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Experimental Research on Kinematic Features of Agricultural Tractor Movement on Asphalt Pavement

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Abstract. Experimental research on agricultural tractor movement, acquisition and archiving of kinematic features is an important issue in the analysis of braking and acceleration processes. The obtained traffic parameters depend on the environmental conditions, condition and type of pavement, load, tire pressure and the area of tire-pavement cooperation. The acceleration factor, and in particular the braking process, is determined by the coefficient of friction enabling the assessment of forces and moments acting at the tire-road interface. The kinematic features known as a result of measurements can be used to assess the extent of road safety. The article describes experimental research aimed at understanding the kinematic features of agricultural tractor movement without a trailer on a homogeneous asphalt surface at three pressures in drive tires.

1 Introduction

The movement of vehicles, apart from the driver's abilities, depends on the transferred forces and moments acting in the area of the tire-road interaction [1, 2]. The vehicle motion parameters depend not only on the driver's intentions, but also on the adhesion coefficient, which is determined by the characteristics of the road surface [3], tires [4, 5, 6] and the environment [7, 8]. Apart from external factors, the traffic parameters are influenced by construction changes and modernization of vehicles [9, 10, 11].
Agricultural tractors are intended for work in various types of terrain and surfaces of various structures. The versatility of the tractor requires the driver to control the tire pressure. Moving on the marshy and soft terrain, the possibility of transferring forces and moments at the contact of the tire with the ground is used with reduced tire pressure. Lowering the pressure increases the contact surface area and reduces unit pressure on the substrate [12]. The farm tractor moves both on uneven terrain, overcoming various obstacles, which affects the tires and suspension [9, 13], and on paved roads with reduced tire pressure.
The ability to accelerate under given environmental and surface conditions determines the possibility of starting, overtaking or avoiding obstacles on the road. The adhesion coefficient determined in the literature does not take into account changes in tire pressure

values and their influence on the vehicle motion parameters. The sources provide only the ranges of the adhesion coefficient for a given surface described in words (Tab. 1). Variable values of tire pressure may contribute to changes in the obtained acceleration values, and thus to changes in the safety range of the agricultural tractor traffic on the asphalt surface. The research is in line with the global trend of testing vehicles and machines in real conditions of use, which in many cases show imperfection of analyzes based on simulations or tests performed only in laboratory conditions [14, 15, 16, 17].

The article presents the results of road tests of the agricultural tractor acceleration and braking process on a dry and clean asphalt surface for three tire pressure values. In order to verify the effect of pressure changes, which is favorable in the conditions of marshy terrain and not tested in traffic conditions on paved surfaces. Tire pressure is a parameter that is easy to adjust and control. It plays an important role in reducing slippage during cultivation work. This aspect greatly affects fuel consumption and the time needed to cultivate the soil. Damanauskas et al. in 2015 indicate that reducing tire pressure reduces drive wheel slip and fuel consumption, while increasing work efficiency, and the occurrence of skid in the range of 7 to 15% can be considered normal when working in soil [18].

Table 1. The most common ranges of the adhesion coefficient according to various literature data and IES own research [19].

The type and condition of the surface		Coefficient of friction	
		Rebate μ_p	Slide μ_s
Concrete	dry	0.8 - 1.08	0.7 – 0.9
	wet	0.25 - 0.75	0.15 – 0.65
Asphalt	dry	0.7 - 1.08	0.6 – 0.9
	wet	0.4 - 0.6	0.3 – 0.5
Stone cube clean	dry	0.7 – 0.8	
	wet	0.4 – 0.5	
Dusty stone cube	dry	0.6 – 0.7	
	wet	0.25 – 0.35	
Clinker	dry	0.6 – 0.7	
	wet	0.4 – 0.5	
The dirt road is hard	dry	0.5 – 0.6	0.2 – 0.3
	wet	0.3 – 0.4	0.2 – 0.3
Gravel		0.45	0.5
The road is covered with snow		0.1 – 0.4	0.1 – 0.3
Icy road		0.05 – 0.15	0.05 – 0.2

2 Methodology and measurement place

The experimental studies were performed in three stages. In each of the stages, 10 tests of intense acceleration from a stopped start and heavy braking to a stop were made. Acceleration of the tractor took place with the change of gears until the speed of about 35 km / h was reached. Each trial ended with an independent measurement of the distance traveled by the vehicle with a ribbon gauge. The test vehicle was a DEUTZ FAHR tractor. The vehicle was equipped with tires in the following dimensions: 380/85 R24 / on the front axle / and 420/85 R34 / on the rear axle /.

Fig. 1. Test vehicle view during testing.

For the tests, the vehicle was equipped with an ADIS 16385 measuring device from Analog Devices. The ADIS 16385 system has three piezoroscopes integrated in one "measuring cube" and three capacitive accelerometers positioned perpendicular to each other in a Cartesian system. The measuring equipment used is characterized by a measurement uncertainty of 2% [20, 21]. In the tractor, the measuring system has been leveled and placed on the rear window of the vehicle. A portable computer with dedicated software was used for data acquisition and archiving (Fig. 2).

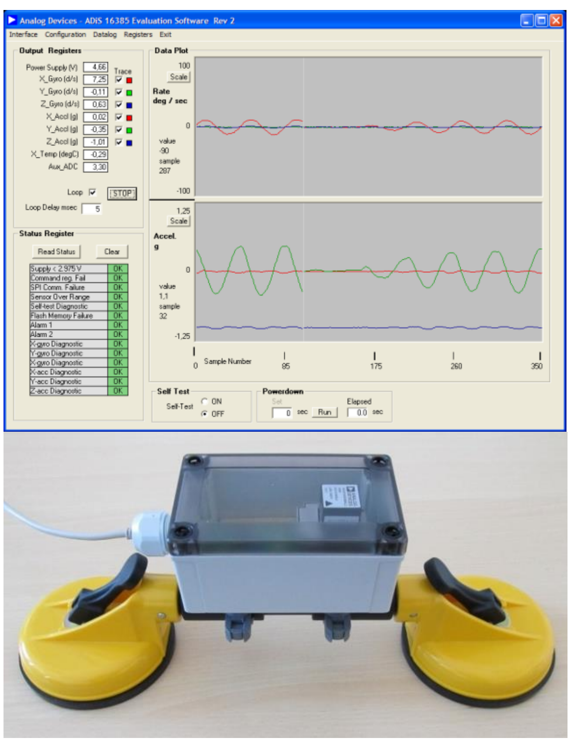

Fig. 2. View of the window of the measuring system and ADIS 16385.

The surface on which the tractor was moving was asphalt, visually dry and clean. The research section was located on a single-carriageway road. The surface was in good condition, without cracks or longitudinal undulations, there were single transverse irregularities on it. All runs from the standing start were one-way. The view of the pavement during road tests is shown in Figure 3.

Fig. 3. View of the test surface.

In addition to the visual assessment of the road surface, surface temperatures and environmental characteristics were measured. These measurements were performed before starting the experimental tests and after their completion (Table 2).

Table 2. Measurement results of environmental measurements prior to road tests.

	Level 1		Level 2		Level 3	
	Before research	After research	Before research	After research	Before research	After research
Road surface temperature [°C]	+ 6.4	+ 5.4	+ 5.4	+ 5.4	+ 5.4	+ 4.4
Air temperature [°C]	+ 6.5	+ 5.7	+ 5.7	+ 5.7	+ 5.7	+ 5.3
Relative humidity RH [%]	66.2	66.6	66.6	68.0	68.0	69.5
Atmospheric pressure [hPa]	981.7	982.5	982.5	982.6	982.6	982.7

3 Research results

Measurements of intense acceleration and braking were made with the use of the same vehicle, with two operators, on the same stretch of the test surface. The tests were conducted using the same methodology. Before starting the intensive acceleration tests, the tire pressure, the static radius of the rear tires in which the pressure was changed, and the pressure force on the individual wheels were measured (Tables 3, 4). The results of the vehicle acceleration measurements in the subsequent stages are presented in Tables 5-7. The results of measurements of the total distance traveled by the test vehicle are presented in Tables 8-10.

Table 3. Tire pressure value and rear tire static radius.

Tire pressure	Level1	Level2	Level3
Left front	0.13 MPa	0.13 MPa	0.13 MPa
Right front	0.13 MPa	0.13 MPa	0.13 MPa
Left rear	0.22 MPa	0.16 MPa	0.10 MPa
Right rear	0.22 MPa	0.16 MPa	0.10 MPa
Static radius	314 mm	312 mm	301 mm

Table 4. The value of the pressure force on individual wheels.

Wheel	Force [N]
Left front	12490
Right front	12890
Left rear	9700
Right rear	10630

Table 5. Values of average longitudinal acceleration of the vehicle – Level 1.

Level 1 0.22 MPa	I gear [m/s^2]	II gear [m/s^2]	III gear [m/s^2]	IV gear [m/s^2]	V gear [m/s^2]	MFDD [m/s^2]
Average of the measurements	1.84	1.11	1.05	0.79	0.71	5.18
Standard deviation	0.23	0.18	0.15	0.11	0.13	0.84

Table 6. Values of average longitudinal acceleration of the vehicle – Level 2.

Level2 0.16 MPa	I gear [m/s^2]	II gear [m/s^2]	III gear [m/s^2]	IV gear [m/s^2]	V gear [m/s^2]	MFDD [m/s^2]
Average of the measurements	1.90	1.23	1.08	0.87	0.83	5.15
Standard deviation	0.15	0.12	0.15	0.09	0.10	0.35

Table 7. Values of average longitudinal acceleration of the vehicle – Level 3.

Level3 0.10 MPa	I gear [m/s^2]	II gear [m/s^2]	III gear [m/s^2]	IV gear [m/s^2]	V gear [m/s^2]	MFDD [m/s^2]
Average of the measurements	2.14	1.31	1.08	0.84	0.82	4.68
Standard deviation	0.23	0.22	0.15	0.19	0.25	0.32

Table 8. Measurement results for the total distance traveled by the test vehicle – Level 1.

Level 1 0.22 MPa	Tractor DEUTZ FAHR					
	Test time [s]	The total stopping distance measured measuring tape [m]	The total stopping distance is determined from the values of longitudinal acceleration [m]	Time of the braking process [s]	Braking distance [m]	The speed of the initial braking process [km/h]
Average of the measurements	17.95	96.23	96.36	2.60	9.90	33.49
Standard deviation	1.49	8.24	8.18	0.34	2.02	1.54

Table 9. Measurement results for the total distance traveled by the test vehicle – Level 2.

Level2 0.16 MPa	Tractor DEUTZ FAHR					
	Test time [s]	The total stopping distance measured measuring tape [m]	The total stopping distance is determined from the values of longitudinal acceleration [m]	Time of the braking process [s]	Braking distance [m]	The speed of the initial braking process [km/h]
Average of the measurements	16.68	88.77	88.73	2.70	11.65	33.35
Standard deviation	0.68	3.45	3.42	0.22	1.72	0.82

Table 10. Measurement results for the total distance traveled by the test vehicle – Level 3.

Level3 0.10 MPa	Tractor DEUTZ FAHR					
	Test time [s]	The total stopping distance measured measuring tape [m]	The total stopping distance is determined from the values of longitudinal acceleration [m]	Time of the braking process [s]	Braking distance [m]	The speed of the initial braking process [km/h]
Average of the measurements	16.59	86.01	85.96	3.13	10.41	34.19
Standard deviation	0.73	4.34	4.33	0.19	1.42	1.05

4 Evaluation of the results of measurements

All measurement tests were performed on one day in environmental conditions that can be considered constant, and slight temperature changes did not affect the obtained values of longitudinal acceleration. In all three stages, the obtained values of acceleration in particular gears and the value of the average full deceleration (MFDD) are almost identical, and the ranges of values of standard deviations overlap. This proves the full repeatability of the tractor driving processes during road tests. The indicated values also suggest no significant influence of tire pressure changes on the obtained values of longitudinal acceleration and full average deceleration (MFDD), and, consequently, on the safety range of the tractor movement on the asphalt surface. The slight change in the static radius of the tire did not adversely affect the driving parameters of the farm tractor. However, it should be noted that the tractor was not loaded with either the working tools or the trailer.

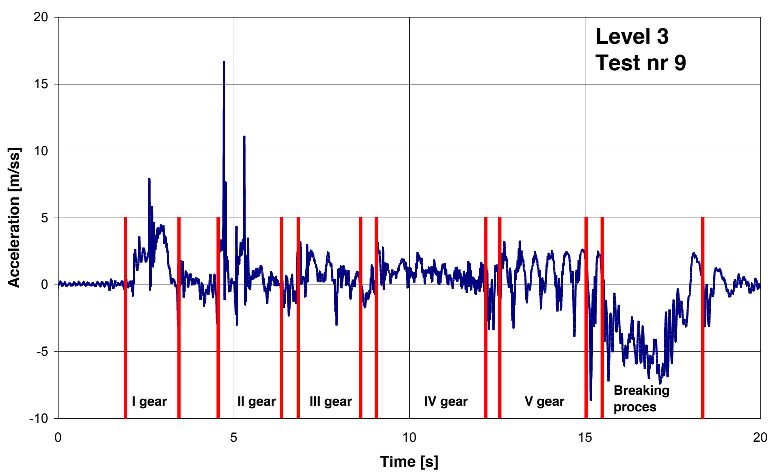

Fig. 4. An example of the characteristics of the acceleration and braking process for the tire pressure of 0.10 MPa.

5 Summary

The conducted experimental studies of the agricultural tractor motion were aimed at the evaluation of acceleration and braking processes as a function of tire pressure. The results of the measurements showed that in the absence of a load of the tractor with a trailer or working tools, pressure changes in the drive tires and changes in the static radius of the tire in the tested pressure range from 0.10 to 0.22 MPa did not adversely affect the vehicle's driving processes on a hard surface. In all three stages of the tests, the vehicle used the adhesion coefficient to the same extent, which proves that the range of forces and moments transmitted to the surface was similar for both the acceleration and braking processes. The scope of road safety of a moving agricultural tractor without a trailer on a homogeneous asphalt surface is constant, and the impact of pressure changes in the drive tires did not have a direct impact on the kinematic parameters of the vehicle motion. Further research directions may be related to the wheel pressure parameters related to the research by Janulevičius and Damanauskas in 2015, which define the parameters appropriate for minimizing fuel consumption in the case of wheel slip control [22]. The influence of these parameters has not been investigated in terms of safety while driving on paved surfaces.

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