleration values for the Mercedes S500 Coupe

Parameters	Values		
Actual speed *(km.h^{-1})*	58	100	150
Acceleration distance [m]	29,3	66,34	209,6
Vehicle acceleration [m.s^{-2}]	6,1	5,53	5,67
Efficiency of using the adhesion coefficient μ [-]	0,62	0,56	0,58
Acceleration time			
Measured acceleration time [s]	3,1	4,97	9,2
Manufacturer declared acceleration time [s]	2,1	4,5	9,3

During the measurement, we noted that the smallest difference between the acceleration time values measured by us and those given by the manufacturer was during acceleration to 150 km.h^{-1}, where our time was only 0.1 s shorter. On the contrary, the largest difference was found out during acceleration to 60 km.h^{-1}, where we differed from the manufacturer by time 1 s. When accelerating to a speed of 150 km.h^{-1}, we reached a speed of 100 km.h^{-1} in 4.9 s on a 65.46 m track and a speed of 60 km.h^{-1} in 2.77 s. The measured higher power was therefore only apparent at a higher speed, and thanks to the higher power, the vehicle caught up on the time lost from the start. The differences could have been caused by different conditions during vehicle testing during the start than the manufacturer had. Another reason could be the weathered condition of the road, or the use of winter tires, which could have caused worse grip conditions.

Deceleration

We braked from a total of three speeds as shown in Tab. 5, with the greatest braking deceleration recorded when braking from a speed of 108 km.h^{-1} and using the XL meter measuring device, the value of 129.62 m. As for the differences in the resulting values when using different measuring devices, the smallest difference was visible when measuring from an initial speed of 155 km.h^{-1}. The difference was 85.82 m when using the roll meter and XL meter. On the contrary, the smallest difference was recorded when braking from a speed of 58 km.h^{-1}, while using the XL meter the braking distance was 0.99 meters

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longer. Different values of the measured braking distances can result from very poor visibility of the braking tracks during all measurements, but also from the device recording the braking distance during the brake application when the vehicle had not yet left a braking track.
Similar research and measurement methodology were also conducted by the authors Ivanov et al., 2017 who were involved in their research with a method for determining the coefficient based on the analysis of the vehicle deceleration and the relative slip of its braking wheels. The authors, according to the developed method, carried out tests of the adhesion properties of studded and non-studded winter tires on ice. The tests consisted of a series of braking of the Ford Focus car with the rear axle brakes. The shift of the maximum of the φ-S diagram of the studded tire to the region of large relative slip is determined. It was suggested that the effectiveness of electronic active safety systems may decrease when the tread of the studded tire. Kuchar et al. 2022, who dealt with the accuracy of three selected devices based on acceleration measurement: accelerometer – XL meter, the global position measurement device by VBox and the constructed 5th wheel, which allows a very accurate measurement of distance along with speed and acceleration of the vehicle. The accuracy of recordings was tested during various driving conditions when all the three measuring devices were attached to the vehicle and authors obtained similar results. Authors Otat et al. *(2021)* within their study carried out an analysis by two methods in order to determine the vehicle dynamic performances where in the first part of the paper, they have used the analytical method to establish the dynamic performances of a vehicle and in the second part of study addressed another method to determine the performances of the vehicle by means of computerized simulations. Similar results were obtained by authors Ondruš, Hockicko *(2015)* who dealt with the issue of car braking, particularly with M1 category and braking deceleration measurement of the vehicle Mazda 3 MPS was carried out by the declerograph XL Meter Pro.

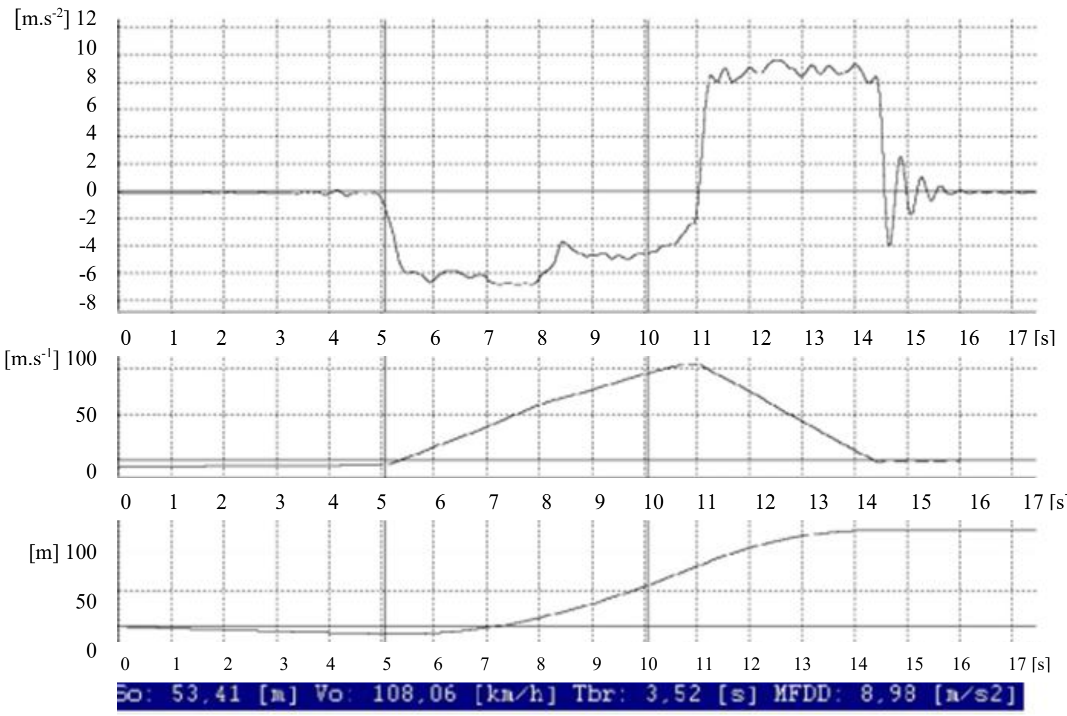

Fig. 4 Graph of measured values Mercedes S500 Coupe, approach speed: 108 $km.h^{-1}$, braking distance: 53.41 m, braking time: 3.52 s, braking deceleration: 8.98 $m.s^{-2}$

Tab. 5 Resulting values during deceleration on a Mercedes S500 Coupe

Parameters	Values		
Deceleration – initial speed *($km.h^{-1}$)*	58	108	155
Braking deceleration [$m.s^{-2}$]	8,89	8,98	8,51
Braking time [s]	2,02	3,52	5,71
Efficiency of using the adhesion coefficient μ [-]	0,9	0,91	0,87

Braking distance			
Visible braking distance measured by a rollmeter	16	33	43,8
Total braking distance measured by measuring devices	16,99	53,41	129,62

CONCLUSIONS

There are many factors that affect driving dynamics. After processing all the measured results, we found that the tested vehicle has more power and engine torque than the manufacturer states. On the Mercedes S500, the higher power was evident when accelerating to 150 km.h^{-1}. At other speeds, we were slightly behind the data given by the manufacturers. The largest difference in the resulting braking distance values was when braking from a speed of 155 km.h^{-1}, while the smallest difference was when braking from a speed of 58 km.h^{-1}. In this case, it can be seen that the vehicle meets the parameters declared by the manufacturer and without "large" costs, because the values determined during the vehicle technical inspection only to determine whether the vehicle complies or does not comply are insufficient. It is possible from such graphic displays or values also to determine the delay for the transmission status, time losses during gear shifting. The results of measurement show the mutual correlation of the performed dynamic tests of both the engine and the entire tract from braking to acceleration. To achieve the time specified by the manufacturer, it can be deduced that we would need even better tires, that is, with higher adhesion, given that the initial measured power was higher and all this is determined only by the tires, or then change the surface of the pad or climatic conditions. The differences are equalized at 100 km.h^{-1} and so here we see that in the end the engine had to be modified because we achieved a better time at 150 km.h^{-1} than the manufacturer states, where the tires play no longer such a role and it is purely about performance, because it cannot slip at such high speeds.

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