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Certain Results of Examination of Technical Stochastic Stability of A Car After Accident Repair

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CERTAIN RESULTS OF EXAMINATION OF TECHNICAL STOCHASTIC STABILITY OF A CAR AFTER ACCIDENT REPAIR

Strictly as per the compliance and regulations of:

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Jerzy Kisilowski [α], Jarosław Zalewski [Ω]

Abstract - This paper presents the chosen results of simulation of sports car mathematical model in different conditions of motion. The car model was loaded with the extra mass representing both driver and passenger. The location of the center of mass was disturbed, as if the car had previously been damaged due to side impact accident, and then repaired without the control of basis points in its body. It is shown how the car body can be damaged as a result of side crash at different velocity.

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I. Introduction

One of the most important issues concerning road traffic in recent times is the car, human and road active and passive safety. The scope of much research is the examination of different aspects of safety within the driver – car – surrounding system. The aim of this paper is to show the chosen results of examination of stochastic technical stability of a sports car mathematical model, with the consideration of the changes caused by the side impact crash and an after accident repair, as well as road conditions and disturbances coming from the road surface. Definition of stochastic technical stability is presented in [2], [3], [4] and [5]. In [1] the stability of discrete and continuous structures is presented, whereas in [9] – general mechanical criteria of retaining the stability by the car. These criteria are used in theory of road car dynamics. In [10] the mathematical description of the process of crash of vehicles is presented.

The necessity of conducting such research results, among others, from the statistical data. The authors concentrated on side impact accidents and their share in general number of accidents in Poland. Collisions were not analyzed.

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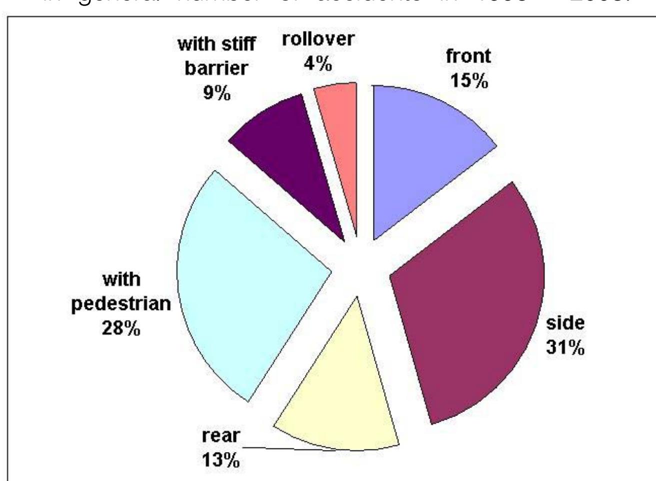
II. Chosen analysis of Road Accidents

In figure 2.1 percentage share of side impact crashes in general number of accidents is shown. This type of crashes establishes over 30 per cent of all accidents in Poland between 1995 and 2008. Taking into consideration the severity of injuries as well as deformations of car body, it is important to pay attention to both the reasons and the consequences of side impact crashes, which can occur in further exploitation of cars repaired after accident. There is often lack of control of geometric parameters of car body after repairing or changing the damaged parts.Statistics concerning road accidents with comments are also in [6], [8] and [11].

Taking into consideration what is mentioned above, the authors decided to focus on the analysis of side impact crash in the process of simulations (oblique location of the cars involved in accident in the moment of crash) and the examination of motion of the car, that was involved in this crash. The model of a sports car was chosen. Then the assumption was made, that neither the body of the chosen car was controlled on a special frame, nor its mass – inertia parameters were checked

Fig. 2.1 : Percentage share of different types of Crashes in general number of accidents in 1995 - 2008.

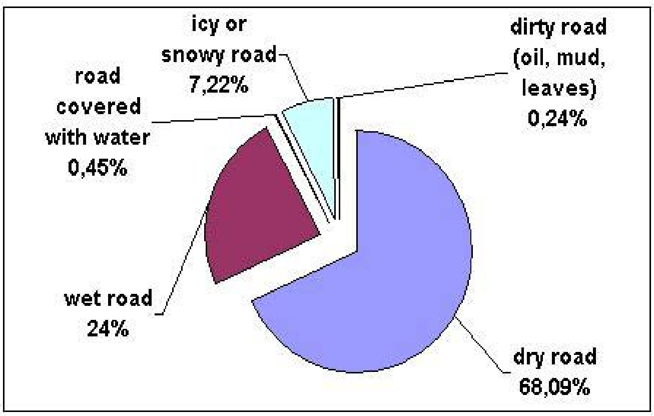


Source : own research.

Another factor taken into account during the preparation of the simulation were the extreme conditions of road traffic. Among the accidents, for example in 2005, around 36 per cent (fig. 2.2) occurred in bad road conditions (wet road, snow, dirt, oil, leaves on the road), 32 per cent during bad weather (fig. 2.3). It made the authors to implement similar conditions to the simulation. Randomly occurring unevenness of the road was also added.

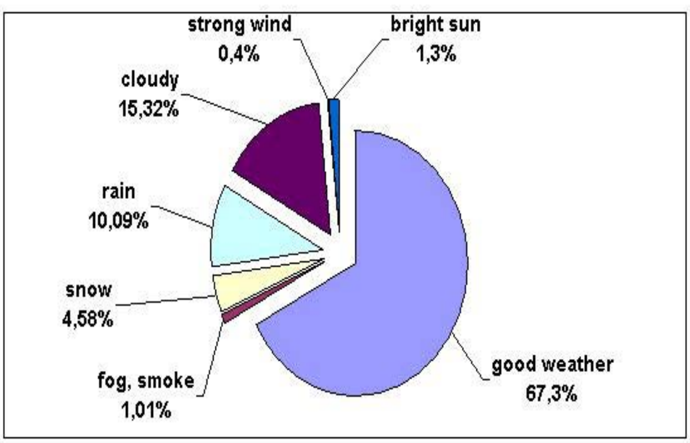
The additional simulation of side impact crash accident was done with the use of PC-Crash 8.0. Its purpose was to show deformations of a sports car body. The simulation of car motion after accident and repair was done with the use of MSC Adams 2005r2

Fig. 2.2 : Percentage share of accidents connected to road conditions in poland in 2005.



Source : own research.

Fig. 2.3 : Weather conditions during road accidents in Poland in 2005.



Source : own research

III. Simulation of Side Impact Crash in PC Crash Software

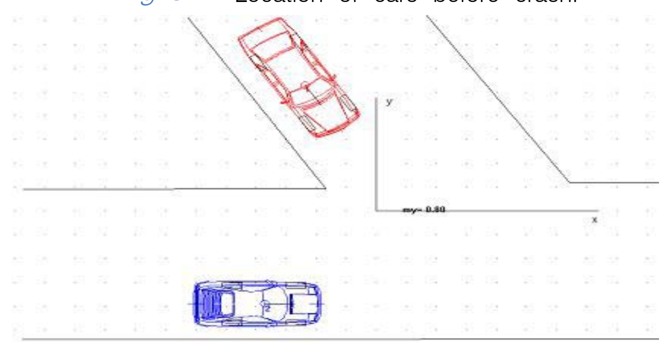
To examine the depth of deformation in car body as a result of side crash, a simulation in PC-Crash software was done with the relevant parameters. The situation reflects oblique side crash. The car being hit is Ferrari 355 GTS and the car hitting is Mercedes S500. Results of this simulation are shown for two sets of velocities of colliding cars. The authors would like to pay attention to potential deformations of a sports car body, which can occur as a result of side crash. It is also necessary to mention the consequences in the further exploitation of such car.

Basic assumptions concerning the simulation of the oblique side impact crash:

- the motion is set on a dry road surface ($\mu = 0{,}8$);
- the cars move with two sets of velocities:
a) Ferrari – 50km/h, Mercedes – 60km/h;
b) Ferrari – 80km/h, Mercedes – 100km/h;
- the whole mass of Ferrari was increased from 1350kg to 1500kg, adding the mass of the driver and the passenger;
- the whole mass of Ferrari was increased from 2100kg to 2395kg, adding the mass of the driver and three passengers;
- the height of the center of mass for Mercedes was set on 0,6m, for Ferrari - on 0,45m.

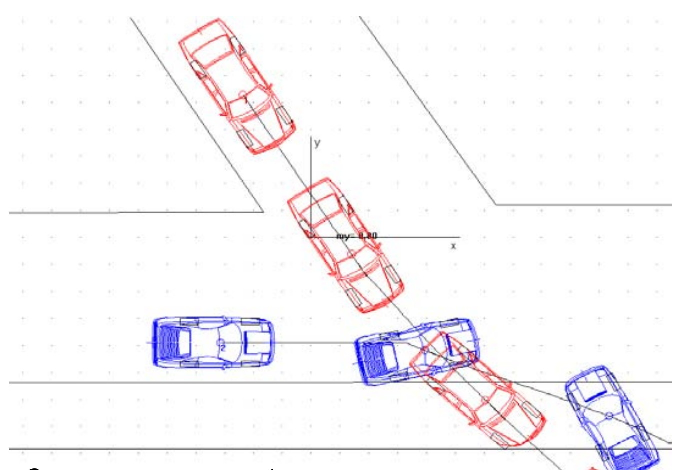
In fig 3.1 the location before the crash is presented, while in fig. 3.2 a, b – the motion of both cars during the crash as a sequential location of both cars for each set of velocities respectfully. Damages to the sports car body are shown in fig. 3.3a, b.

Fig. 3.1 : Location of cars before crash.



Source : own research

Fig. 3.2a : Simulation of oblique side impact crash for velocities 50km/h (Ferrari) and 60km/h (Mercedes).



Source : own research.

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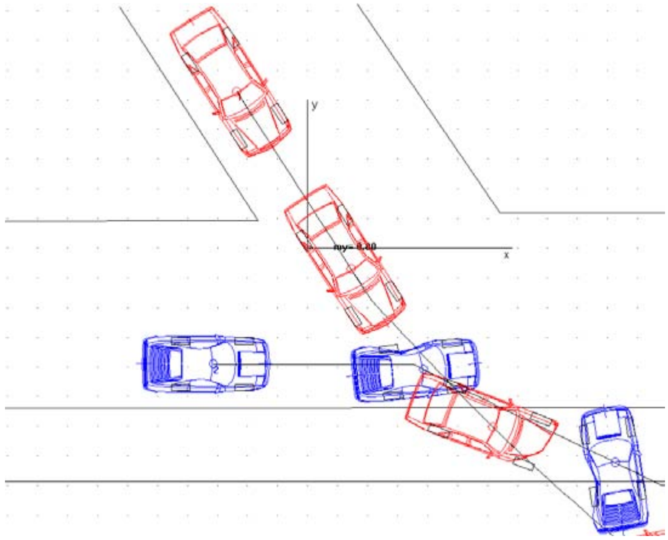
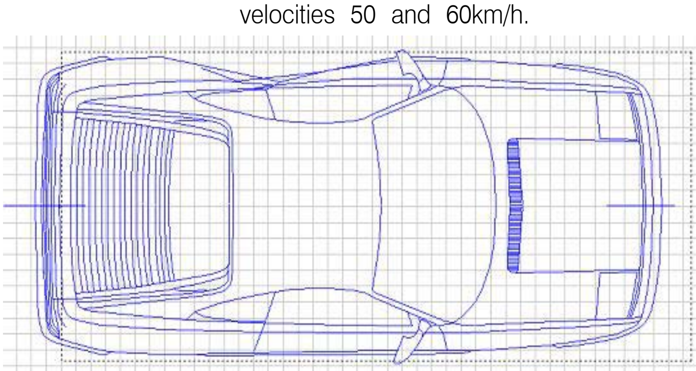
The simulation was realised for several times, during which the repetitiveness of the depth of deformations in car bodies was observed. Other parameters, for example velocities after the crash, differ in every simulation. However, the tolerance of such difference ranges from 2 to 5%, depending on if the car was hitting, or was being hit.

Fig. 3.2 a : Simulation of oblique side impact crash for velocities 80km/h (Ferrari) and 100km/h (Mercedes).



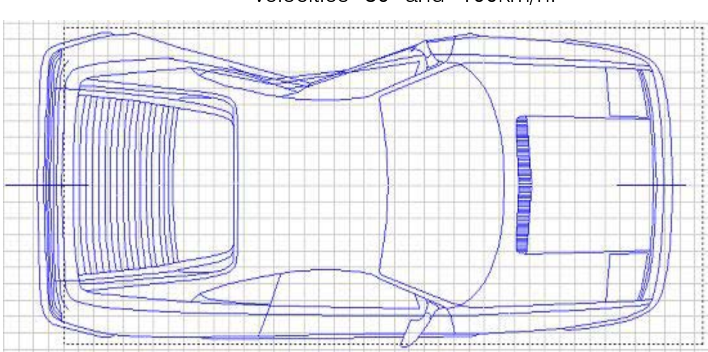
Source : own research.

Fig. 3.3 a : Deformation of the sports car body for the velocities 50 and 60km/h.



Source : own research.

Fig. 3.3b : Deformation of the sports car body for the velocities 80 and 100km/h.



Source : own research.

In table 3.1a i 3.1b exemplary protocols of both accidents for both velocity configurations are shown.

The depth of the deformations is worth noticing. At v = 60km/h, the hitting car (Mercedes) has its front deformed by 0,33m, and at v = 50km/h for Ferrari it is 0,25m in the left side part of its body. It is also important to consider the mutual penetration of both cars.

The results of the simulation for the second set of velocities present almost 0,6m deformation for Mercedes and 0,43m deformation of side part in Ferrari.

The authors are especially interested in the deformation of the sports car, because on such basis the scale of disturbances of the center of mass after repair of a damaged car can be assumed. It is due to the lack of control of geometric and inertia parameters of car body in the process of the elimination of damages.

Tab. 3.1a : Protocol of the side crash for velocities 50 and 60km/h.

car	Mercedes-Benz S 500	Ferrari - 355 Berlinetta
INITIAL VALUES OF PARAMETERS		
Before crash velocity [km/h]:	**60.00**	**50.00**
Angle of the car [deg] :	-57.43	0.00
Angular velocity around z axis [1/s] :	0.00	0.00
Location of cm in x axis [m] :	-2.36	-3.14
Location of cm in y axis [m] :	5.26	-3.91
Location of cm in z axis [m] :	0.60	0.45
Velocity along z axis [km/h] :	0.00	0.00
Lateral tilt [deg] :	0.00	0.00
Roll angle (around y axis)[deg] :	0.00	0.00
Angular velocity around x axis [1/s] :	0.00	0.00
Angular velocity around y axis [1/s] :	0.00	0.00
FINAL VALUES OF PARAMETERS		
After crash velocity [km/h]:	**48.05**	**55.86**
Velocity change dv [km/h] :	14.56	23.25
Angle of the car [st.] :	-41.31	168.94
Angular velocity around z axis [1/s] :	0.01	0.65
Location of cm in x axis [m] :	11.10	15.03
Location of cm in y axis [m] :	-10.84	-8.79
Location of cm in z axis [m] :	0.60	0.44
Velocity along z axis [km/h] :	0.03	0.17
Lateral tilt [deg] :	1.61	-1.52
Roll angle (around y axis) [deg] :	0.00	5.02
Angular velocity around x axis [1/s] :	-0.13	-0.70
Angular velocity around y axis [1/s] :	0.00	0.09
Depth of the deformations [m] :	0.33	0.25
Restitution coefficient k	0.10	

Source : own research.

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Tab. 3.1b : Protocol of the side crash for velocities 80 and 100km/h.

Pojazd	Mercedes-Benz S-500	Ferrari 355-Berlinetta
INITIAL VALUES OF PARAMETERS		
Before crash velocity [km/h]:	**100.00**	**80.00**
Angle of the car [deg] :	-57.43	0.00
Angular velocity around z axis [1/s] :	0.00	0.00
Location of cm in x axis [m] :	-2.36	-3.14
Location of cm in y axis [m] :	5.26	-3.91
Location of cm in z axis [m] :	0.60	0.45
Velocity along z axis [km/h] :	0.00	0.00
Lateral tilt [deg] :	0.00	0.00
Roll angle (around y axis) [deg] :	0.00	0.00
Angular velocity around x axis [1/s] :	0.00	0.00
Angular velocity around y axis [1/s] :	0.00	0.00
FINAL VALUES OF PARAMETERS		
After crash velocity [km/h]:	**78.79**	**90.87**
Velocity change dv [km/h] :	26.54	42.38
Angle of the car [st.] :	92.37	- 179.59
Angular velocity around z axis [1/s] :	1.60	0.00
Location of cm in x axis [m] :	22.80	33.01
Location of cm in y axis [m] :	-19.54	-15.66
Location of cm in z axis [m] :	0.60	0.46
Velocity along z axis [km/h] :	0.08	-1.36
Lateral tilt [deg] :	8.18	-6.84
Roll angle (around y axis) [deg] :	-0.02	-1.75
Angular velocity around x axis [1/s] :	-0.03	0.30
Angular velocity around y axis [1/s] :	0.24	-0.21
Depth of the deformations [m] :	0.58	0.43
Restitution coefficient k	0.10	

Source : own research.

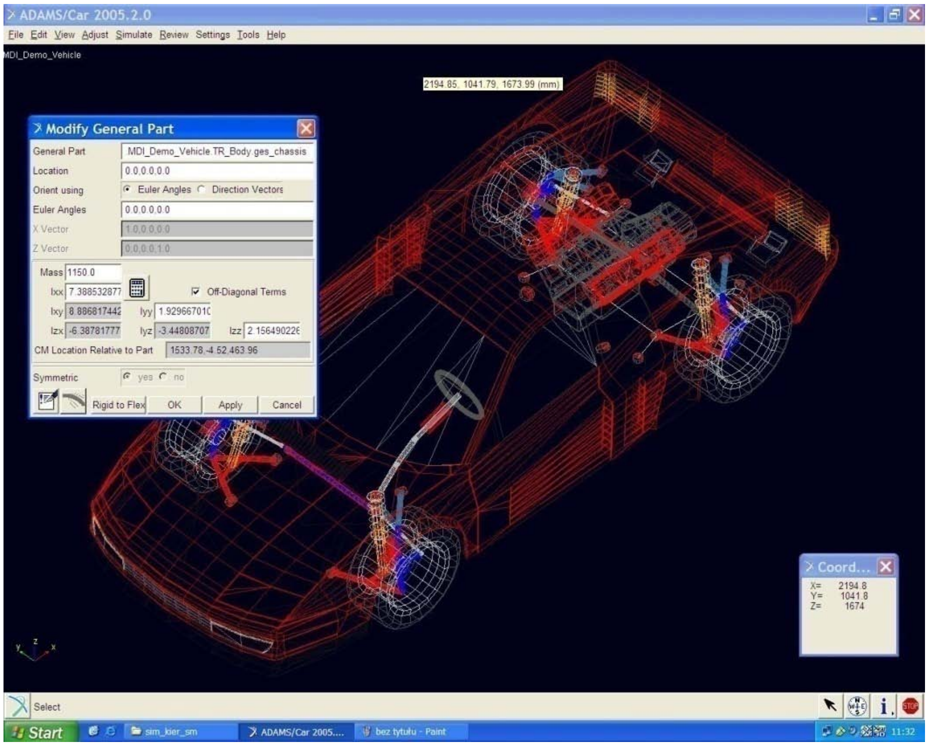
IV. Description of the Simulation of Car Mathematical Model with the Disturbed Center of Mass

The object of the simulation was the model of a sports car. For this model the mass and location of the driver and the passenger was included in the mass–inertial parameters. The model is shown in fig. 4.1.

The simulation, realizing the maneuver of double lane change was done with the use of MSC Adams/Car 2005r2 software. It was prepared for the conditions given below:

- additional mass representing the driver (85kg) and the passenger(70kg) was included;
- with the use of static moments new coordinates(x, y, z) of the center of mass of car body were calculated. Initial location of the center of mass was (1450.0mm, 0.0mm, 450.0mm) in relation to the point called "origo", which is the point of the beginning of the axis system that is situated on the road surface and moves with the car. The initial mass of the car body was 955kg. The location of the center of mass after adition of the driver and the passenger changed to (1533.78mm, -4.52mm, 463.96mm). The mass of the car body increased to 1150kg. The location of the center of mas is calculated in relation to the point called „origo", which lies at the beginning of the axis system connected to the road surface but moving along with the car. The location of coordinates (x,y) can also be calculated as in [4];
- disturbance was added to the coordinates calculated for the driver and the passenger. This disturbance is assumed to be a result of the previous crash and a possibility of the change of mass and moments of inertia. Two cases were taken into consideration. Basing on the results from p. 3 it was assumed, that in the process of repair the coordinates of the center of mass will not be restored to their initial location. No literature, describing the typical disturbances of the center of mass in car body after accident and repair, was found. New coordinates of the center of mass were defined as follows: x and y were transformed by 150mm, while the coordinate z – by 40mm (1383.78mm, 145.48mm, 503.96mm). As a result of those transformations new values of inertia and deviation moments were obtained;
- the car rides for 700m realizing the maneuver of double lane change. Omitting long obstacle was simulated here. The car moved at 100km/h, on the icy road surface ($\mu = \sim 0{,}30$);
  time of the maneuver t = 25s;
- two trajectories were obtained – a solid line for the car
- with additionally disturbed center of mass as a result of an accident, and a dash line for the car without after accident disturbances. In fig. 5.2 lateral displacement in function of time is shown for both the car with disturbed center of mass of its body by 150mm, and that with the undisturbed one.

Fig. 4.1 : Sports car model used in the simulation of motion.



Source : MSC Adams| Car.

V. Examination of Stochastic Technical Stability of Car Mathematical Model

The Ω set (the set containing the part of the trajectory in the range $[t_1;\ t_1+T]$) of the area of states E was divided into 10 classes every 50 mm: [K1; K10] (fig. 5.1a). In the plot road parameters and geometric parameters of the car were not taken into consideration.

The Ω' set (the set containing the part of the trajectory in the range $[t_1';\ t_1'+T']$) of the area of states E was divided into 10 classes every 50 mm: [K1'; K10'] (fig. 5.1b). On the axis of lateral displacement (x) the classes of both sets are marked.

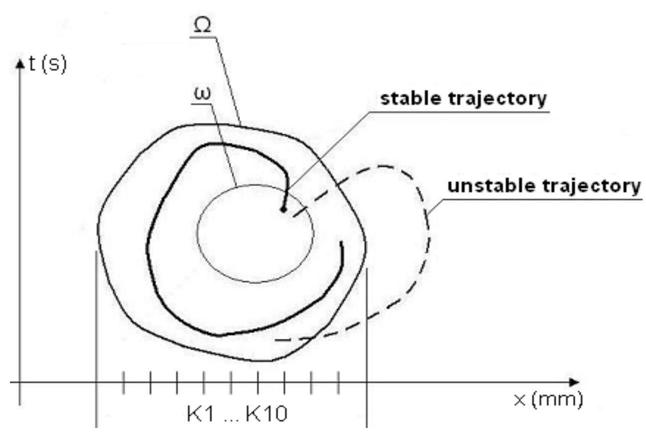
The frequencies of occurrences were counted for two areas:

- the area of omitting the obstacle $[t_1;\ t_1+T]$ – time frame [6s;16s] for every 10m of the road;
- final area, when the car finishes the maneuver $[t_1';\ t_1'+T']$ – time frame [22s; 25s] for every 10m of the road.

These time frames were divided into sub-frames with the step of $\Delta t = 0{,}375$s (fig. 5.2).

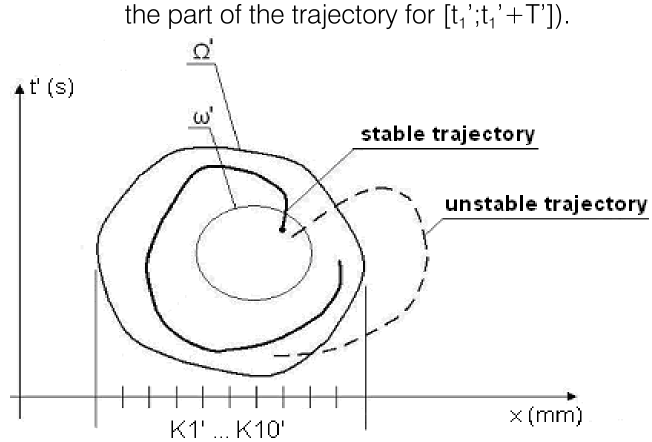
In fig. 5.3a, b the parts of trajectories from fig. 5.2 are shown, on which the frequencies of occurrences are examined, for the maneuver realized in the conditions of disturbing the horizontal coordinates of the center of mass in car body (respectively for $[t_1;\ t_1+T]$ and $[t_1';\ t_1'+T'])$.

Fig. 5.1 a : Ω series in the area of states E containing the part of the trajectory for $[t_1;\ t_1+T]$).



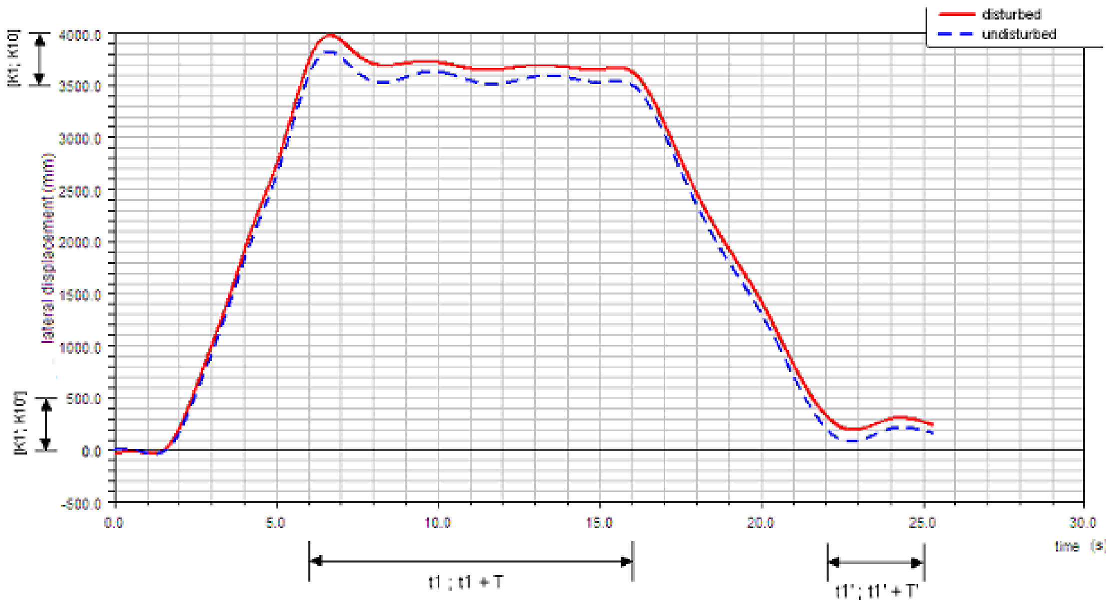
Source : own research.

Fig. 5.1 b : Ω' series in the area of states E containing the part of the trajectory for $[t_1';t_1'+T']$).



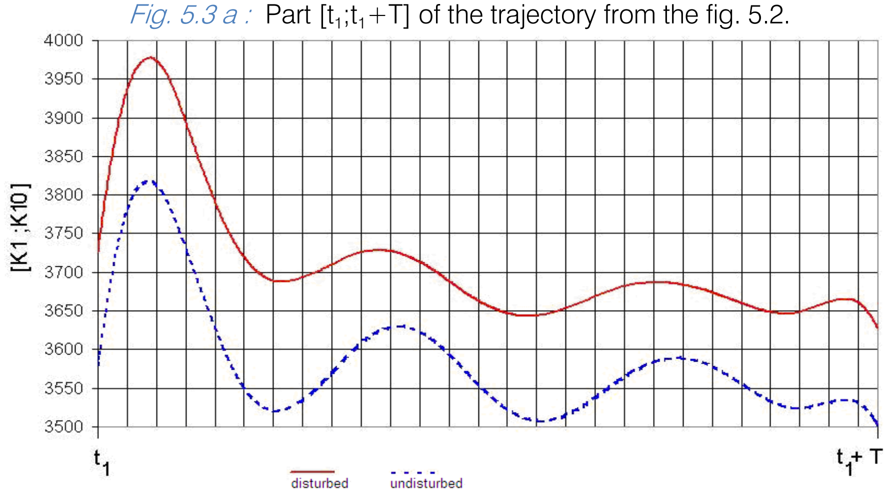
Source : own research.

Fig. 5.2 : Lateral displacement of the car with the disturbed by 150 mm (solid line) and undisturbed (dashed line) center of mass of its body.



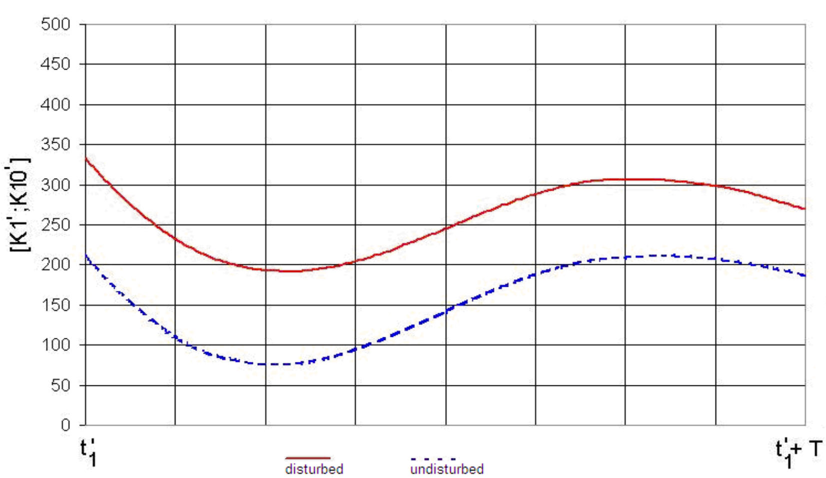
Source: own research

Fig. 5.3 a : Part $[t_1;t_1+T]$ of the trajectory from the fig. 5.2.



Source : own research.

Fig. 5.3 b : Part $[t_1';t_1'+T']$ of the trajectory from the fig.5.2.



Source : own research.

VI. Results

Analysis was made for the time frame $[t_1; t_1+T]$. The frequencies of occurrences were counted as follows. In every step of the time frame the frequencies of existence of the solution in each class were examined. Basing on [3]

$$W(K_j) = \frac{T_{Kj}}{T} = \frac{N_{Kj} \cdot \Delta t}{N \cdot \Delta t} = \frac{N_{Kj}}{N} \qquad (5.1)$$

where:

T_{Kj} - time of remaining in the given class;

- N_{Kj} - the number of sub-frames, for which the solution remains in the given class.

The values of the frequencies of occurrences are presented in tab. 6.1 – 6.2. Kolmogorov – Smirnov test (λ test) was performed in order to verify the H_0 hypothesis about the incompatibility of the step curve and the continuous probability on the significance level α=0,05. D_n, D_x, D_n' and D_x' here mean the Kolmogorov – Smirnov statistics. Normal and Rayleigh means were analyzed.

Tab. 6.1 : Verification of the hypothesis on the basis of λ test for the step curve and the continuous probability for [t1; t1+T], without disturbances, normal and Rayleigh means.

class	N_{Kj}	W(Kj)	step curve F(Kj)	continuous probability (normal means) F(u)	D_n	critical value	λ test (α =0,05)	N_{Kj}	W(Kj)	step curve F(Kj)	continuous probability (Rayleigh means) F(x)	D_x	critical value	λ test (α = 0,05)
1	12	0,445	0,445	0,98745	0,54245	0,37543	hypothesis accepted	12	0,445	0,445	0,98515	0,54015	0,37543	hypothesis accepted
2	8	0,296	0,741	0,99998	0,25898	0,45427	hypothesis rejected	8	0,296	0,741	0,99999	0,25899	0,45427	hypothesis rejected
3	4	0,148	0,889	1	0,111	0,62394	hypothesis rejected	4	0,148	0,889	1	0,111	0,62394	hypothesis rejected
4	0	0	0,889	1	0,111	-	-	0	0	0,889	1	0,111	-	-
5	1	0,037	0,926	1	0,074	0,97500	hypothesis rejected	1	0,037	0,926	1	0,074	0,97500	hypothesis rejected
6	1	0,037	0,963	1	0,037	0,97500	hypothesis rejected	1	0,037	0,963	1	0,037	0,97500	hypothesis rejected
7	1	0,037	1	1	0	0,97500	hypothesis rejected	1	0,037	1	1	5,84E-10	0,97500	hypothesis rejected
8	0	0	1	1	0	-	-	0	0	1	1	5,84E-10	-	-
9	0	0	1	1	0	-	-	0	0	1	1	5,84E-10	-	-
10	0	0	1	1	0	-	-	0	0	1	1	5,84E-10	-	-

Source : own research.

Tab. 6.2 : Verification of the hypothesis on the basis of λ test for the step curve and the continuous probability for [t1; t1+T], with disturbances of the center of mass by 150mm, normal and Rayleigh means.

class	N_{Kj}	W(Kj)	step curve F(Kj)	continuous probability (normal means) F(u)	D_n	critical value	λ test (α = 0,05)	N_{Kj}	W(Kj)	step curve F(Kj)	continuous probability (Rayleigh means) F(x)	D_x	critical value	λ test (α = 0,05)
1	0	0	0	0,25462	0,25462	-	-	0	0	0	0	0	-	-
2	0	0	0	0,25462	0,25462	-	-	0	0	0	0	0	-	-
3	5	0,185	0,185	0,71226	0,52726	0,56328	hypothesis rejected	5	0,185	0,185	0,52608	0,34108	0,56328	hypothesis rejected
4	13	0,482	0,667	0,99990	0,33290	0,36143	hypothesis rejected	13	0,482	0,667	0,99993	0,33293	0,36143	hypothesis rejected
5	5	0,185	0,852	0,99999	0,14799	0,56328	hypothesis rejected	5	0,185	0,852	1	0,148	0,56328	hypothesis rejected
6	1	0,037	0,889	1	0,111	0,97500	hypothesis rejected	1	0,037	0,889	1	0,111	0,97500	hypothesis rejected
7	1	0,037	0,926	1	0,074	0,97500	hypothesis rejected	1	0,037	0,926	1	0,074	0,97500	hypothesis rejected
8	0	0	0,926	1	0,074	-	-	0	0	0,926	1	0,074	-	-
9	1	0,037	0,963	1	0,037	0,97500	hypothesis rejected	1	0,037	0,963	1	0,037	0,97500	hypothesis rejected
10	1	0,037	1	1	2,22E-16	0,97500	hypothesis rejected	1	0,037	1	1	3,35E-10	0,97500	hypothesis rejected

Source : own research.

VII. Conclusions

The examination of stochastic technical stability was made within two aspects. Trajectories of car motion and the frequencies of the occurrence of deviation from the initial location were compared. The analysis was made for the trajectories of motion after the double lane change maneuver and returning to initial lane.

If, according to fig. 5.1a and 5.1b, the area in which the trajectory can occur is divided into 10 equal sections, then for time $[t_1; t_1+T]$ it can be specified, whether the trajectories will leave this area. For such criteria the trajectories, after omitting the obstacle, remain in Ω area.

Maximal values of amplitudes of the trajectories for the car with the center of mass disturbed are near the border of stability, according to the accepted criteria. We believe that if the disturbances are increased, the trajectory will leave the Ω area.

Another scope of the conclusions concerns the frequencies of occurrence of the trajectories in the specified sections. As seen in tab. 6.1 and 6.2, the frequencies of occurrences in classes 4 and 5 are much higher for the trajectory of the car with the disturbed center of mass. For example, in class 4, for the car with the undisturbed center of mass the frequency of occurrences is zero, whereas for the car with the disturbed center of mass it is 0,482. In class 5 it is 0,037 and 0,185 respectively.

Maximal amplitude values of the trajectory for the car with the undisturbed center of mass for in classes 9 and 10 are zero, and for the car with the disturbed center of mass 0,037 in both classes.

As it is seen, the disturbances of the center of mass meaningly influences both the maximal values of amplitudes of the trajectories and the frequencies of occurrences in class for high amplitudes of trajectories.

VIII. Bibliography

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