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CONTRIBUTION TO THE RESEARCH OF AN ACCEPTABLE TEST FOR THE IDENTIFICATION OF THE BEHAVIOR PARAMETERS OF TRUCK VEHICLE

Miroslav Demić [1], Aleksandar Đurić [2], Aleksandar Grkić [3], Momir Drakulić [4], †Slavko Muždeka [5]*

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RESEARCH ARTICLE

ABSTRACT: The design of engine vehicles cannot be imagined without considering the mutual relations in the complex dynamic system Driver - Vehicle - Environment. Inconsistency between any of the connections in the mentioned system leads to disruption in the functioning of the system as a whole, which in some cases can lead to catastrophic consequences. The necessity of knowing the parameters of behavior on the road for traffic safety is especially emphasized. Therefore, in practice, it is researched in different conditions. It was considered expedient to establish the reliability of some tests used during the research of truck behavior on the road. A detailed analysis, based on the study of the interdependencies of the controlled (steering wheel angle and torque at the steering wheel) and partially controlled excitation (vehicle velocity) concluded that the overtaking test is the most acceptable for these researces.

KEY WORDS: *truck vehicle, road behaviour, tests*

[1]*Miroslav Demić, PhD, Engineering science academy of Serbia, Belgrade, Serbia, Kraljice Marije 16, soba 218a, Belgrade, Serbia (*Corresponding author), demic@kg.ac.rs, https://orcid.org/0000-0003-2168-1370*

[2]*Aleksandar Đurić, MSc, University of defense, Military academy, Department of military mechanical engineering, Veljka Lukica Kurjaka 33, Belgrade, Serbia, aleksandar_djrc@yahoo.com, https://orcid.org/0000-0002-2165-528X*

[3]*Aleksandar Grkić, AMSS, Center for motor vehicles, Kneginje Zorke 58, Belgrade, Serbia, aleksandargrkic@gmail.com, https://orcid.org/0000-0002-7890-1787*

[4]*Momir Drakulić,* University of defense, *Military academy, Department of military mechanical engineering, Veljka Lukica Kurjaka 33, Belgrade, Serbia, drakulic.momir@gmail.com, https://orcid.org/0000-0002-8367-7281*

[5]*Slavko Muždeka, PhD, University of defense, Military academy, Department of military mechanical engineering, Veljka Lukica Kurjaka 33, Belgrade, Serbia, https://orcid.org/0000-0002-6189-9473*

PRILOG ISTRAŽIVANJU PRIHVATLJIVOG TESTA ZA IDENTIFIKACIJU PARAMETARA PONAŠANJA TERETNOG MOTORNOG VOZILA NA PUTU

REZIME: Projektovanje motornih vozila se ne može zamisliti bez sagledavanja međusobnih relacija u složenom dinamičkom sistemu Vozač – Vozilo – Okruženje. Neusaglašenost između bilo koje od veza u pomenutom sistemu, dovodi do poremećaja u funkcionisanju sistema kao celine, a što u nekim slučajevima može dovesti i do katastrofalnih posledica. Ovde se posebno ističe neophodnost poznavanja parametara ponašanjana na putu za bezbednost saobraćaja. Zbog toga se u praksi vrši istraživanje istog u različitim uslovima. Ocenjeno je celishodnim da se ustanovi pouzdanost nekih testova koji se koriste tokom istraživanja ponašanja kamiona na putu. Detaljnom analizom, zasnovanom na istraživanju međusobnih zavisnosti kontrolisanih (ugao i moment na točku upravljača) i delimično kontrolisane pobude (brzina) zaključeno da je test preticanja najprihvatljiviji za ta ispitivanja.

KLJUČNE REČI: *teretno motorno vozilo, ponašanje na putu, testovi*

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INTRODUCTION

In order to systematically study the relationship in the Driver-Vehicle-Environment system (DVE), it is necessary to adopt a methodology. The most acceptable methodology is based on automatic control, in which the vehicle is presented as a system composed of different subsystems. These subsystems may or may not be isolated from each other [1-3]. In the abundance of literature data on possible DVE connections [1-8], it was considered expedient to present a simple scheme [4], Figure 1.

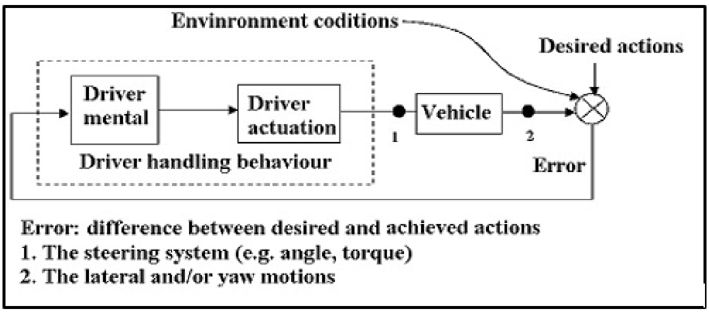

Figure 1 Control system: Driver-Vehicle-Environment

The driver follows the desired trajectory and compares it with the wanted one. He also has in mind the conditions imposed by the environment (width of the road, curvature, obstacle on the road, or the existence of crosswinds). Regardless of this information, the driver continuously receives information about the vehicle, such as velocity, rpm and engine temperature, steering wheel rotation angle, etc.

The driver's main goal is to keep the vehicle on the road and on a precisely defined path. To succeed in this, he must adjust the vehicle velocity to the condition of the road and drive the vehicle according to his driving skills. Adequate driving speed depends on the road conditions in which the vehicle is moving.

Having in mind the road conditions, the driver acts on the vehicle controls in accordance with the information he has, and in [3], they are categorized as controlled (steering wheel angle and torque on it), partially controlled (vehicle velocity), or insufficiently / not controlled influences (micro and macro road relief, wind, etc.). There are several papers in the contemporary literature that consider this problem [1-8].

The vehicle is a member of a cybernetic system that is regulated by the driver will [1]. Therefore, it is important to investigate its dynamic characteristics, and especially the characteristics of road behavior. In order to identify the dynamic parameters of vehicle behavior on the road in general, three approaches are used, namely [9-19]:

- Experimental;
- Dynamic simulation using vehicle models;

- Combination of the first two methods.

As is known [9-19], each of these approaches has its advantages and disadvantages. Bearing in mind that this is explained in detail in the mentioned references, there will be no more talk about it. In the general case, the movement of vehicles is done on uneven roads and curvilinear paths in the level of roads. The path can be identified on the basis of its spatial geometry (macro-relief) and micro-roughness (micro-relief) [20-24]. In order to soften the impact of road parameters on registered values, all research was conducted on the airfield runway near Belgrade, that has same characteristics of micro-roughness in width and length.

This paper will discuss the research of an acceptable test for the identification of vehicle behaviour parameters on the road. Special attention is paid on tests: rectilinear driving test, DLC test and overtaking test.

1. EXPERIMENT

As mentioned, the aim of the research was to establish acceptable tests for determine behavior parameters of the FAP 1118 truck on the road. The mentioned truck had a 4x4 drive formula and a load capacity of 4 t. The maximum weight of the test vehicle is 11000 kg, and during the test the vehicle was partially loaded (weight 7800 kg). The measuring chain for measuring the dynamic parameters of the vehicle consisted of the following elements:

- Kistler Correvit S-350 sensors for direct, slip-free measurement of longitudinal and transverse vehicle dynamic;
- HBM Quantum MX 840B universal measuring acquisition system;
- B-12 acceleration sensor, located in the center of gravity of the rear truck bridge;
- SST 810 dynamic inclinometer, placed in the center of gravity of the vehicle. With it, angle, velocity and acceleration was measured around the X, Y and Z axes of the vehicle;
- Steering wheel shaft angle and torque sensor.

The scheme of measuring points is given in Figure 2.

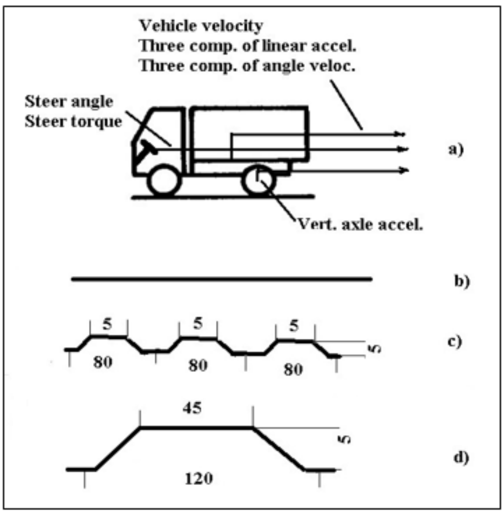

Figure 2 a)Diagram of measuring points during the FAP 1118 vehicle behavior test b)sketch of overtaking test; c), sketch of DLC test; d) rectilinear driving- dimensions, [m] It must be noted that the experiment included the registration of a number of values, but in this paper were analyzed separately: steering wheel angle and steering wheel torque, vehicle velocity and as most important, road behavior parameters [3], lateral vehicle acceleration and yaw. Based on previous experiences at the Military Academy, it was considered expedient to test the vehicle in following conditions:

- Rectilinear driving test with both hands on steering wheel (with maximum vehicle speed 30 km / h);
- DLC test (with maximum vehicle speed 45 km / h);
- overtaking test (with maximum vehicle speed 45 km / h).

The tests were performed on the base of the airport near Belgrade, and a sketch of the test route is given in Figures 2b, 2c and 2d. During the experiment, driver controlled variables (angle and torque at steering wheel), partially controlled variables (velocity) and variable close related to a micro relief of the road (acceleration of the vehicle's rear axle center) were registered [3, 25]. For the illustration, Figure 3 shows the time histories of the mentioned excitations during the overtaking test. Their change in the time domain is clearly visible.

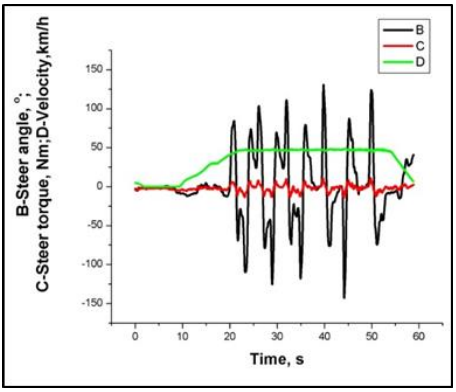

Figure 3 Time history of registered input values during the overtaking test

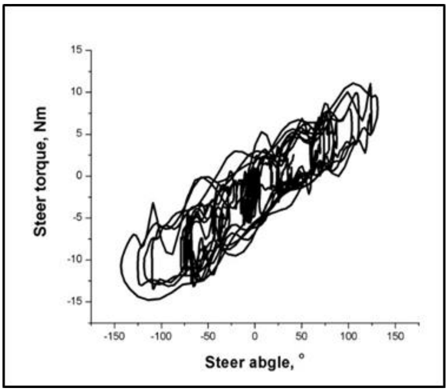

Figure 4 Couple: Steer angle – Torque at steering wheel during overtaking test

It was considered expedient to show the interdependencies of controlled and partially controlled input quantities, Figures 4, 5 and 6.

Based on Figures 4-6, it can be argued that there are links between driver motivations, which will be discussed later. For further analysis, Figure 7 shows the time changes of the lateral acceleration of the center of gravity and the angular velocity of the vehicle yaw.

From Figure 7 it can be determined that the observed parameters of the vehicle center of gravity during the overtaking test depend on time and that they belong to the group of random processes, which analysis will be performed later.

In order to determine an acceptable test to investigate the behavior of the truck on the road, accelerated tests were performed during its movement on a straight path, during the DLC test and overtaking test.

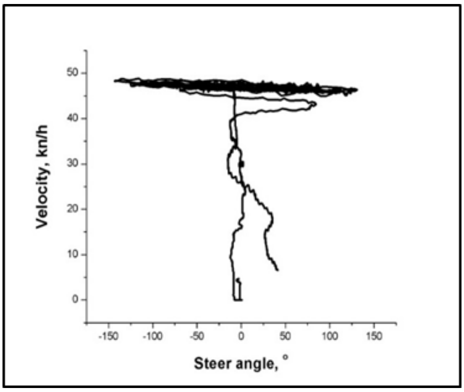

Figure 5 Couple: Angle of steering wheel – vehicle velocity during overtaking test

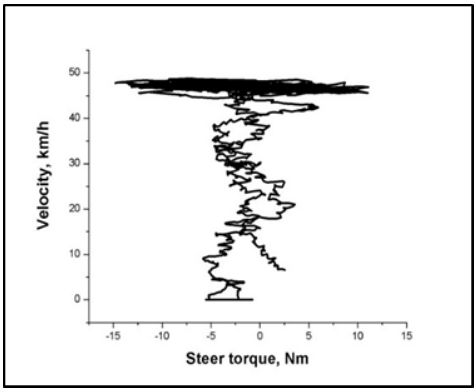

Figure 6 Couple: Torque to steering wheel – vehicle velocity during overtaking test

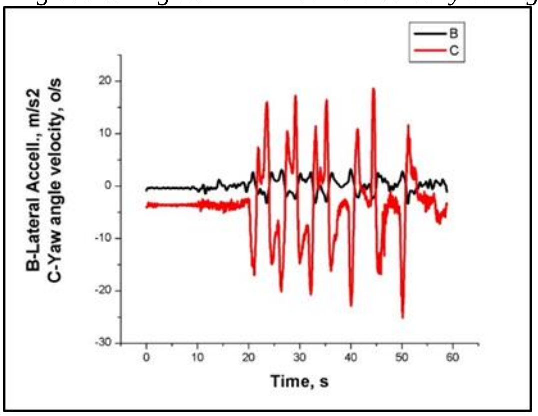

Figure 7 Lateral acceleration and angular yaw velocity of the truck during the overtaking test

2. DATA ANALYSIS

As the discretization was performed at 50 Hz and depending on the test, at at least 1024 points, the frequency range is 0.05 to 25 Hz [26-29]. The analysis of random and bias errors, for the number of data used, showed that a sufficient number of averaging of 100 (for autonomous signal) and 138 for coupled values, which achieves a minimum reliable frequency of 0.073, which is acceptable in our case [26-28]. Frequency analysis was performed for all observed excitations in the range 0.08 to 25 Hz, but it was considered expedient to graphically display spectrum modules up to about 1.1 Hz [3] in the case of controlled and partially controlled excitations, (which is illustrated in Figures 8-10 , for the overtaking test).

Analyzes of the calculated spectrum modules for all tests showed that their maximum amplitudes of angle and torque at the steering wheel and vehicle velocity were in the range up to about 0.5 Hz. This points to the need for further analyzes to be conducted for lower frequencies, e.g. up to a maximum of 1.1 Hz, which is in accordance with [3].

Having in mind Figures 4-6 which show interdependencies, it was considered expedient to determine the extent to which there is a statistical link between registered controlled and partially controlled excitations [26-28]. In this sense, the functions of ordinary coherences were calculated, using the *Demparcoh* program [29] and shown in Figures 11, 12 and 13.

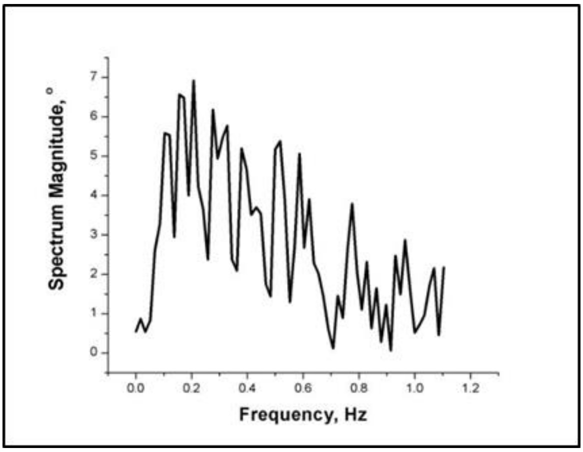

Figure 8 The magnitude of the steering angle amplitude spectrum during the overtaking test

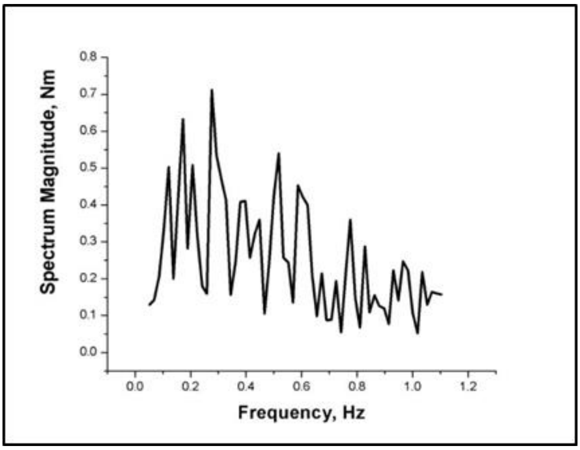

Figure 9 The magnitude of the torque amplitude spectrum at the steering wheel during the overtaking test

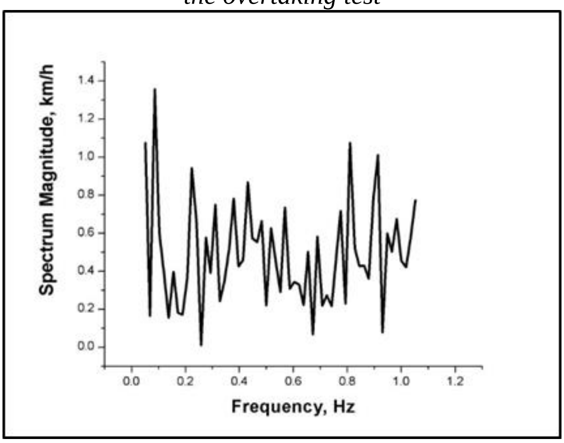

Figure 10 Velocity spectrum magnitude during overtaking test

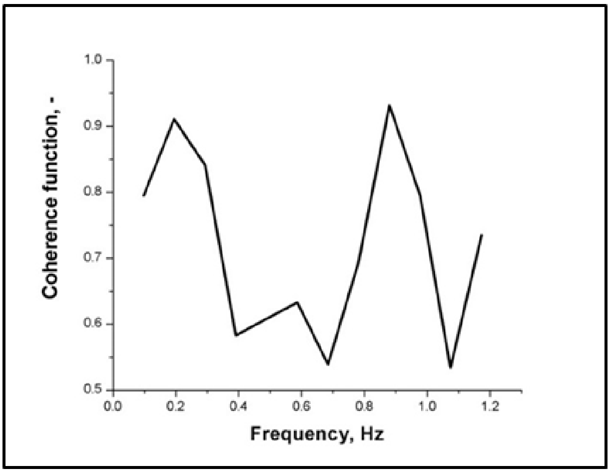

Figure 11 Coherence: Angle of steering wheel– torque at steering wheel during overtaking test

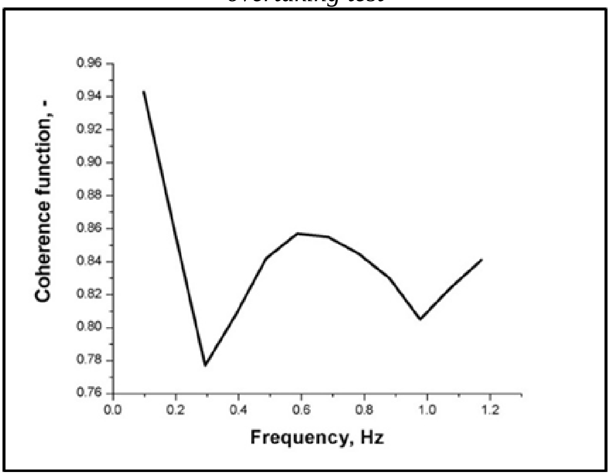

Figure 12 Coherence: Angle of steering wheel – vehicle velocity during overtaking test

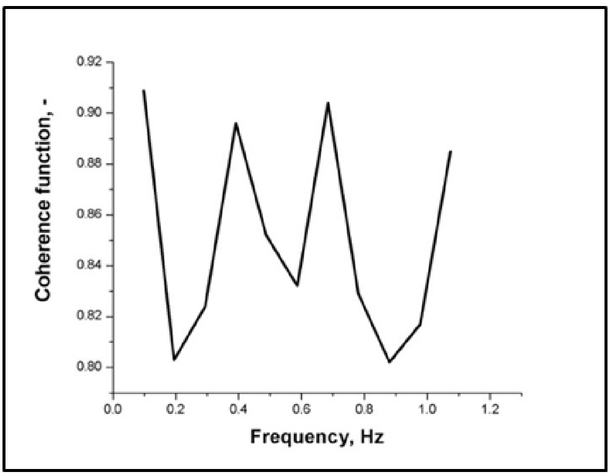

Figure 13 Coherence: Torque at steering wheel – vehicle velocity during overtaking test

The analysis of Figures 11-13 showed that the coherence in the characteristic range up to 1.1 Hz is in the range 0.55 to close to 0.94, which shows that the selected excitations are not independent [26-28], so this must be kept in mind during the analysis.

For the purpose of further analysis, it was considered expedient to calculate cross-spectra of registered values [26-28], using the software Analsigdem [29]:

- steering wheel angle – lateral acceleration and yaw;
- torque at steering wheel - lateral acceleration and yaw;
- vehicle velocity – lateral acceleration and yaw.

As is known, cross-spectra represent a quantity that indicates whether there is a relationship between the observed pairs of quantities [26-28]. For illustration, the following are the cross-spectrum modules: steering wheel angle - lateral acceleration and yaw (Figure 14), torque at steering wheel - lateral acceleration and yaw (Figure 15) and vehicle velocity - lateral acceleration and yaw (Figure 16), during the DLC test. By analyzing all the data, partially shown in Figures 14-16, it was found that there is a coupling between input (steering wheel angle, torque at steering wheel, vehicle velocity) and output values (lateral acceleration and yaw). However, it should be borne in mind that the measured lateral accelerations and yaw are functions of simultaneous driver action on the steering wheel (angle, torque) and fuel slipper, so that based on cross-spectrum can not distinguish influence of separate values to output excitations. All the more so because we have shown that the adopted inputs are not independent, but that there is a connection between them, which was discussed earlier. It was considered expedient to perform an additional analysis based on the so-called partial coherence functions [26-28]. Therefore, we will briefly present the theory of signal decoupling, on the example of three, interconnected input values [26-28].

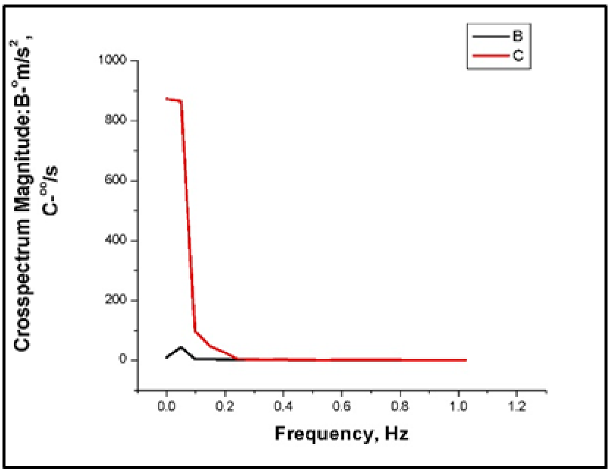

Figure 14 Cros-spectra: steering wheel angle – lateral acceleration, steering wheel angle -yaw during DLC test

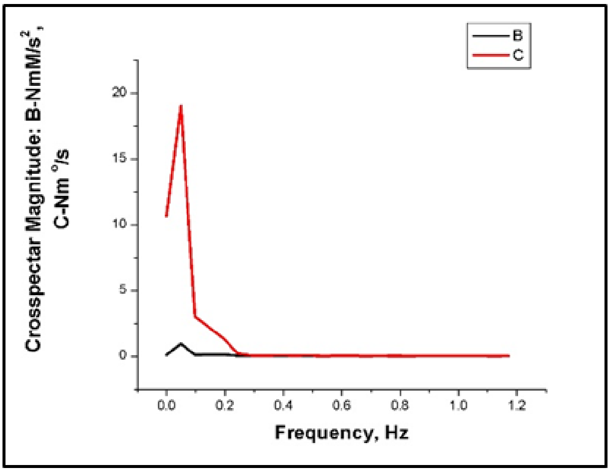

Figure 15 Cros-spectra: Torque at steering wheel – lateral acceleration, Torque at steering wheel -yaw during DLC test

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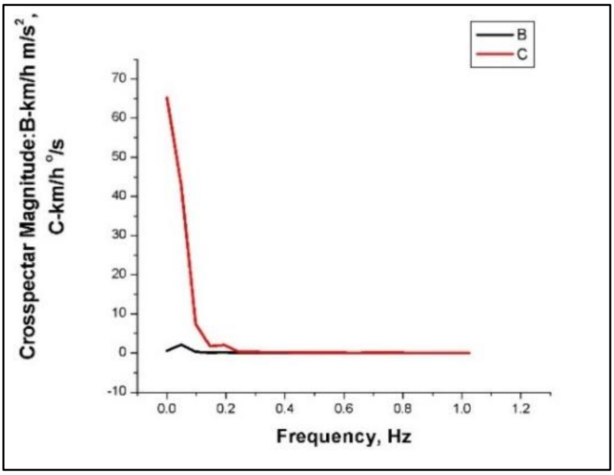

Figure 16 Cros-spectra: Velocity – lateral acceleration, Velocity -yaw during DLC test

The problem is schematically shown in Figure 17. Figure 17a shows that, in terms of regulation, the problem belongs to the group of systems with multiple inputs and outputs, which is presented to systems with multiple inputs and one output for easier solution, Figure 17b [26-28]. It is obvious from the picture that each individual output variable can be observed as a function of input variables, which are correlated.

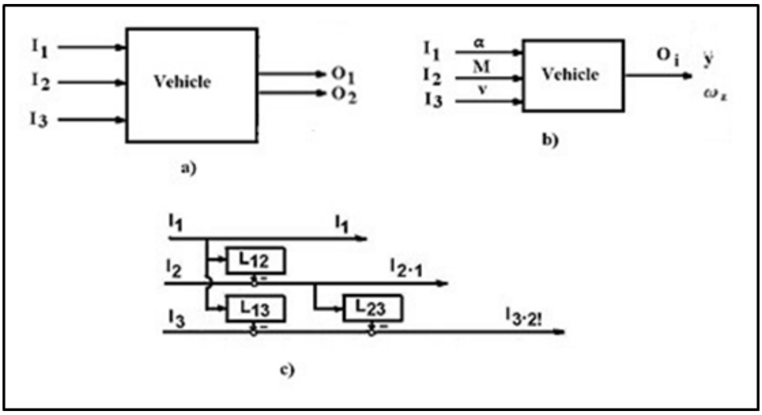

Figure 17 Scheme of a system with three input and two output sizes (legend: I1-I3 present input excitation values (α, M, v), and O1-O2 registered lateral accelerations and yaw (a_y, ω_z)

The spreading of the input quantities is done on the basis of the expression, Figure 17c [26-28]:

$$\begin{aligned} I_1 &= I_1 \\ I_{2.1} &= I_2 - L_{12} I_1 \\ I_{3.2!} &= I_3 - L_{13} I_1 - L_{23} I_{2.1} \end{aligned} \tag{1}$$

Expression (1) uses quantities according to Figure 17, and transfer functions between conjugate expressions defined by expression [26-28]:

$$L_{12} = \frac{I_2}{I_1} \qquad L_{13} = \frac{I_3}{I_1} \qquad L_{23} = \frac{I_{3\cdot1!}}{I_{2\cdot1!}} \tag{2}$$

According to [26-28], the functions of partial coherences are defined by expression:

$$\gamma^2_{iQ(i1)!} = \frac{\left[S_{iQ(i-1)!}\right]^2}{S_{xx(i-1)!} S_{QQ(i-1)!}} \tag{3}$$

where are:

- $S_{iQ(i-1)}$ – cross-spectrum,
- $S_{xx(i-1)!}$, $S_{QQ(i-1)!}$ – appropriate auto-spectrum

In order to calculate the partial coherence functions, the Demparcoh program was used [29].

Using the mentioned program, the functions of partial coherences during rectilinear driving were calculated, shown in Figures 18 and 19.

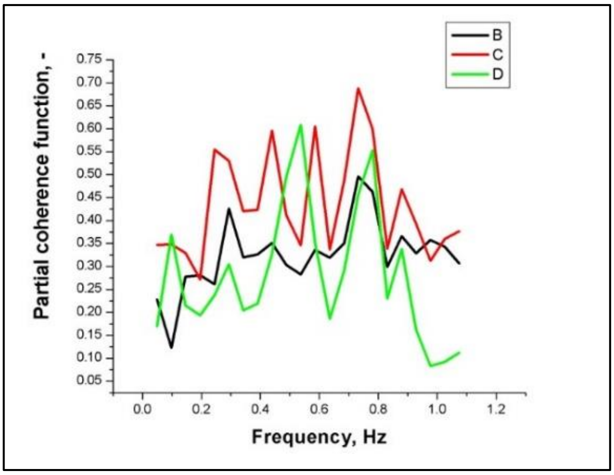

Figure 18 Partial coherence function: lateral acceleration – steering wheel angle(B), torque at steering wheel with the excluded influence of the steering wheel (C) and velocity with excluded influence of angle and torque at steering wheel (D), in rectilinear drive test

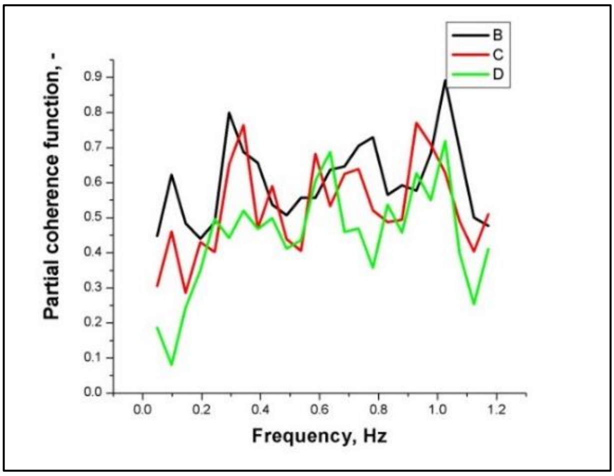

Figure 19 Partial coherence function: yaw – steering wheel angle (B), torque at steering wheel with excluded influence of steering wheel angle (C) and velocity with excluded influence of angle and torque at steering wheel (D), in rectilinear driving test

By analyzing the data from Figures 18-19, it can be determined that there is a statistical link between the registered kinematic parameters of the vehicle center of gravity movement and input excitations in the frequency range up to about 1.1 Hz. When it comes to lateral acceleration (Figure 18) in the area of the excitations largest amplitudes, the greatest impact has the torque on the steering wheel, and the least the vehicle velocity. Figure 19 shows that the steering angle has the greatest influence on the yaw and vehicle velocity has the smallest. It is noted that these effects are not unambiguous, especially above about 0.5 Hz, so it was considered expedient to analyze values that carry more information about the signal energy in the range up to about 1.1 Hz. The most practical value is RMS, which is calculated for all partial coherence functions and shown in Table 1.

***Table 1** Partial coherence functions in rectilinear driving test*

Measured value	*, -	**, -	***, -
Lateral acceleration, m/s^2	0.333	0.448	0.315
yaw, $^o/s$	0.614	0.545	0.469

* - Steering wheel angle
**- Torque at steering wheel with excluded steering wheel angle
***-Vehicle velocity with excluded angle and torque at steering wheel

By analyzing the data from Table 1, it can be determined that all kinematic parameters of vehicle center of gravity movement are affected by controlled and partially controlled excitation. At the same time, the torque on the steering wheel has the greatest impact on lateral acceleration during rectilinear driving, and the vehicle velocity has the least. When analyzing the yaw, the angle of the steering wheel has the greatest influence, and the vehicle velocity has the least. For illustration, Figures 20 and 21 show the partial coherence functions of the vehicle during the DLC test.

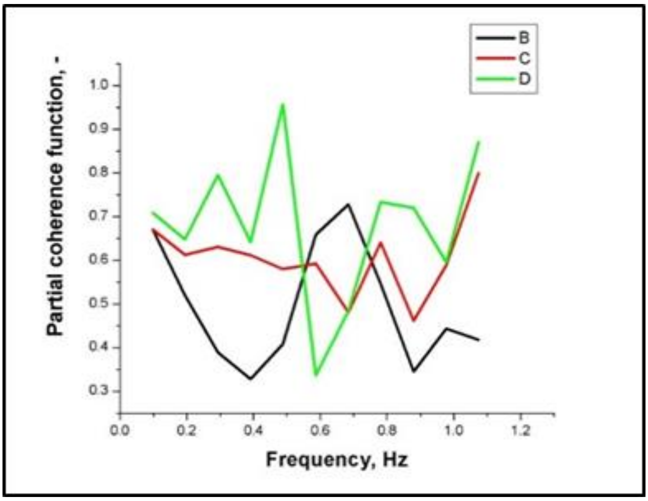

Figure 20 Partial coherence function: lateral acceleration – steering wheel angle (B), torque at steering wheel with excluded influence of steering wheel angle (C) and velocity with excluded influence of angle and torque at steering wheel (D) during DLC test

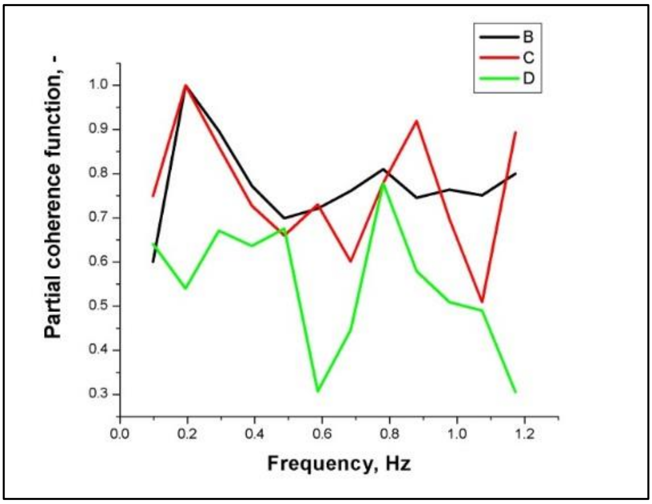

Figure 21 Partial coherence function: yaw – steering wheel angle (B) , torque at steering wheel with excluded influence of steering wheel angle (C) and velocity with excluded influence of angle and torque at steering wheel (D) during DLC test

The analysis of the calculated partial coherence functions shown in Figures 20 and 21, in the case of DLC test, shows that there is an influence of controlled and partially controlled excitations on the kinematic parameters of the vehicle center of gravity movement. Figure 20 shows the greatest influence of vehicle velocity on the lateral acceleration in the area of maximum excitation amplitudes, and the smallest steering wheel angle. When it comes to yaw during the DLC test, the steering wheel angle has an almost identical effect at the torque and the vehicle velocity has the lowest. In the regions higher than about 0.5 Hz, the effects are not so unambiguous, so it was considered expedient to calculate the effective values of the partial coherence functions and show them in Table 2.

***Table 2** Partial coherence functions during DLC test*

Measured value	*, -	**, -	***, -
Lateral acceleration, m/s^2	0.513	0.613	0.701
yaw, $^o/s$	0.782	0.772	0.566

* - Steering wheel angle,
** - Torque at steering wheel with excluded influence of steering wheel angle,
*** - Vehicle velocity with excluded angle and torque at steering wheel.

By analyzing the data from Table 2, it can be determined that the vehicle velocity shows the greatest impact on lateral acceleration, and the smallest steering wheel angle. The steering wheel angle shows the greatest influence on the yaw during the DLC test and the smallest on the vehicle velocity. For illustration, Figures 22 and 23 show the partial coherence functions in the case of lateral acceleration and yaw, during the overtaking test.

Based on Figure 22, it can be argued that in the area of most interesting frequencies, up to about 0.5 Hz, during the overtaking test, the angle and torque at the steering wheel have the greatest impact on lateral acceleration, and vehicle velocity the least. When observing the yaw, the greatest influence has the torque at steering wheel and almost the same, the steering wheel angle and vehicle velocity has the least influence. For further analysis, it was considered expedient to calculate, as in previous cases, the effective values of the partial coherence functions, Table 3.

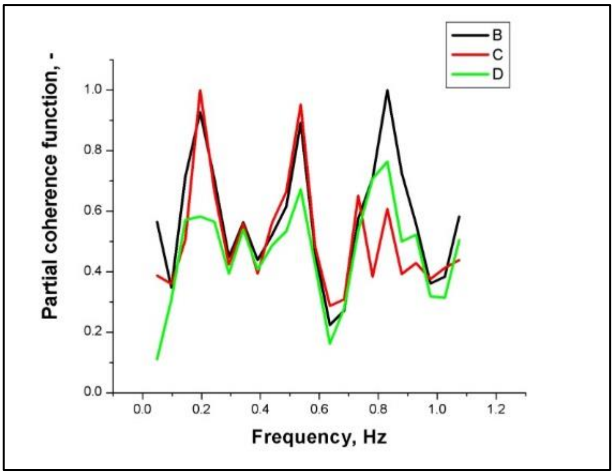

Figure 22 Partial coherence function: lateral acceleration – steering wheel angle (B), torque at steering wheel with excluded influence of steering wheel angle (C) and vehicle velocity with excluded influence of angle and torque at steering wheel (D) during overtaking test

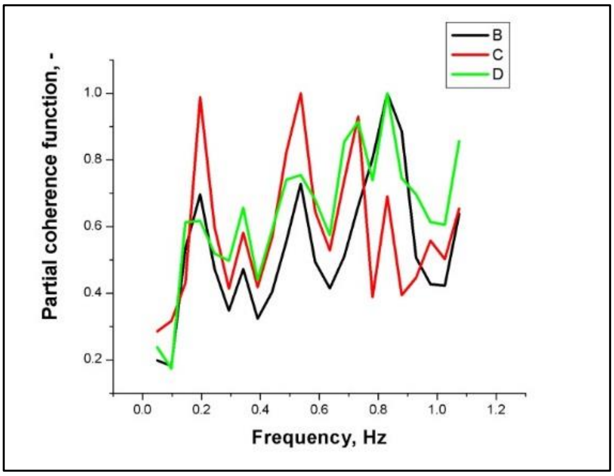

Figure 23 Partial coherence function: yaw – steering wheel angle (B), torque at steering wheel with excluded influence of steering wheel angle (C) and vehicle velocity with excluded influence of angle and torque at steering wheel (D) during overtaking test

Table 3 *Partial coherence functions during overtaking test*

Measured value	*, -	**, -	***, -
Lateral acceleration, m/s^2	0.607	0.543	0.491
yaw, ^{o}/s	0.568	0.620	0.670

* - Steering wheel angle;

** - Torque at steering wheel with excluded influence of the steering wheel angle;

*** - Vehicle velocity with excluded steering wheel angle and torque at steering wheel

By analyzing the data from Table 3, it can be determined that the steering wheel angle shows the greatest impact on lateral acceleration and the least vehicle velocity. The vehicle velocity has the greatest influence on the yaw, and the smallest steering wheel angle. Based on the previous analysis, it can be argued that this test also allows a good expression of the influence of controlled and partially controlled excitation on the parameters of vehicle handling. It was expected that there was no identical influence of the observed excitations in overtaking tests and DLC tests, which can be explained by nonlinearities in vehicle suspension systems [24].

As conclusion, the overtaking test can be used as the most suitable and the safest, during the research of truck behavior parameters on the road.

3. CONCLUSIONS

Based on the performed research, it can be concluded that there is an influence of controlled (angle and torque of the steering wheel) and partially controlled excitation (velocity) on the parameters of vehicle behaviour on the road.

The used methodology of data processing in the frequency domain made it possible to determine that the most pronounced values of the spectrum of excitation amplitudes (input quantities) are up to about 0.2 Hz. As there is a statistical link between the mentioned initiatives, it was considered expedient to use the method of "dissociation" based on partial coherence functions for further research.

The effects of the observed motives are not unambiguous in all tests. After comprehensive analyses, it can be argued that the rectilinear test does not cause sufficient impact on the parameters of truck behaviour on the road, and that the DLC tests and overtaking tests allow a good expression of the impact on these parameters. Therefore, overtaking tests and DLC test can be used as reliable tests, but due to simplicity and safety, the overtaking test is preferred.

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