A CONTRIBUTION TO THE IDENTIFICATION OF PARAMETERS OF BUS HANDLING

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Abstract: *During the motion, the vehicle is affected by the environment. A driver who has in mind its impact acts on the available vehicle mechanisms and carries out the ride in the safest way. The overall engagement of the driver and the vehicle during the ride is assessed by the term "vehicle handling on the road". In the literature there are several definitions of the concept of vehicle handling on the road. The most acceptable definition "the vehicle handling on the road" includes a set of driver-vehicle-road system properties, that characterizes the option of variation of parameters in the level of vehicle motion induced by the desire of the driver."*

The vehicle handling can be assessed on the basis of several parameters: lateral displacement of the vehicle centre of gravity, vehicle yaw, required angle of rotation of steering wheels, roll of the sprung mass, etc.

In the present manuscript is deemed useful to investigate the behavior of the bus IK312 M from the product range of Ikarbus (Serbia) from the point of view of changes of the lateral acceleration and angular speed (yaw velocity) in function of the steer angle. To identify the behavior of buses on the road, the methodology used is based on the "cross" values (crosspectrum, croskorelation function and a common histogram), which enabled a comprehensive analysis of the registered size. The obtained results can be useful in conceptual designing of new buses.

Keywords: *Bus, handling, steering angle, lateral acceleration, yaw velocity*

Received: 10/11/2019 Accepted: 16/01/2020 Published online: 14/06/2020

I. INTRODUCTION

Motion of the vehicle from one place to another is carried out along a path whose configuration is very complex, and consists of straight and curvilinear parts of different curves and orientations.

The causes of the deviation of ride from straight line motion of the vehicle are:

• Spatial disposition of roads is such that it consists of a large number of straight and curvilinear sections, which inevitably requires constant correction of the direction of motion of vehicles;

• Driver must avoid any obstacle that may occur on the road, such as other vehicles, pedestrians, sudden obstacles (e.g. landslide rocks, road holes, icy areas), parked vehicles, etc.

During the motion, the vehicle is affected by the environment [1-12]. A driver who has in mind its impact acts on the available vehicle mechanisms and carries out the ride in the safest way. The overall engagement of the driver and the vehicle during the ride is assessed by the term "vehicle handling on the road". In the literature [1-12] there are several definitions of the concept of vehicle handling on the road. The most acceptable definition [1] "the vehicle handling on the road” includes a set of driver-vehicle-road system properties, that characterizes the option of variation of parameters in the level of vehicle motion induced by the desire of the driver".

The vehicle handling can be assessed on the basis of several parameters: lateral displacement of the vehicle centre of gravity, vehicle yaw, required angle of rotation of steering wheels, roll of the sprung mass, etc.

The cited definition includes terms “steerability” and “stability” of the “driver-vehicle system”, which in the current literature have a common goal to explain the concept: the dynamics of the system: “driver-vehicle-environment”. This problem is still very actual, despite the application of modern systems for the regulation of dynamic characteristics of the vehicle while driving (ABS, ESP, etc.). So far, due to the lower speed of buses in relation to passenger motor vehicles, more attention has not been paid to the mentioned problem. However, by building roads of higher categories there are buses that achieve high speeds, so it is necessary to study their behavior on the road in order to increase active traffic safety. Therefore, there will be more in the text below on the identification of the steering parameters of the bus handling on the road). It was considered appropriate that the procedure be applied to the IK312M intercity bus [13], with only the experimental identification of the handling parameters of the above-mentioned bus on the road.

II. METHOD

The observed bus, whose main purpose is intercity ride, was subjected to specific tests, which included characteristic exploitation cases (transient and non-stationary modes of bus ride). In the selection of tests, as well as the test regimes, the requirement of the bus manufacturer was primary [13]. In Table 1, a description of the applied test regimes is given.

Table 1. *Test regimes*

	Description of the test	Speed, km/h
1.	Random influence on steering wheel	58-60
2.	„Slalom“ ride	80
3.	„Slalom“ ride	92
4.	Double change of lane (similar to ISO 3888 for passenger cars, [14])	40
5.	Double change of lane (similar to ISO 3888 for passenger cars [14])	54-70
6.	Minimal turn of steering wheel (left – right)	80
7.	Minimal turn of steering wheel (left – right)	110
8.	Change of lane	90
9.	Streight-line ride	70

As already mentioned, handling of the bus on the road can be assessed on the basis of several parameters. In the particular case, it is considered appropriate to examine the handling of the said bus from the aspect of the lateral acceleration and angular velocity (yaw) related to the angle of rotation of the steering wheel (in case of identification of the driver parameters it is also necessary to register the torque applied at the steering wheel [3]).

During the tests, a highly trained driver was engaged, who had a reliable driving strategy and minimal errors in the case of repeating tests (speed, trajectory selection, etc.). Steering wheel angle is registered using the HBM W100 converter, which was attached to the steering column.

To register lateral acceleration and angular yaw speed, the gyroscopic stabilized platform RMS FES 44 was applied, installed at the bus center of gravity. All registered data are stored on a personal computer, and the scheme of the used measuring equipment is shown in Figure 1.

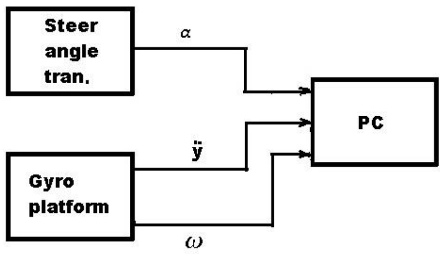

Figure 1. *Scheme of the used measuring equipment*

During the test, the bus was equipped with standard equipment. The air pressure in tires was adjusted according to the manufacturer's recommendations [13]. The driver, test engineer and measuring equipment were on the bus, so the total mass was 13325 kg (maximum permissible mass 18000 kg) [13].

During the test, discretization of the registered signals was performed with the step of increment 0.01 s. Duration of the signal depends on the type of test within the range of 11 to 20 s, (1100 to 2000 points).

Tests were conducted at the airport near Belgrade and on the “Belgrade-Niš” highway. All recorded values are given as time series, and for illustration, in Figures 2, 3 and 4, the results obtained during the performance of the overtake test for speed of 40 km / h (test number 4) will be shown.

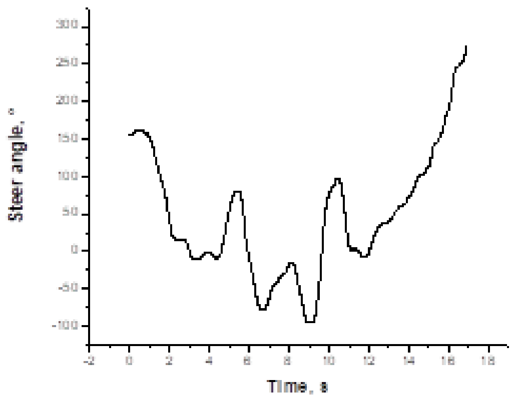

Figure 2. *Steering wheel angle*

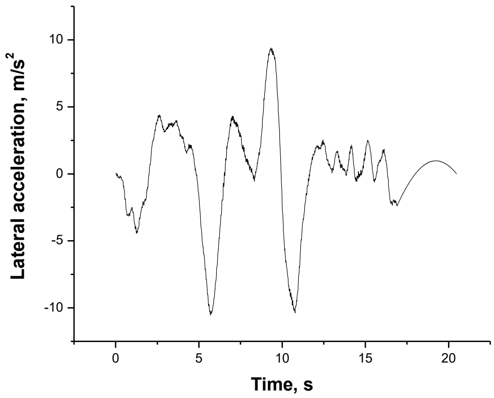

Figure 3. *Lateral acceleration*

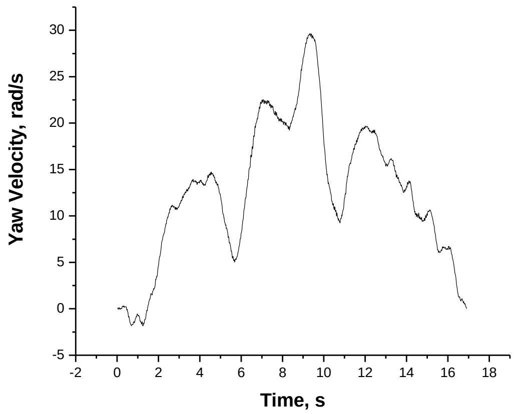

Figure 4. *Angular speed (yaw)*

By analyzing all the data, whose illustrative examples are partially shown in Figures 2-4, it can be determined that the observed variables are very much dependent on the type of test and the speed of the bus. This points out to the fact that they have to be further analyzed. It is customary that in these investigations the observed variables should be shown due to the angle of rotation of the steering wheel, which is for illustration purposes, given in Figures 5 and 6.

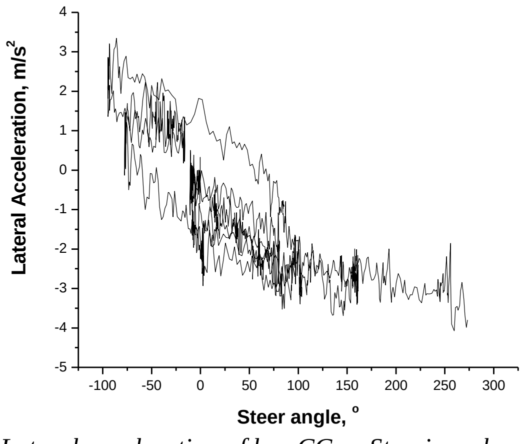

Figure 5. *Lateral acceleration of bus CG vs Steering wheel angle*

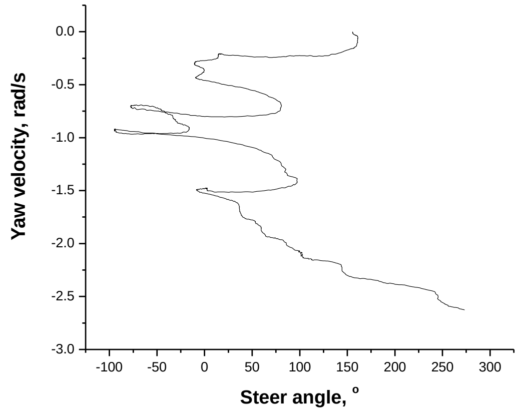

Figure 6. *Yaw vs Steering wheel angle*

An analysis of all the data, illustrated in Figures 5 and 6, indicated the need for more detailed analysis, using frequency analysis and the theory of "crossed" values [15]. The signal length allowed the frequency analysis in the domain 0.09 to 50 Hz [15], which is satisfactory for this type of test [4]. It is useful to calculate statistical errors in performing the frequency analysis [15]. For the observed technical system (bus), the accepted resonant frequency of the sprung mass of 2 Hz, the technical damping 0.2 and the minimum interesting frequency of 0.09 Hz, the actual "bias" errors were -0.004, the actual random errors for one realization 0.1, the real random errors of the crossed values 0.118, for the number of 100 averages during the calculation of spectra.

In order to perform frequency analysis and calculate "crossed" values, the programs Analsigdem and Demparkoh [16] were applied. As developed software for spectral analysis enabled at least 256 averages, these calculated errors were less than the ones declared and acceptable [13].

III. DATA ANALYSIS

As, in the particular case, the only input (regulating) variable was the angle of rotation of the steering wheel, it was considered appropriate to analyse in more detail its frequency content. In this sense, the amplitude spectra of the steering wheel for all the tests are calculated, and for the illustration, in Figure 7, the spectrum in case of test 4 is shown. It is noted that the graphics are shown only to about 2.5 Hz, although the spectra are calculated for a domain up to 50 Hz. This was done due to the fact that the spectra levels for frequencies greater than 2.5 Hz were relatively small.

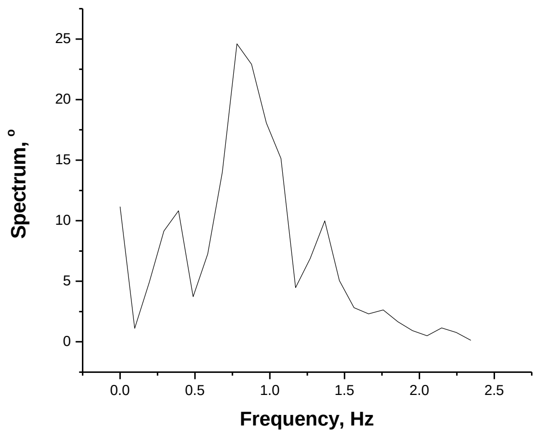

Figure 7. *Amplitude spectra of the steering wheel angle during the performance of overtake test at V=40 km/h (test 4)*

An analysis of the shapes of all the calculated angles of steering wheel, illustrated in Figure 7, shows the characteristic dominant frequencies, where strongest signal values are concentrated. In addition, there are also a number of higher, secondary frequencies. From the aspect of the driving strategy it can be argued that in the area of dominant, i.e., primary frequencies, the driver exhibits regulatory activity in the form of an active choice of the desired vehicle motion [3]. On the other hand, secondary frequencies indicate the driver's activity in compensating for the deviation of the actual vehicle path and the reference path of the marked path. In most cases, three peaks are expressed, and not always the largest one comes first. This can be explained by the difference in energy that the angle of rotation of the steering wheel is carried during the test. In Table 2, the dominant frequencies in which more significant peaks occur will be shown.

Table 2. *Dominant frequencies*

Test No.	f_1, Hz	f_2,Hz	f_3,Hz
1.	0.09	0.29	0.87
2.	0.39	1.36	1.66
3.	0.19	0.87	1.07
4.	0.39	0.78	1.36
5.	0.09	0.29	0.48
6.	0.39	0.78	1.36
7.	0.48	0.87	1.17
8.	0.29	0.97	1.36
9.	0.19	0.58	1.07

Based on the data in Table 2 it can be argued that the most significant first peak comes in the interval 0.09-0.48 Hz, the second one in the interval 0.29 to 1.36 Hz, and the third in the interval 0.48 to 1.36 Hz, which depends on the type of test, and the driver's reaction on the steering wheel. It should be emphasized that the position of the dominant frequencies is influenced by the speed of the bus and the type of trajectory, which can be seen from the table attached.

To determine whether there is a statistical link between the observed couples: “Angle of the steering wheel - Lateral acceleration” and “Angle of the steering wheel – Yaw angle of the bus”, using the Demparcoh program [16], the ordinary coherence functions were calculated for all tests. For the sake of illustration, in Figures 8 and 9, an illustrative example for test No. 7 is shown.

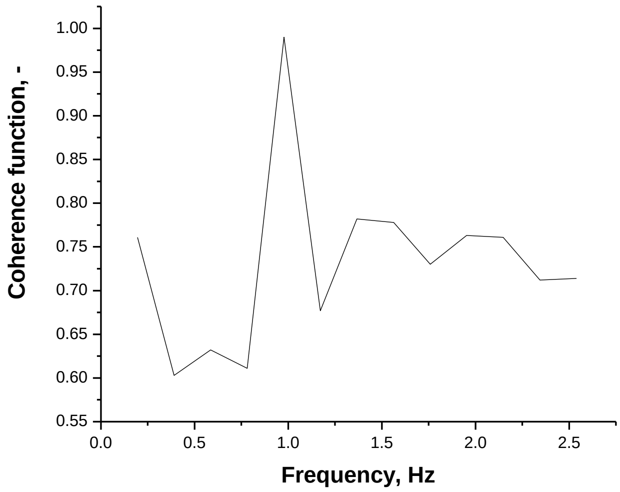

Figure 8. *Coherence function: Steering wheel angle - Lateral acceleration*

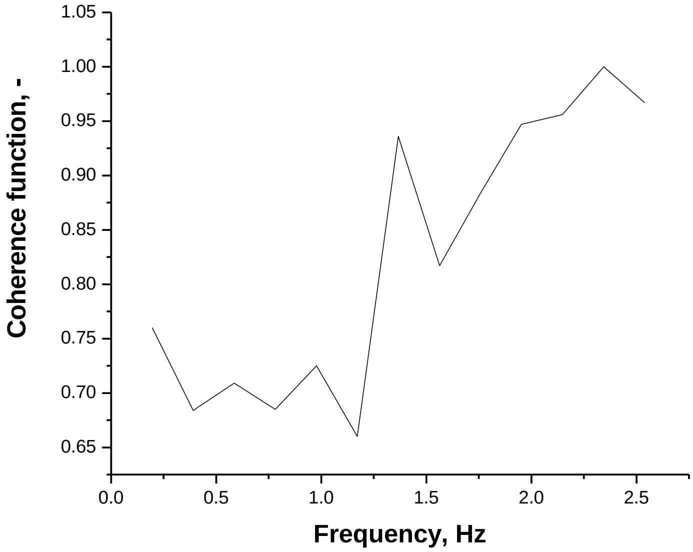

Figure 9. *Coherence function: Steering wheel angle – Yaw angle*

By analysing all the data on the coherence functions, partially shown in Figures 8 and 9, it has been established that there is a significant statistical link between the observed values in an interesting range of frequencies up to 2.5 Hz, since the coherence function is greater than 0.65 [15].

With this in mind, it is considered to be useful to use cross-values in further analysis. In this sense, using Demparcoh software [16], the crosspectra for the following couples were calculated: “Angle of the steering wheel - Lateral acceleration” and “Angle of the steering wheel – Yaw angular velocity” of the bus. These variables are calculated for all tests, and for illustration purposes, in Figures 10 and 11, an example for test No. 5 is given.

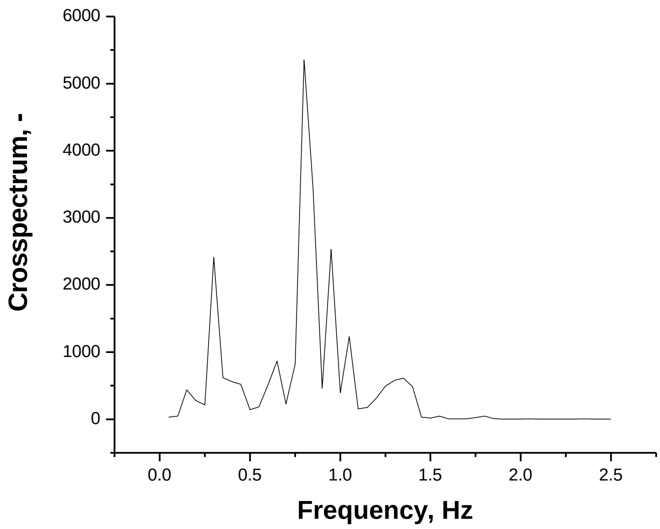

Figure 10. *Crosspectra: Steering wheel angle – Lateral acceleration of bus CG, test No 5*

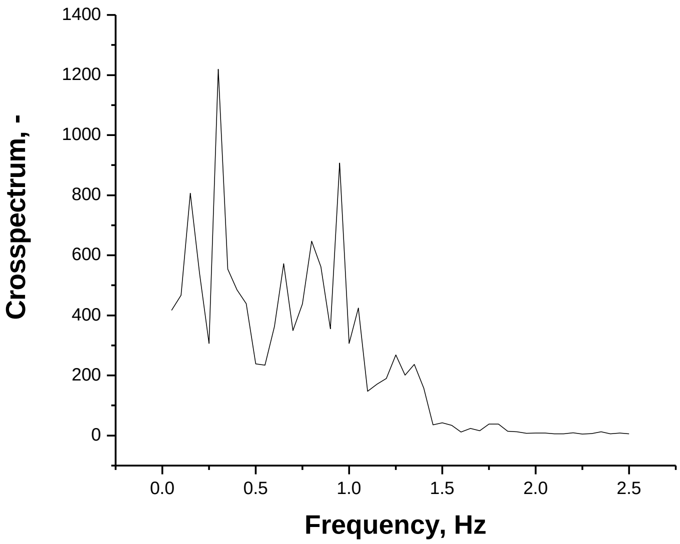

Figure 11. *Crosspectra: Steering wheel angle – yaw angular velocity, test No 5*

An analysis of all the data, partially given in Figures 10 and 11, showed that most of the energy is distributed for frequencies up to about 2 Hz. There are characteristic dominant frequencies in which the peaks (energy) are more significant. It is therefore considered appropriate to present these frequencies in Table 3.

Table 3. *Crosspectra dominant frequencies*

Test No	f_1, Hz *	f_2, Hz *	f_1, Hz **	f_2, Hz **
1.	0.40	0.93	0.11	0.93
2.	0.20	0.55	0.20	0.55
3.	0.16	1.12	0.16	0.32
4.	0.23	0.41	0.23	0.41
5.	0.25	0.45	0.25	0.50
6.	0.30	0.95	0.20	0.95
7.	0.18	0.54	0.18	0.45
8.	0.17	0.42	0.25	0.51
9.	0.20	0.55	0.25	0.50

**Lateral acceleration*
***Yaw angular velocity*

By analysing the data in Table 3 it was found that the first dominant frequency of the spectra “Steering wheel angle - Lateral acceleration” is in the interval 0.16 to 0.40 Hz, and the second in the interval 0.41 to 1.12. For crosspectra “Steering wheel angle – Yaw angular velocity” of the bus, first is in the interval 0.11 to 0.25, and the second within the interval 0.32 to 0.95.

It was estimated that it is also useful to calculate crosscorelation functions [15], using the Analsigdem software [16]. For the sake of illustration, in Figures 12 and 13, croscorelation functions for test No 1 are shown.

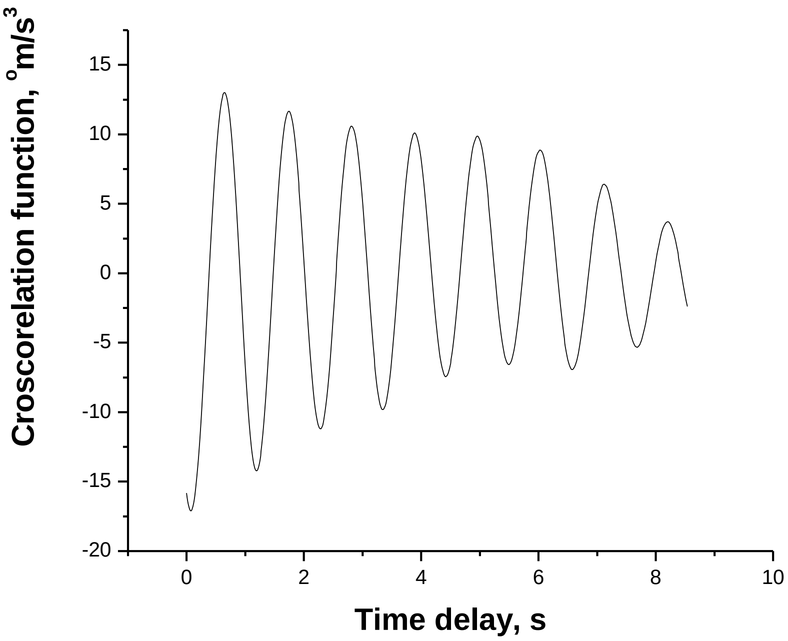

Figure 12. Crosscorelation function of the couple: Steering wheel angle – Lateral acceleration, test No 1

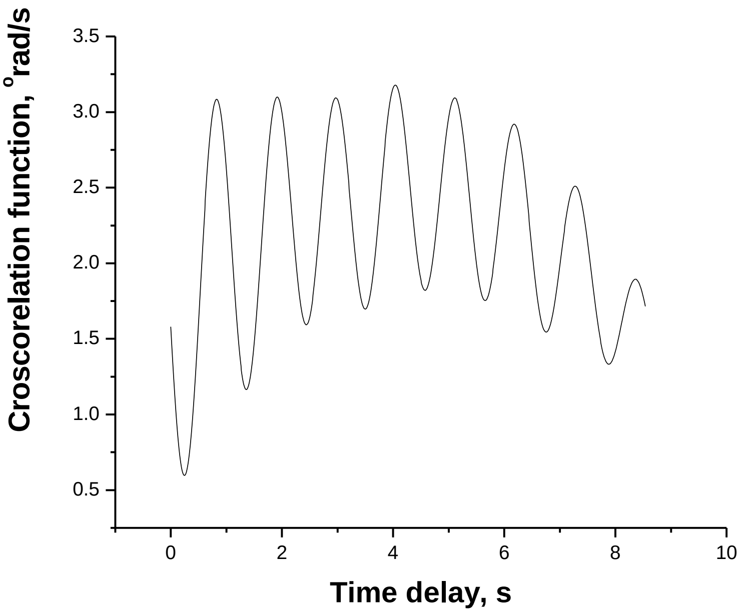

Figure 13. Crosscorelation function of the couple: Steering wheel angle – Yaw angular velocity, test No 1

On the basis of all the calculated variables of the crosscorelation functions, partially shown in Figures 12 and 13, the time delay of the said signals is determined, and the data are shown in Table 4.

__Table 4.__ Time delay of signals

Test No	Time delay: Steering wheel angle – Lateral acceleration	Time delay: Steering wheel angle – Yaw angular velocity
1.	0.65	0.84
2.	1.66	4.94
3.	4.14	4.32
4.	6.54	0.00
5.	9.82	0.00
6.	1.86	5.48
7.	1.40	1.36
8.	5.84	2.70
9.	2.82	7.41

By analysing the data in Table 4, it can be determined that the delay depends on the type of test and for the pair: Steering wheel angle - Lateral acceleration, it appears within the range from 0.65 to 9.82 s. For the pair: Steering wheel angle – Yaw angular velocity of the bus 0 to 7.42, s.

By using the same software, crossed histograms were also calculated (in conjunction with the joint probability), and the areas in which both observed variables appear are determined [15]. Histograms are calculated in the interval ±100, divided into 100 fields. For the sake of illustration in Figures 14 and 15, the histograms of the observed pairs of variables in test No 7 are presented.

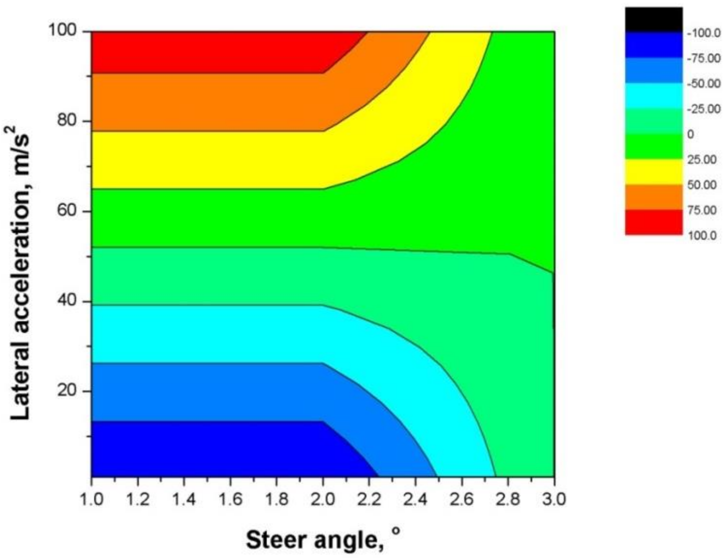

__Figure 14.__ "Crossed" histogram for the couple: Steering wheel angle-Lateral acceleration, test No 7

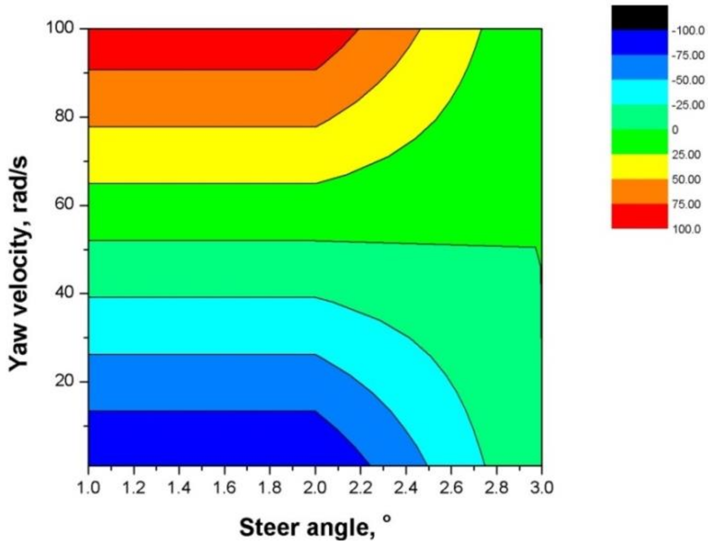

Figure 15. "*Crossed" histogram for the couple: Steering wheel angle-Yaw angular velocity*

By analyzing all calculated histograms, it has been established that in the case of a couple: Steering wheel angle-Lateral acceleration, the number of simultaneous occurrence of the observed variables ranges from 1.65 to 5.96, and for the couple: Steering wheel angle-Yaw angular velocity it is 1.05 to 5.81.

IV. CONCLUSION

Based on the performed research, it is possible to conclude the following:

1. Knowledge of the dynamic characteristics of a bus in transient and non-stationary motion regimes is the starting point for enhancing performance, i.e. defining the criteria on the basis of which some variables will be defined at the initial design stage.

2. The applied methodology for identifying dynamic characteristics of a bus according to the concept of "crossed" values (cross-spectra, cross-correlation functions, histograms) provides possibilities for studying and improving parameters of the complex dynamic bus system.

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