CONTRIBUTION TO RESEARCH OF DRIVER-VEHICLE-ROAD DYNAMIC SYSTEM ENCOUNTER OF THE VEHICLE TO IMPACT OBSTACLE

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Abstract: *While driving, the driver is looking the environment (road, traffic, wind influence, vibrations etc.) and acting on various commands in order to have most optimum movement. The overall engagement of the driver and vehicle in relation to environment is defined with the term of handling (vehicle behavior on the road).*

Vehicle behavior on the road can be rate based on different parameters: angle and torque at steering wheel, oscillatory motion of the vehicle centre of gravity (especially lateral movement), yaw and vehicle roll, turn angle of steer able wheels and similar.

The goal of the research is to determine is there a need for driver to act on steering wheel of tested vehicle while driving rectilinear and encountering on obstacle.

The research have determine that vehicle encounter at sudden obstacle on the road, inevitably is making the need for driver to roll steer wheel of the tested vehicle, in order to maintain rectilinear movement which is significant not only for dynamic of mentioned system but for road maintenance too.

Keywords: *vehicle, vehicle dynamic, impact obstacle, steer wheel angle*

Received: 08/09/2020 Accepted: 05/04/2021 Published online: 31/05/2021

1. INTRODUCTION

While driving, the driver is looking the environment (road, traffic, wind influence, vibrations etc.) and acting on various commands in order to have most optimum movement. The overall engagement of the driver and vehicle in driving in relation to environment is defined with the term of *handling* (motor vehicle behavior on the road) [1-9].

There is little different number of definitions for the term of handling in literature. Definition according to [9] is:

"Vehicle behavior on the road contain set of system properties: driver-vehicle-road, which characterizes change of the parameters in line of vehicle movement, caused by the desire of the driver".

Vehicle behavior on the road can be rate based on different parameters: angle and torque at steering wheel, oscillatory motion of the vehicle centre of gravity (especially lateral movement), wind and vehicle rolling, turn angle of steer able wheels and similar [9-13].

The term of handling includes vehicle handling and stability parameters. In that sense, special attention will be paid to system behavior in specific exploitation situation. Namely, while driving one can frequently encounter at road obstacle, impact holes and similar. The driver in order to hold the vehicle motion set course (for example rectilinear) is affecting on vehicle controls, respectively steering wheel.

This paper research that using Land Rover 110 vehicle encounter an obstacle. More precise, the goal of this research is to determine is there a need for driver to act on steering wheel of the tested vehicle while driving rectilinear and encountering on obstacle. Researching this topic, various experimental researches have been made that will be more describe in paper. It is important to note that the goal of this research was not to investigate the driver parameters as regulator of the driver-vehicle-road dynamic system [14].

The experiment was made with specified vehicle, which basic characteristics are given in table 1. All the values, beside moment of inertia have been measured on vehicle, while moments of inertia have been taken from literature [15].

Table 1. *Basic technical characteristics of the vehicle Land rover Defender 110*

Wheelbase	2794, mm
Wheel track width	1486, mm
Unladen vehicle mass	2125, kg
Vehicle ground clearance	250, mm
Tire label	235/85R16
Moment of inertia of roll (Ixx)	744, kgm^2
Moment of inertia of pitch (Iyy)	2440, kgm^2
Moment of inertia of yaw (Izz)	2478, kgm^2
Position of the center of gravity from front axle and height	1.4 m, 1 m

The research have been made on horizontal asphalt surface on which it is placed obstacle of the profile shown in the figure 1 in two cases: crossing a discrete (impact) obstacle simultaneously with two tires and crossing an obstacles which have been moved one in relation to the other for 700 mm (by vehicle length). In future, the term alternate will be used for the second case of research. The vehicle velocity when crossing obstacle were from 10 km/h to 40 km/h.

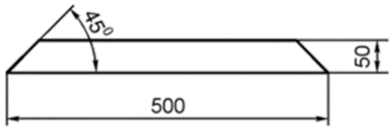

Figure 1. *Dimensions and profile of discrete obstacle*

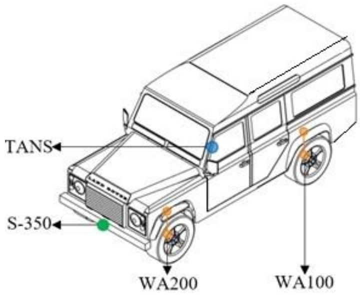

Figure 2. *Measuring points*

The position of measuring points is given in figure 2. For vehicle acceleration measurement and mass gravity angular speed measurement triaxial Kistler TANS sensor was used. Kistler S-350 measurement system with optical velocity sensor was used for vehicle speed measurement (longitudinal and lateral, which haven't been considered in this paper). Spring deformation in vehicle suspension system has been register with inductive transducer of shift type HBM WA. The acquisition of the measured values has been done with two measuring amplifiers HBM QuantumX MX 840B, which have been connected with PC. Data processing has been made using HBM Catman Easy software.

For illustration, figure 3 is showing amplifiers that are being position and set for measurement. All data are recorded with sampling frequency of 50 Hz (sample rate 0.02 s).

Figure 3. *Amplifiers position in tested vehicle*
left – longitudinal velocity (and lateral velocity, which was not being considered in this paper); middle – mass gravity vehicle motion parameters; right – spring deformation

2. MAIN CONTENTS

Considering large amount of measurements, it is being determined that, for illustration, figures 4-8 partially show changes of the measuring data, when doing test of vehicle encounter on alternately placed obstacles, with speed of 30 km/h.

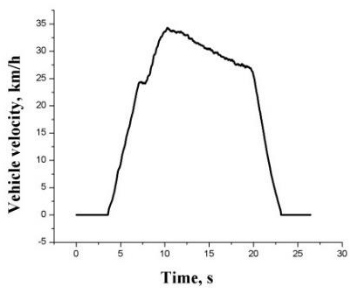

Figure 4. *Speed change when vehicle encounter on alternately placed obstacles*

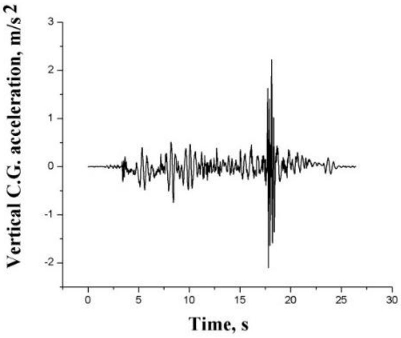

Figure 5. *Dependence of the mass gravity vertical acceleration when vehicle encounter on alternately placed obstacles*

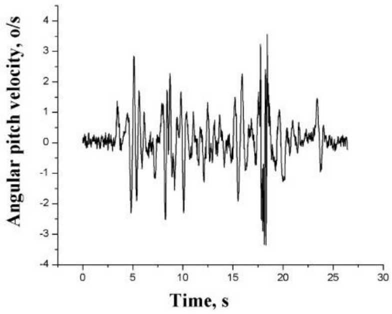

Figure 6. *Dependence of the vehicle pitch speed when vehicle encounter on alternately placed obstacles*

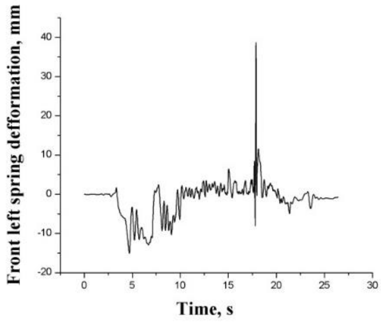

Figure 7. *Dependence of the front left spring deformation when vehicle encounter on alternately placed obstacles*

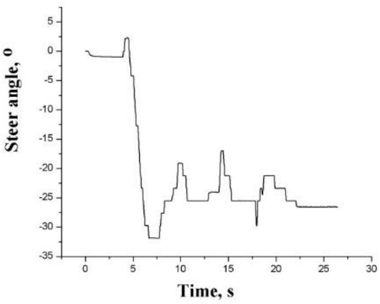

Figure 8. *Dependence of the steering wheel turning angle when vehicle encounter on alternately placed obstacles*

Analyzing the data, partially shown at figures 4–8, it has been noticed that there is dependence between measured data and driver force reaction which have been manifested in acting to fuel supply commands (gear change) and steer wheel turning angle. Because of that, it is considered expedient to make more precise data analyze to determine is there a link between observed vehicle dynamic parameters when encountering on impact obstacles and driver reaction shown to steering wheel.

All the data analyze is showing that it is useful to calculate cross spectrum value of some values, when making characteristic test of encounter on impact obstacle with 30 km/h speed. To be more precise, the pairs of values have been looked:

- steering wheel angle – vehicle speed;
- steering wheel angle – mass gravity longitudinal acceleration;
- steering wheel angle – mass gravity lateral acceleration;
- steering wheel angle – mass gravity vertical acceleration;
- steering wheel angle – vehicle roll velocity;
- steering wheel angle – vehicle pitch velocity
- steering wheel angle - vehicle yaw velocity;
- steering wheel angle – vehicle right front spring deformation;
- steering wheel angle – vehicle right rear spring deformation;
- steering wheel angle - vehicle left front spring deformation;
- steering wheel angle - vehicle left rear spring deformation.

All calculations have been made using Analsigdem software [16], whose theory is explained more detail in [17, 18], with time step of 0.02 s in 1322 points, which made it possible to analyze the data in range of 0.0378 to 25 Hz [17, 18]. This frequency interval is completely satisfy with ride comfort requirements, because it involve vide areas of high sensitivity man to oscillations, like everything important resonant frequencies of man and vehicle [1-7, 9-13]. Taking into account that phase angles are not giving relevant information's about process amplitudes [17, 18], for illustration, figures 9-12 are partially showing characteristic cross spectrum modules.

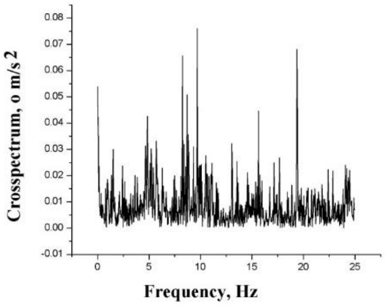

Figure 9. *Cross spectrum magnitude: steering wheel angle–vertical vehicle acceleration*

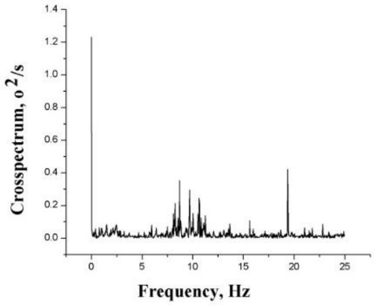

Figure 10. *Cross spectrum magnitude: steering wheel angle–vehicle pitch velocity*

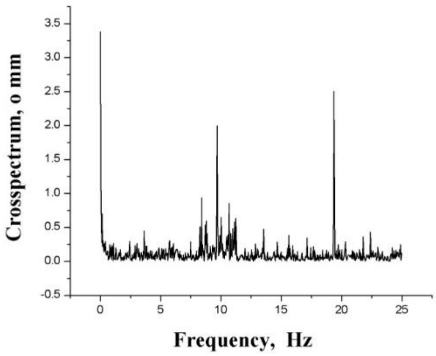

Figure 11. *Cross spectrum magnitude: steering wheel angle–right front spring deformation*

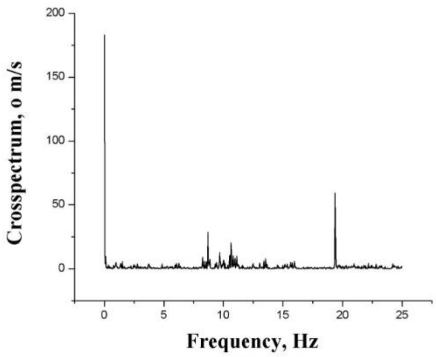

Figure 12. *Cross spectrum magnitude: steering wheel angle–vehicle speed*

Analyzing the data, partially shown in figures 9–12, we can see resonant frequencies, close by areas round 2 (driver-steering wheel angle and sprung mass resonant frequency [14]), 8–11 (vertical resonant frequency of the powertrain [1-7, 9]) and 18–20 Hz (unsprung masses resonant frequency) [1-7,9].

Note that information that cross spectrum is showing are not enough for analyze of vehicle dynamic influence at driver reaction (steering wheel), because measured parameters of vehicle dynamic are interconnected (for example, tire vibrations are influencing vehicle vibrations etc.). Therefore, it was deemed expedient to use partial coherent function concept [17, 18], which allows that excitation values be „stretch". Practically, that means that exit values (in our case steer wheel angle) are being analyzed in function of uncoupled input values (speed, spring deformations, mass gravity linear parameters and vehicle body angular motion parameters), on the way that eliminate their mutual influence [17, 18].

As this procedure is more detail described in [17, 18], it will not be talked of it here and readers will be direct on quitted references. Calculation of partial coherent functions is done using Demparcoh software [16], with 512 averaging which is wary acceptable from aspect of results reliability [17, 18].

It is considered expedient, because of abundance of data gathered for all tests, which on figures 13 and 14 show partial coherent functions for vehicle encounter test on impact obstacle with speed of 40 km/h. As the goal of the research was to determine is the encounter of the vehicle on obstacles on the road causing driver action on steer wheel, calculated partial coherent functions on mentioned figures are shown for area of 4 Hz frequency, because this area is showing frequency of driver turning the steer wheel [14].

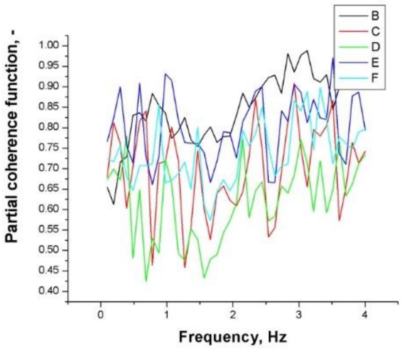

Figure 13. *Partial coherence steering wheel angle (The curve B in figure 13 is showing vehicle speed, curve C right front spring deformation with out of gear influence on speed, curve D right rear spring deformation with out of gear influence on speed and deformations of front right spring, curve E left front spring deformation with out of gear influence of speed and deformation of front and rear right spring, curve F left rear spring deformation with out of gear influence of speed and deformation of front and rear right and front left spring)*

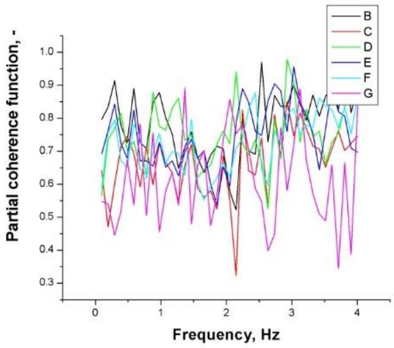

Figure 14. *Partial coherent functions steering wheel angle (The curve B in figure 14 is showing longitudinal vehicle acceleration, curve C lateral acceleration with out of gear longitudinal acceleration, curve D vertical acceleration with out of gear influence of longitudinal and lateral vehicle acceleration, curve E vehicle body roll speed with out of gear influence of longitudinal, lateral and vertical acceleration, curve F vehicle pitch speed with out of gear influence of longitudinal, lateral and vertical acceleration of mass gravity and roll speed of vehicle body, curve G vehicle winding angular velocity with out of gear influence of longitudinal, lateral and vertical acceleration of mass gravity and roll and pitch speed of vehicle body)*

Data processing of all calculated partial coherent functions, illustrated in figures 13 and 14, has show that vehicle dynamic when encountering an obstacle is causing driver action, in his attempt to maintain vehicle direction, acting on steering wheel. The value of observed partial coherent functions has been from, close by borders of 0.3 to 1 (it, practically means that in observed vehicle-driver-road system are nonlinearity and noise due to clearance, because coherent functions are lover or equal to one [17, 18]).

In order to make better analyze vehicle dynamic influence on driver reaction to steering wheel, it is considered expedient to make calculation of average values partial coherent functions in wide frequency area (to the upper limit that is allowed by signal digitalization, 25 Hz). Results are spread in two groups, because of large quantity, and shown in tables 2 and 3.

Table 2. *First group partial coherent functions average value*

Speed	V, km/h	Right front spring deformation	Right rear spring deformation	Left front spring deformation	Left rear spring deformation
10	8.106E-001	6.702E-001	7.453E-001	7.316E-001	7.141E-001
20	8.886E-001	5.984E-001	4.308E-001	6.979E-001	6.794E-001
20 alternately	8.982E-001	3.277E-001	4.408E-001	4.497E-001	6.406E-001
30	8.665E-001	5.257E-001	6.065E-001	7.676E-001	7.282E-001
30 alternately	9.834E-001	7.126E-001	6.582E-001	8.703E-001	8.625E-001
40	9.121E-001	7.544E-001	6.622E-001	8.771E-001	7.876E-001

Table 3. *Second group partial coherent functions average value*

Speed	Longitudinal vehicle body acceleration	Lateral Vehicle body acceleration	Vertical Vehicle body acceleration	Body roll velocity	Body pitch velocity	Body yaw velocity
10	6.105E-001	5.260E-001	5.722E-001	5.939E-001	4.792E-001	4.584E-001
20	6.105E-001	5.552E-001	6.200E-001	5.939E-001	4.792E-001	3.215E-001
20 alternately	5.025E-001	3.477E-001	5.122E-001	5.426E-001	6.040E-001	2.250E-001
30	6.954E-001	5.855E-001	5.879E-001	5.653E-001	6.120E-001	4.222E-001
30 alternately	8.663E-001	8.124E-001	8.391E-001	8.872E-001	8.813E-001	7.172E-001
40	8.106E-001	6.702E-001	7.453E-001	7.316E-001	7.141E-001	5.950E-001

Data processing and analyzing data in table 2, can be determine that vehicle speed is influencing at driver reaction on steering wheel when vehicle encounter on impact obstacle (depending on test, average value are from 0.8106 to 0.9834). The influence of spring deformation is little lower and is affected with test conditions (depending on test, average values are from 0.3277 to 0.8771).

Based on data given in table 3 it can be argued that acceleration of mass gravity and angular speeds of vehicle body are having close by influence at driver behavior with vehicle encountering on impact obstacle (depending of test, average values are from 0.3477 to 0.8872).

The obtained results showed that encounter at obstacle, inevitably, is making steering wheel rolling in order to maintain rectilinear driving and are significant not only for dynamic of mentioned system but for road maintenance too.

3. CONCLUSION

The research carried out, made it possible to determine that vehicle encounter on sudden obstacle at the road, inevitably is making the need for driver to roll steering wheel of the vehicle. The driver is acting on steering wheel to maintain rectilinear movement of the vehicle. There is correlation between secondary vehicle movement (characteristic mass oscillations) and steering wheel angle. The obtained results can be connect with road conditions: sadden obstacles, impact holes etc.

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