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STUDIES REGARDING THE INFLUENCE OF THE SQUISH IN-CYLINDER MOVEMENT OF THE AIR IN A DIESEL ENGINE

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Abstract: *The objective of this paper is to establish the influence of the in-cylinder squish motion of the air on the turbulence inside the cylinder, which leads to a different output: effective power and torque. The simulation was implemented in AVL FIRE ESE DIESEL in order to simplify the simulation and reduce the simulation time. The engine that was implemented is a Mercedes-Benz E220 engine type OM611 220 CDI, 92 kW, because the piston can be cut through to measure the precise shape so that the simulation is as close as possible to the real combustion chamber. In order to modify the squish, the distance from the piston to the cylinder head was modified (standard is 1 mm and it was modified to 0.5 mm, 1.5 mm and 2 mm), but the compression ratio was kept the same so as to not influence the performance indices.*

Key-Words: *Squish motion, intake, CFD Simulation, AVL FIRE, AVL ESE DIESEL.*

1. INTRODUCTION

Currently, the study of the in-cylinder movement of the air during the intake process for the Diesel engine has been done (a major concern) because the quality of the burning process and therefore the emission quantities can also be changed through a simple modifications of shapes for the piston and intake pipes (manifold), which is why many researchers have emerged in this direction [1][2][3].
The influence of the piston bowl was demonstrated by Jovanovic et al. [4][5] and also many CFD studies were made in this direction [6].
From a simplified point-of-view, there are two types of ideal flow patterns in an engine cylinder: *swirl motion* (with the cylinder axis as the axis of rotation and the flow entering tangentially through the intake ports) and *tumble motion* (orthogonal to the cylinder axis, the axis of motion moves as the cylinder expands and stays halfway between the top cylinder wall and the cylinder head at the bottom). Both are rotational motions, however, the axis of rotation is different in each case.
Depending on the type of engine, one of these patterns is considered optimal because it maximizes the mixture of injected fuel and air, resulting in a homogeneous combustion.

2. IN-CYLINDER MOVEMENTS OF THE AIR FOR THE DIESEL ENGINE

2.1. Swirl and tumble movement

The flow of air admitted into the engine cylinders is usually characterized by a swirl movement, represented in figure 1.a., the tumble movement, represented in figure 1.b., and turbulence intensity. Swirl and tumble are widely known controlled turbulences that may exist within the cylinder, either separately or combined.
These movements are created during the intake stroke, the piston moves towards BDC and the fluid passes over the inlet valves.
Depending on the design of the inlet movements, swirl and / or tumble are created and preserved (or slowly dissipated) into the cylinder when the intake valves are closed. Swirl motion lasts longer than tumble and can affect the post-oxidation process [7].
The swirl number is the angular velocity of swirl motion around the central axis of the cylinder, while the angular velocity of the tumble movement is perpendicular to the axis of the cylinder.

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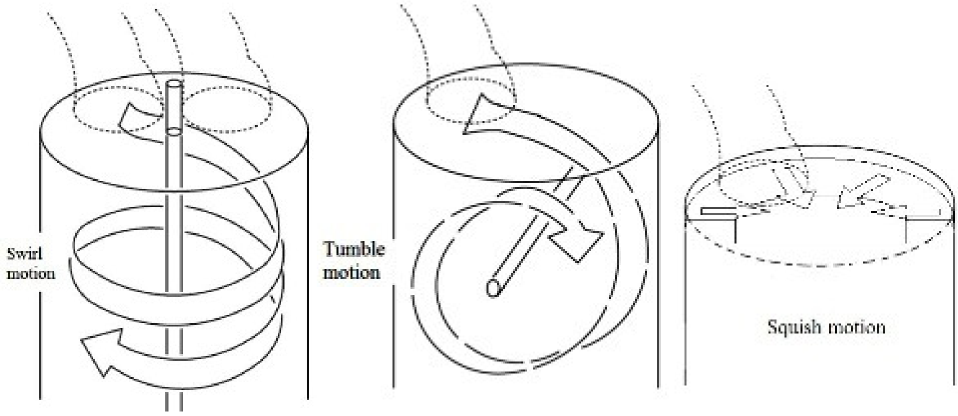
Where there are both these types of movements, they combine to create a single large vortex.
Normally, the swirl motion is used in direct injection Diesel engines, while tumble is used in spark ignition engines. During the engine cycle (the time in which the swirl motion is created and the valves are closed) the swirl movement changes between compression and combustion.
At the end of the compression stroke, the rotation of the swirl motion is larger and the flow of air is forced into the combustion piston bowl. The radius of the swirl motion is reduced, increasing the angular velocity. When the piston moves toward BDC, the opposite is true.
The flow also slows down due to friction with the combustion chamber walls [7].

2.2. Squish movement

The region where the squish motion occurs, represented in figure 1.c., is located on the outer radius of the flat area of the piston. This area is between the piston and the cylinder head, designed to be of approximately 1 mm, which is important for a Diesel engine. When the piston reaches TDC (Top Dead Center) the squish movement also contributes to guide the fuel that is injected.
For a given compression ratio (higher compression ratio offers higher efficiency at a certain level), the heat transfer at TDC is relatively high and by reducing the surface, the heat transfer is also diminished (the surface, the heat transfer …).
Air trapped in the volume between the piston and the cylinder head is forced toward the center of the cylinder and creates a powerful flow.
This flow (squish) can slightly influence combustion process timing after fuel injection.



a) b) c)

Figure 1. In-cylinder motion of the air: a) Swirl, b) Tumble and c) Squish

3. MATERIALS AND METHOD

3.1. Simulation software

The software that was used to simulate the combustion process is AVL FIRE ESE DIESEL. AVL FIRE is a multifunctional software (the latest generation 3D CFD -Computational Fluid Dynamics). It is developed and continuously improved to solve the most demanding problems in terms of geometric complexity, physical and chemical.
CFD is a branch of fluid mechanics which uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. In order to simulate the 3D flow, mixture formation, combustion and pollutant formation, the CFD modeling engine with direct injection is used.
It also makes it possible to analyze the interaction between fuel and air movement admitted into the combustion chamber.
The main advantage of modeling is that it minimizes the CFD simulation time, specifically the numerous studies executed in a relatively short time, based on computing power.
The main interest in flow visualization is admitted cylinders extraction and analysis of virtual motion swirl and tumble motion [8].
Generally the level of information that can be provided by a visualization technique increases with the size of the input data.

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3.2. Simulated engine

The simulated engine is the OM611 220 CDI, 92 kW (Mercedes-Benz E220).
This engine was chosen because the engine is available for further practical analysis.
The simulations were made for different distances between the piston and the cylinder head at TDC, keeping the same compression ratio by slightly changing the profile of the piston bowl.
The steps that followed in AVL FIRE ESE DIESEL for a single simulation were:

- the General Data for the engine were introduced (engine layout, number of cylinders, compression ratio, crank radius, connecting rod length and piston offset);
- the piston parameters were introduced from an actual section of a piston;
- the injector properties were introduced;
- the mesh was generated (2D and 3D) and checked for irregular faces;
- the data for calculation were introduced (crank angle for the start and end of the simulation, engine speed, boundary conditions for the piston, liner and axis);
- fluid properties and initial conditions were introduced;
- the solver control parameter tree was completed (k-zeta-f turbulence model, energy output and no two-stage-pressure correction) and the maximum number of iterations was set to 100;
- output control was set to ensure proper 2D and 3D results;
- combustion model was set to Coherent Flame Model - ECFM-3Z;
- the spray was set, taking into account the fuel consumption at full throttle for the given engine speed;
- the simulation was started and the results were exported using Report Generator.

The first simulation was made for a 0.5 mm distance between the piston and the cylinder head, where a maximum velocity of the intake air was 86.778 m/s at 714 deg CA.
The simulation can be seen in Figure 2.

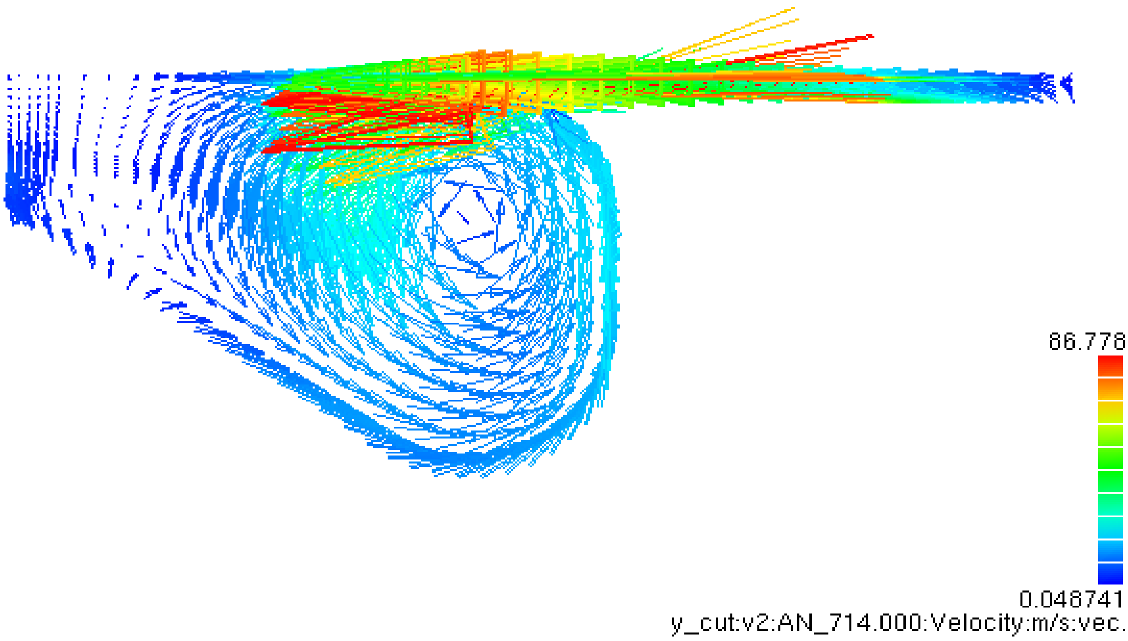

Figure 2. Maximum velocity of the air for 0.5 mm gap at 714 deg CA

The second simulation was made for a 1 mm distance between the piston and the cylinder head, where the maximum velocity of the air was obtained at 710 deg CA (56.949 [m/s]), as shown in Figure 3.
The third simulation was made for a 1.5 mm distance between the piston and the cylinder head, and the forth simulation for a 2 mm distance.
The simulations show a velocity of 40.76 [m/s] at 710 deg CA, and 29.734 [m/s] at 708 deg CA respectively (Figures 4 and 5).

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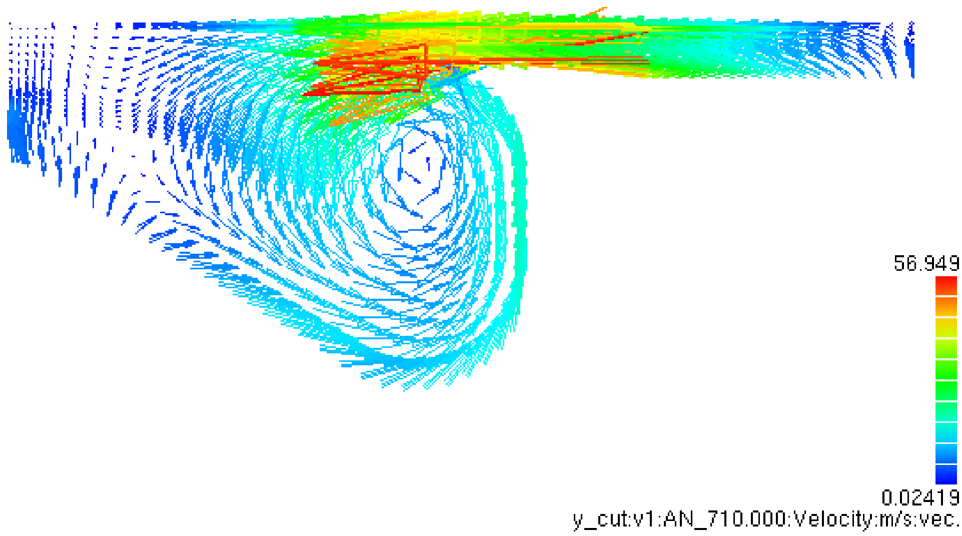

Figure 3. Maximum velocity of the air for 1 mm gap at 710 deg CA

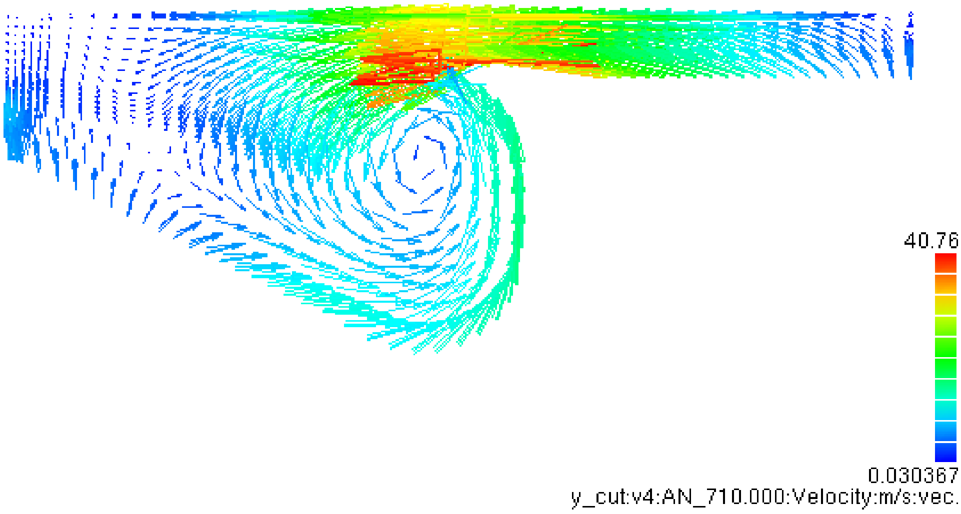

Figure 4. Maximum velocity of the air for 1.5 mm gap at 710 deg CA

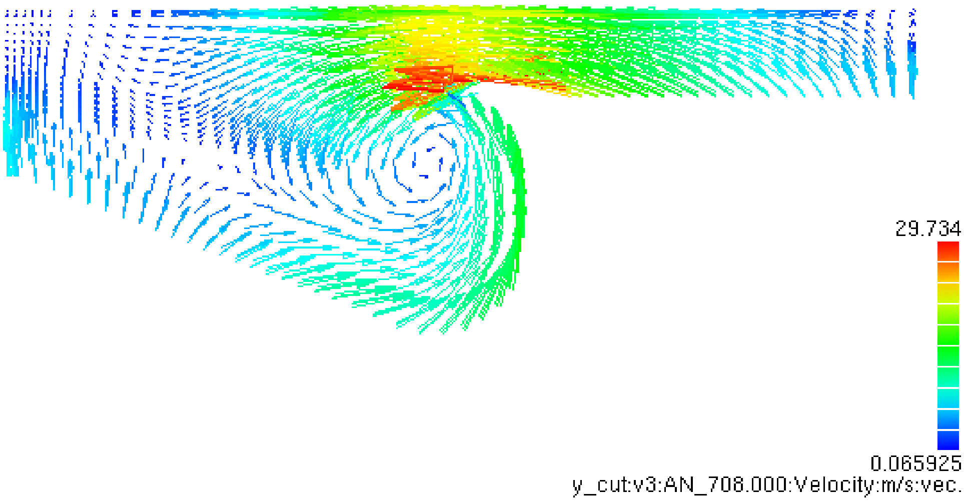

Figure 5. Maximum velocity of the air for 2 mm gap at 708 deg CA

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4. RESULTS

The results of the simulations are presented in table 1 and figure 6.
In table 1, the maximum values for each simulation were outlined with a green background.

Table1
Values for maximum velocity of the air inside the combustion chamber, in all four simulated cases

Max. velocity of the air in the combustion [m/s]	Piston position [deg CA]	700	702	704	706	708	710	712	714	716	718
	TDC gap 0.5 mm	43,83	49,89	56,46	64,05	72,07	79,93	85,59	86,77	77,33	49,21
	TDC gap 1 mm	37,05	41,41	45,68	50,25	54,26	56,94	56,57	51,89	40,61	26,48
	TDC gap 1.5 mm	29,83	32,72	35,5	38,17	40,16	40,76	38,86	33,88	24,86	19,52
	TDC gap 2 mm	23,58	25,38	27,11	28,71	29,73	29,54	27,4	23,15	16,33	16,19

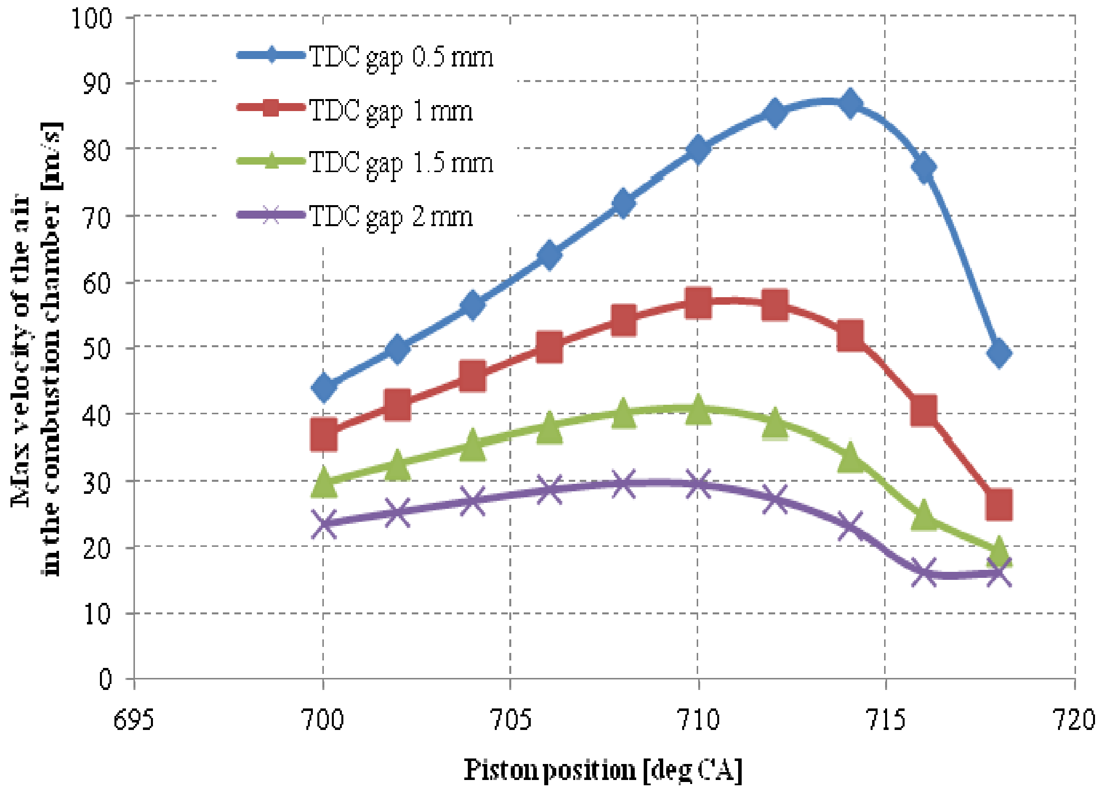

Figure 6. *Maximum velocity of the air in the combustion chamber for all simulation cases*

The effective power was also monitored and the values are presented in Table 2.

Table 2
Values for effective power after the simulations with different gaps

Piston position [deg CA]	0.5 mm	1 mm	1.5 mm	2 mm
Effective power [kW]	87.975	91.899	88.058	76.122

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5. CONCLUSION

When trying to modify the squish motion of the air, all velocities and turbulences change inside the combustion chamber, therefore the performance of the engine differs.
Knowing the maximum velocity of the air inside the combustion chamber, the effective power of the engine was also monitored to see consequent modifications.
The maximum power of the engine was obtained at 1 mm gap. For a 1.5 mm gap the power was lower with 4.17% and for a 2 mm gap the power was lower with 17.16%. For a gap of 0.5 mm, the expected tendency of the power would be a small rise, but the simulation has shown a lower power with 4.26%, therefore the recommended value for the TDC gap is 1 mm.
Future studies will be made on the same engine to see the influence of the TDC gap and implicitly the influence of the squish on pollutant emissions.

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THE STUDY OF ENGINES FUNCTIONING BASED ON EXPERIMENTAL DATA

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Abstract: *The paper highlights the three important and inseparable aspects of the systemic approach of engines functioning and automotives dynamics: to take into account the human-vehicle-field interaction, to handle driving with algorithms specific to systems theory and experimental data analysis with algorithms specific to signal theory. Within the paper, systemic approach of engines functioning and automotives dynamics is based on experimental data obtained from tests, with the help of which it is analysed the dynamic and there are obtained movement mathematical models by using systems identification algorithms. Also, there are shown main methods for experimental data analysis, with the use of probability theory, information theory, correlation analysis and variance analysis; in addition, there are highlighted possibilities given by time analysis, frequency analysis and time-frequency analysis of data. Identification algorithms and analysis procedures assure automotives dynamics and fuel saving study by directly using experimental data or by using established mathematical models and applying concepts and algorithms specific to systems theory. Experimental data were obtained from tests with an electronic control automotive and using acquisition and storage equipment for data given by the on-board computer and taken by embedded sensors.*

Key-Words: *electronic control systems, main statistical characteristics, time-frequency analysis, vehicle engine*

1. INTRODUCTION

Up to present, the study of engine functioning has generated theoretical and experimental studies based on the knowledge of researchers and the practical possibilities for investigation at their disposal; moreover, the approaches were based on the technical level of the engine itself (classic or electronic control systems).

The theoretical developments in the various disciplines, the entry of investigative equipments becoming more and more efficient and the equipment of the engines with electronic control systems (on-board computer, embedded sensors and actuators) are the main factors which have influenced the techniques of the theoretical and experimental study of engines functioning [1][2][3][4][8][9][10].

2. EXPERIMENTAL RESEARCH

To register the functional parameters, during the experimental researches one can use the diagnostic testers, some of them shown in Figure 1: Opel (Figure 1a), Daewoo family (Figure 1b), Dacia Logan (Figure 1c) and Skoda, VW, Audi, SEAT (Figure 1d).

In consequence, the study of engines functioning based on experimental data presents at this point the following specific characteristics: it is a systemic approach, taking into account the action of the driver; it uses concepts and algorithms that have not been used in literature, but that belong to the system dynamics (neural networks, genetic algorithms, fuzzy, neuro-fuzzy algorithms, fractals, extremal analysis, symbolic analysis, tensor analysis etc.); it applies all three techniques to the processing of the experimental data (through the time analysis, frequency analysis and time-frequency analysis); it uses new algorithms and methods for the study of engine's dynamics and fuel saving; it approaches unitarily the whole operation by three inseparable components: identification (the establishing of the mathematical models based on experimental data), control and diagnosis [3][4][5].

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Figure 1. Testers for the acquisition and storage of data from on-board computer

Figure 2 and Figure 3 presents some results acquired from testing the Skoda Octavia car which was equipped with on-board computer and used both petrol and LPG (liquefied petroleum gas).
The graphs on the left side of Figure 3 show the values of engine speed *n* and the graphs on the right side show the values of the throttle shutters' position ξ, the last marking the engine load. The graphs from Figure 3b and Figure 3d show that during the experiments, when it performed normal movement, the engine operated at partial loads, so not the full load ξ = 100%. Figure 4 highlights some functional dependencies between the throttle shutters' position ξ and the engine torque M_e, with Skoda Octavia using petrol in Figure 4a and with Skoda Octavia using LPG in Figure 4b.

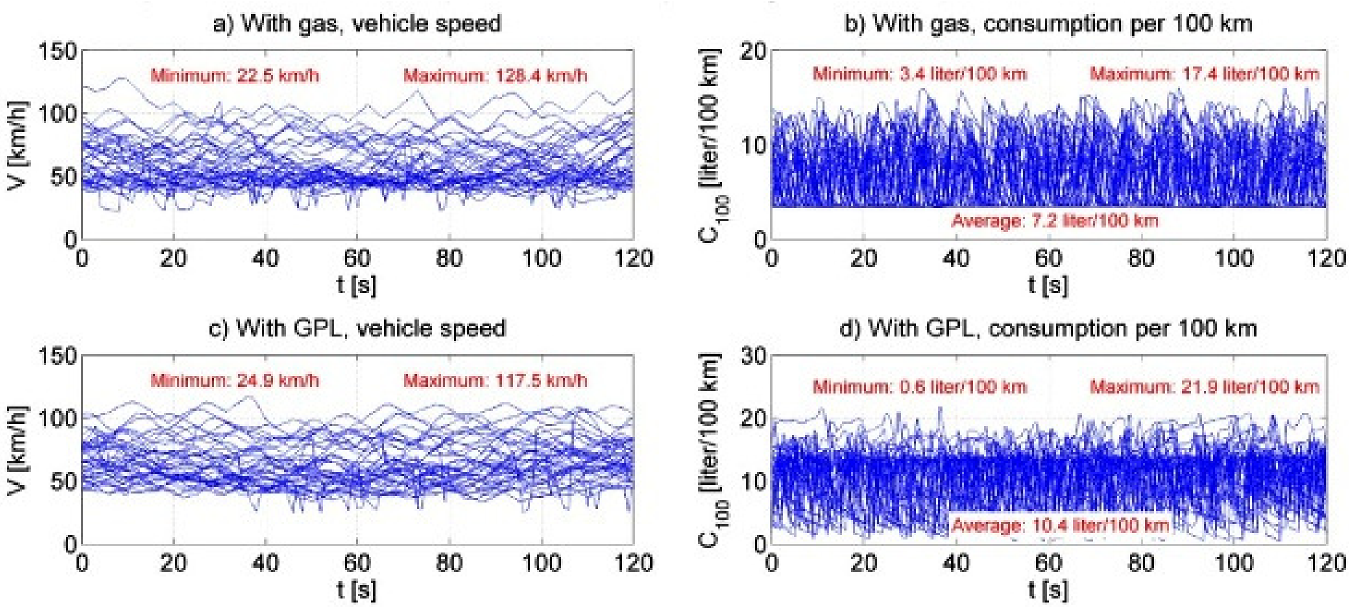

Figure 2. Speed and fuel consumption per 100 km, 40 samples with gas and 40 samples with LPG, Skoda Octavia car

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Based on the experimental values, one can calculate the main statistical characteristics of the first order that are frequently used in literature, as shown in Figure 5 for the speed belonging to a sample with petrol (Figure 5a) and a sample with LPG (Figure 5b) of a Skoda Octavia car.

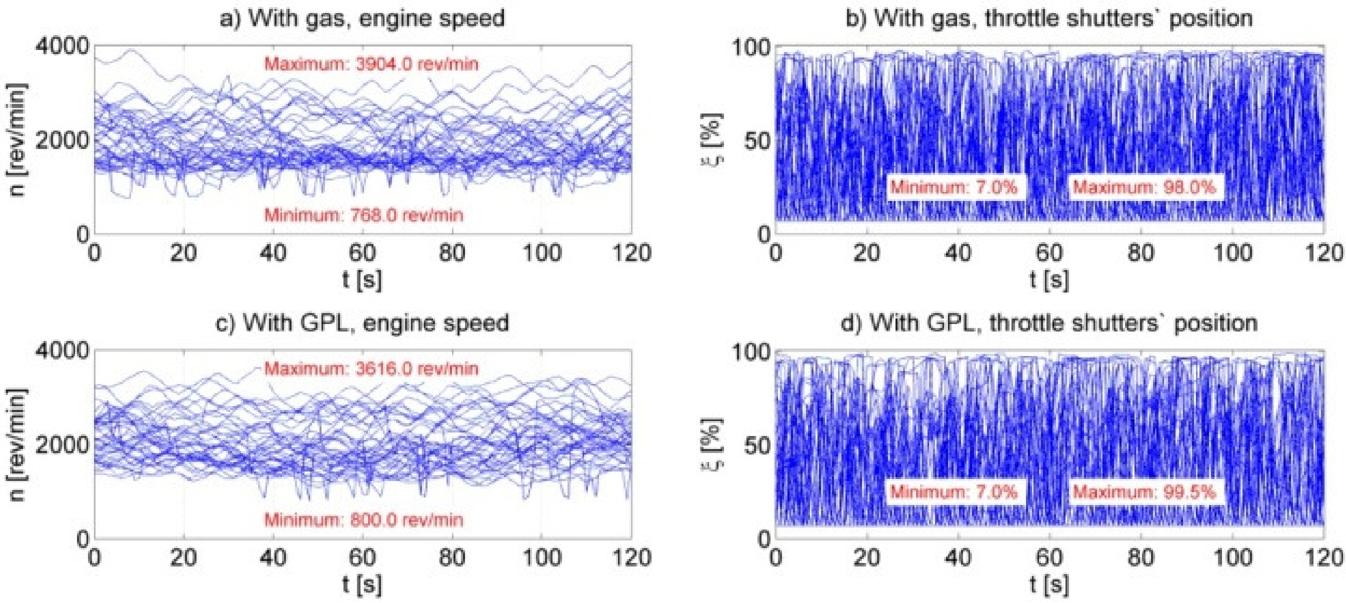

Figure 3. Engine speed and throttle shutter's position, 40 samples with gas and 40 samples with LPG, Skoda Octavia car

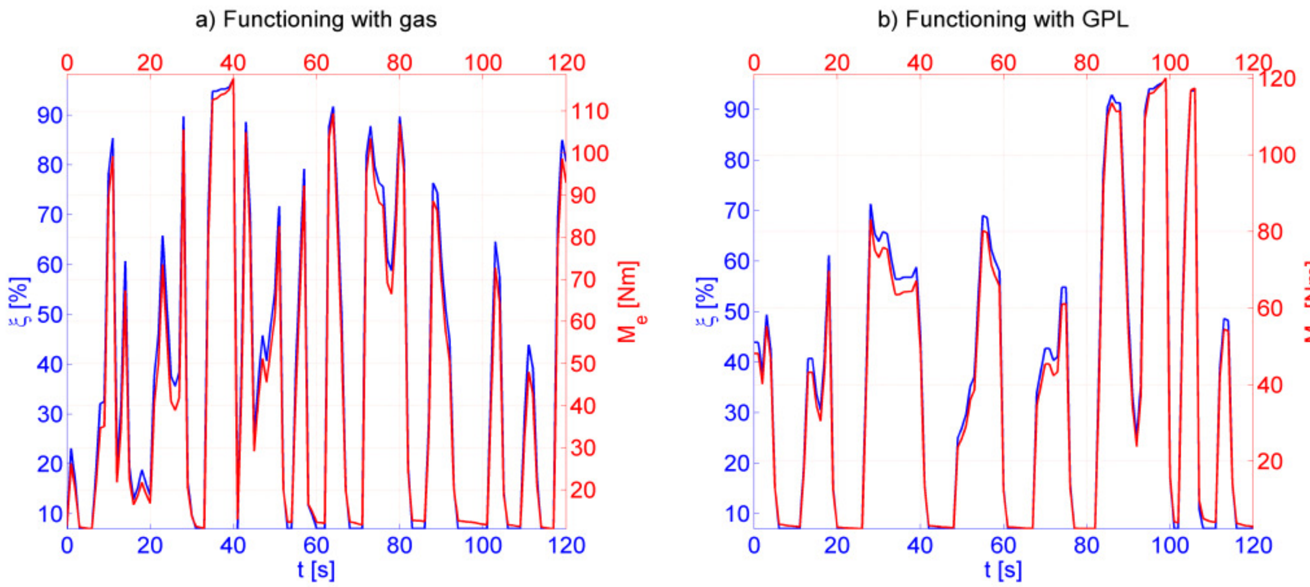

Figure 4. Throttle shutter's position and engine torque, SB12 sample with gas and SG12 sample with LPG, Skoda Octavia car

The graphs in Figure 5 shows, in addition to known parameters (average, variance, standard deviation, coefficient of variation etc.) others used in statistics and electronic control, such as norms of measurements; in electronic control there are being used the H_2 algorithm (which uses rule 2) and the H_∞ algorithm (which uses infinite norm).
Also, on the basis of the experimental data there can be estimated the fuel consumption required to achieve a required average speed, as shown in Figure 6.
Indeed, for example, from Figure 6 it results that in order to achieve an average speed of V_m = *60 km/h* there is required a mean fuel consumption c_{100m} = *4.22 liters/100 km* of gas, or c_{100m} = *5.95 liters/100 km* of LPG, meaning a 41% increase.

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In the graphs of Figure 6 there are shown the experimental values, the trends in the targeted addiction and the 95% confidence intervals.
Figure 7 shows the densities of probability of the engine's torque M_e for eight experimental samples, of which four are with gas (upper graphs) and four are with LPG (lower graphs).
These graphs show that the torque is not subject to the law of Gauss for normal distribution, the curves are not symmetrical to their maximum and present more than one peak.

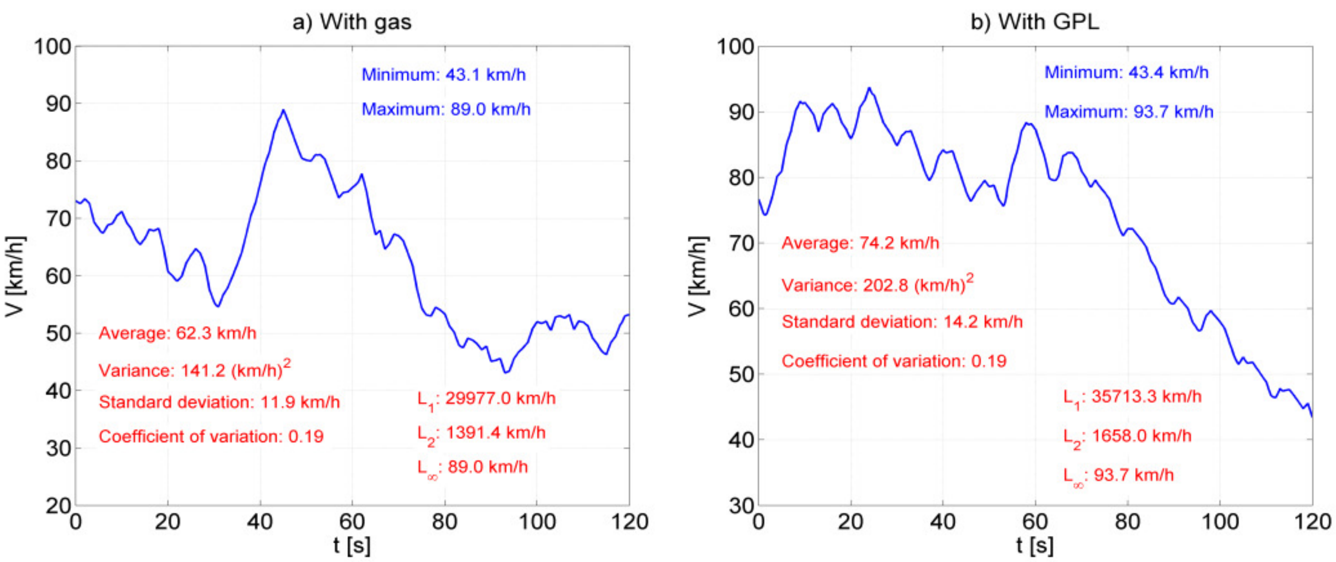

Figure 5. Main statistical characteristics of the first order of speed

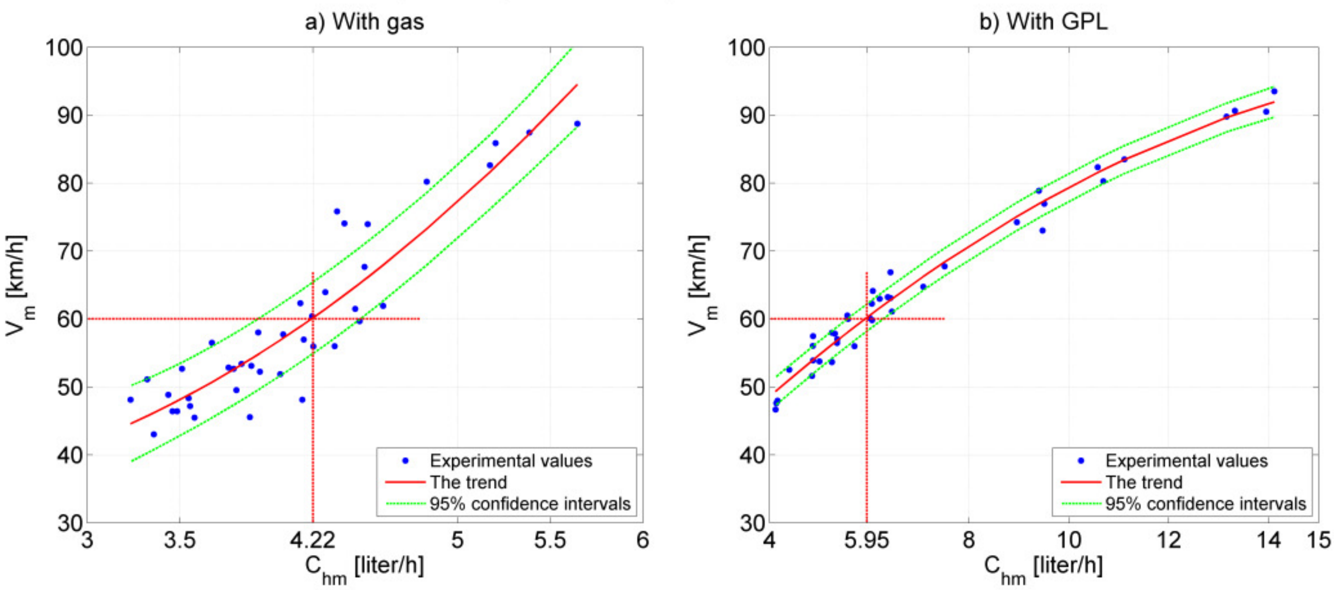

Figure 6. The estimation of the average consumption to achieve a required average speed, 40 samples with gas and 40 samples with LPG

Processing all the experimental data obtained from tests has led to the conclusion that no functional size is subject to the distribution laws, frequently used in classical statistics (Gauss, Weibull, exponential, logarithmic etc.), which requires stochastic analysis of engine functioning, for example by using the bootstrap algorithm [5].
Also, processing the experimental data has shown that dependencies between sizes are emphasized in a non-linear manner; this aspect can be confirmed by applying the correlation analysis, the coherent analysis and the bispectral frequency analysis [4][6][7][8].

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For example, the bispectral frequency analysis, which uses the rank III cumulant, establishes the bispectral of any discrete dynamic series $y^{[n]}$:

$$S_{3y}(\upsilon_1,\upsilon_2) = \sum_k \sum_r C_{3y}(k,r) e^{-j2\pi\upsilon_1 k} e^{-j2\pi\upsilon_2 r} \quad (1)$$

in which
$k \in (-\infty,\infty),\ r \in (-\infty,\infty)$.

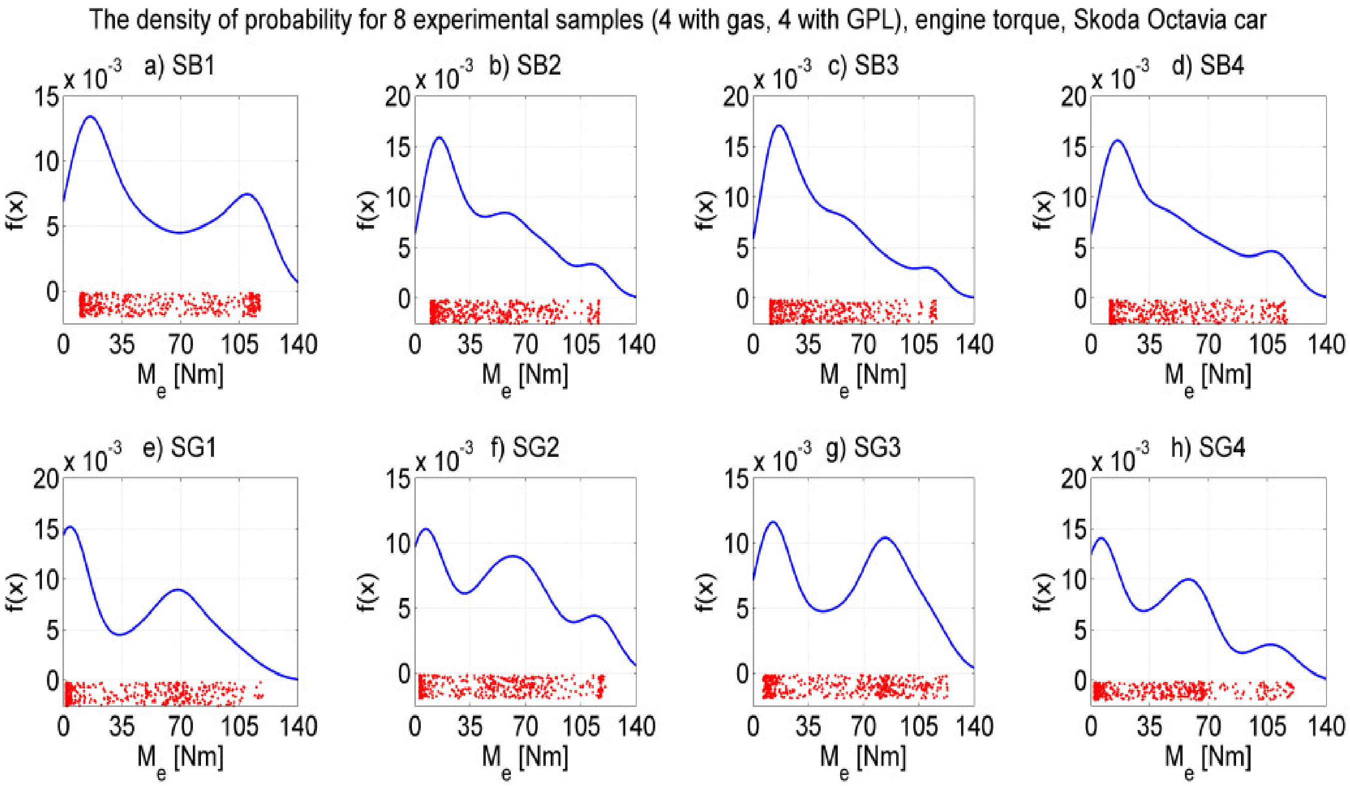

Figure 7. The estimation of density of probability for 8 experimental samples, the engine torque

The rank III cumulant is determined with the ratio:

$$C_{3y}(k,r) = M\left\{ y^*[n]\, y[n+k]\, y[n+r] \right\} \quad (2)$$

which represent an extension of the classical autocorrelation function; the sign "*" is the complex conjugate of the discrete dynamic series $y^{[n]}$.
In formula (1), the frequency bandwidth ν_1 is assigned to the linear constituent and ν_2 is the frequency bandwidth assigned to the non-linear constituent.
For example, Figure 8 shows the results of the engine power bispectral analysis from one experimental sample; because the images from Figure 8b, Figure 8c and Figure 8d are not empty, the engine power dynamic series also contain a non-linear constituent.
The most important consequence of this aspect is that the engine's functioning has to be described by non-linear mathematical models.
The unsteady character of the engine's functioning confirms itself through a time-frequency analysis of experimental data [4][10].
The time-frequency analysis uses different Cohen transforms, wavelet transforms, Stockwell transforms etc.

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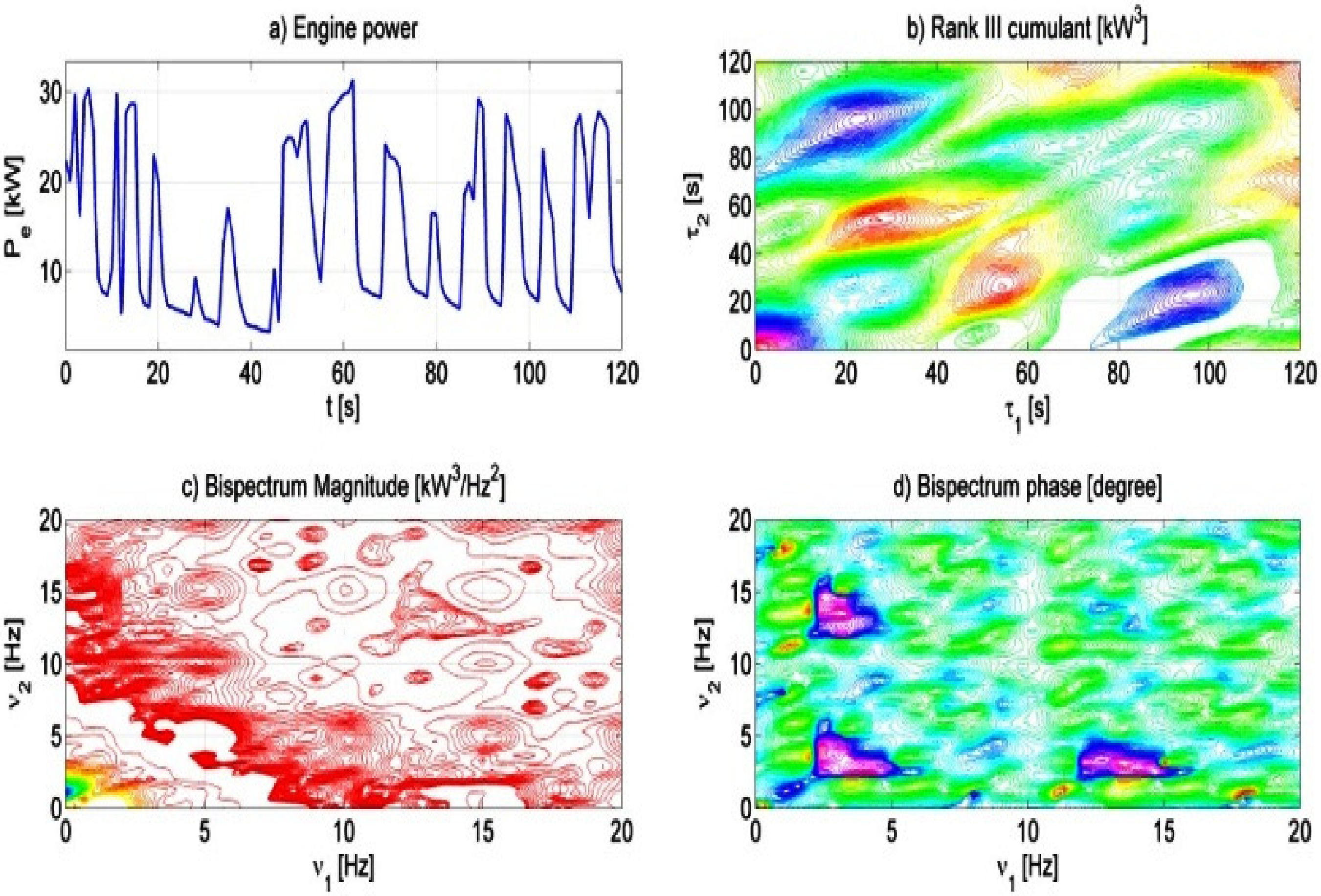

Figure 8. The bispectral analysis of the engine power, SB23 sample with gas

Therefore, for example, the Stockwell transform which represents an extension of the wavelet transform, through a phase correlation, is defined by the ratio [4][10]:

$$Y(\tau, j\upsilon) = \int_{-\infty}^{\infty} y(t) \frac{|\upsilon|}{\sqrt{2\pi}} e^{-\frac{(t-\tau)^2 \upsilon^2}{2}} e^{-j2\pi\upsilon t} \, dt \tag{3}$$

in which the expression that marks the wavelet extension is (t, τ – time, ν– frequency):

$$\varphi(\tau, \upsilon) = \frac{|\upsilon|}{\sqrt{2\pi}} e^{-\frac{(t-\tau)^2 \upsilon^2}{2}} e^{-j2\pi\upsilon t} \tag{4}$$

Figure 9a presents the analysis in classical frequency, which uses the Fourier transform (the graph presents the relative amplitude, that is the current value divided by the maximum value of the amplitude), and Figure 9b presents the time-frequency analysis using the Stockwell transform.
As can be seen from Figure 9b, only the time-frequency analysis shows the time layout of the harmonic constituent with high energy application.
The graphs from Figure 9 show two frequency values (2.4 Hz and 5 Hz) at which the Fourier amplitude has two peaks; Figure 9c shows the instantaneous values for the amplitude.

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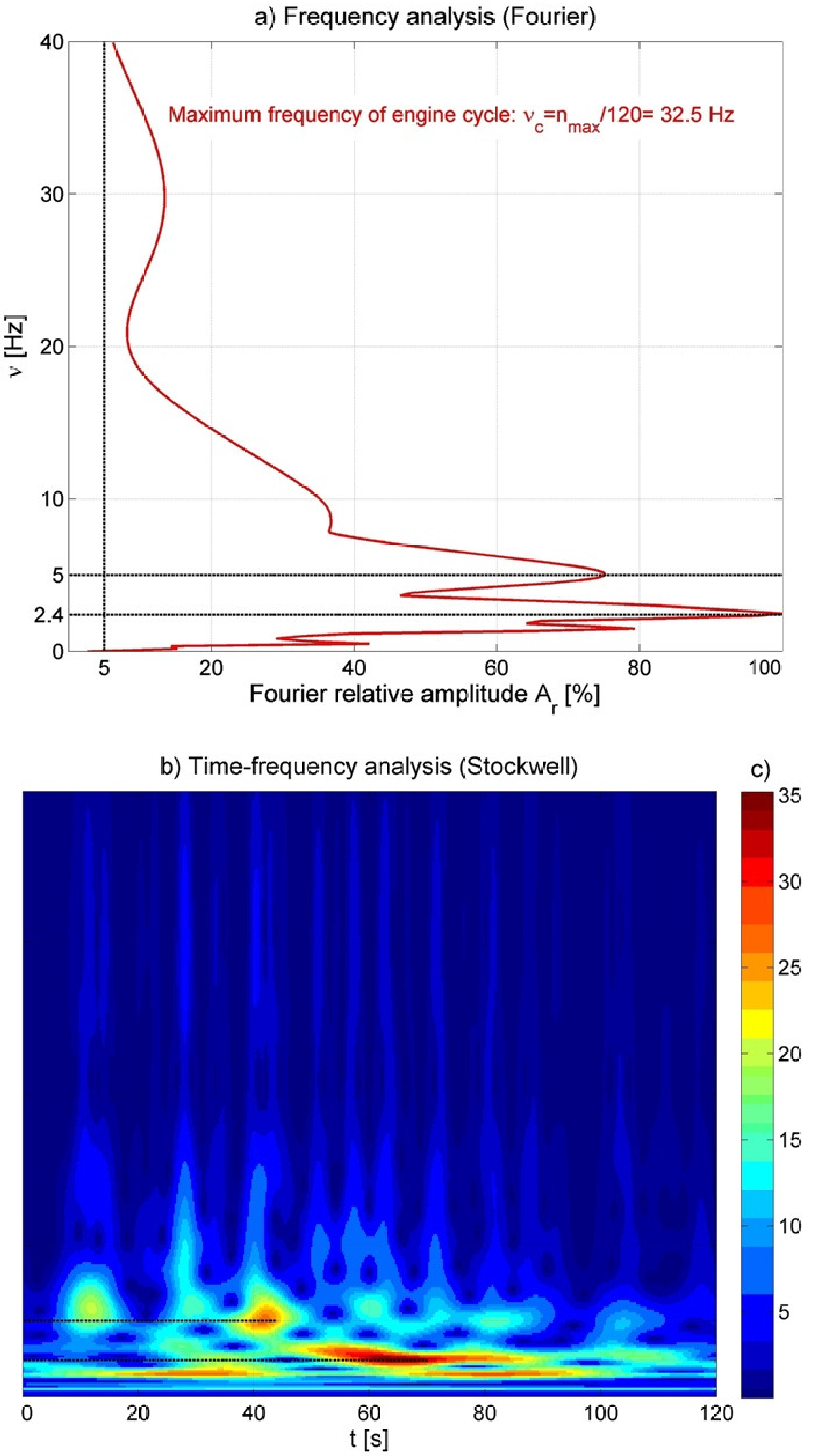

Figure 9. The spectral analysis (in frequency and time-frequency) of the engine torque

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3. CONCLUSION

The study of engines functioning based on experimental data implies using all three techniques to the processing of the experimental data (through the time analysis, frequency analysis and time-frequency analysis) and also using new algorithms and methods for the study of engine's dynamics and fuel saving.
On the basis of the experimental data there can be estimated, for example, the fuel consumption required to achieve a required average speed etc.
Also, based on experimental data we can establish mathematical models of engine functioning, including the analytical expressions of their static characteristics [4][9].
In conclusion, the most important aspect is that the engines functioning has to be described by mathematical models with unsteady time coefficients, for example by using neural networks or neuro-fuzzy algorithms.

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A DEVELOPMENT OF THE VALIDATION SYSTEM OF INDIRECT TPMS

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Abstract: *Indirect tire pressure monitoring system (ITPMS) uses only the software which is embedded in the electronic stability control (ESC) to determine whether the low-pressure of the tire. Because they do not use a sensor, unlike the direct TPMS, there are advantages that can greatly contribute to cost reduction and weight reduction of the vehicle. ITPMS uses a radius analysis and frequency analysis to determine whether the low-pressure of the tire. In case of the radius analysis, the relative change is measured in the radius of the running of the tire according to the change in pressure. Thus, in the case of 1-3 low pressure of the tire, which is accompanied by the wheel difference, it is possible to detect a low pressure. On the other hand the case of the low pressure four wheels, all four wheels cannot be detected by the low pressure conditions using the radius.*
To overcome the disadvantages of this radius analysis method, we use a frequency analysis.
Because of the above-described technical features, ITPMS can only determine whether the low pressure when the vehicle is driving and receives a great influence on the tire and the driving environment. As opposed to using the hardware in the loop simulation (HILS) to verify the effect of the plant and the environment for a typical chassis system, because making the tire model to simulate the non-linear characteristics and the frequency characteristics according to the driving mode of the tire is difficult, the implementation of HILS is not easy.
In this study, we introduce the verification system for verifying effectively on the process of developing ITPMS. We'll investigate developments such as the process of converting to the verification data by using the data measured via actual vehicle traveling, building test data management system to systematically manage the data, building model in the loop simulation (MILS) environment using a parallel processing system for verifying the developed software, simulators for verifying ITPMS performance on the hardware.
We can develop ITPMS effectively through the Verification Process on the basis of the above.

Key-Words: *Indirect tire pressure monitoring system, MILS, simulator, test data management.*

1. INTRODUCTION

By recall cases of Firestone tires and Ford, the US government mandated that ensure the stability of the tire with a tire pressure monitoring system (TPMS) in the car [1]. TPMS legislation of the US government made TPMS legislation of countries such as EU, Korea legislated. The China government also plans to be a duty on vehicles equipped with TPMS [2]. Because appropriate air pressure of the tire is significantly affect the fuel economy of the vehicle in order to improve fuel economy [3], vehicles must inform the air pressure to the driver for maintaining properly the air pressure of the tires. By the two reasons described in the above, in original equipment manufacturing (OEM) it is a trend that vehicles are equipped with TPMS mandatorily [4]. TPMS technique is divided into direct method that uses a sensor and indirect method that does not use a sensor. Since it is getting competitive in the automotive market, OEM want to lower the cost of a vehicle equipped with indirect TPMS on vehicles of less than C segment [5]. Hyundai Autron, Hyundai Mobis and Hyundai Motors did a mass product by developing ITPMS. This paper introduces the equipment and validation process to establish effective verification of ITPMS in the process of developing indirect TPMS and to explain the effect.

2. RELATED WORK

2.1. Indirect TPMS

ITPMS is only software that is embedded in ESC for monitoring the air pressure of the tire without any machine or electronic components.

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The car mounted with ESC has a wheel speed sensor to measure the wheel speed of each wheel. ITPMS checks the air pressure of the tire using wheel speed sensors value that is the input data of the radius analysis and frequency analysis [6].
In case of the radius analysis, the relative change is measured in the radius of the running of the tire according to the change in pressure.
Thus, in the case of 1-3 low pressure of the tire, which is accompanied by the wheel difference, it is possible to detect a low pressure.
There are two kinds of methods for the radius analysis such as using the difference in wheel speed [7], creating a dynamic model of the vehicle with the adaptive filters [8].
On the other hand the case of the low pressure four wheels, all four wheels cannot be detected by the radius analysis that uses the relative changes.
To overcome the disadvantages of this radius analysis method, we use a frequency analysis.
The frequency analysis determines whether the low pressure by detecting a frequency variation of the tire caused by the pressure difference. In other words, the frequency is lower than normal pressure balloon tire. Therefore, frequency analysis unlike the radius analysis can easily detect low pressure four wheels.
Frequency analysis method is how to extract the frequency range of interest by using the fast Fourier transform (FFT) [9], making the tire model with adaptive filter [8] and zero crossing algorithms for counting whether to change the code after passing through the signal processing [10].
Figure 1 shows the ITPMS main concept.

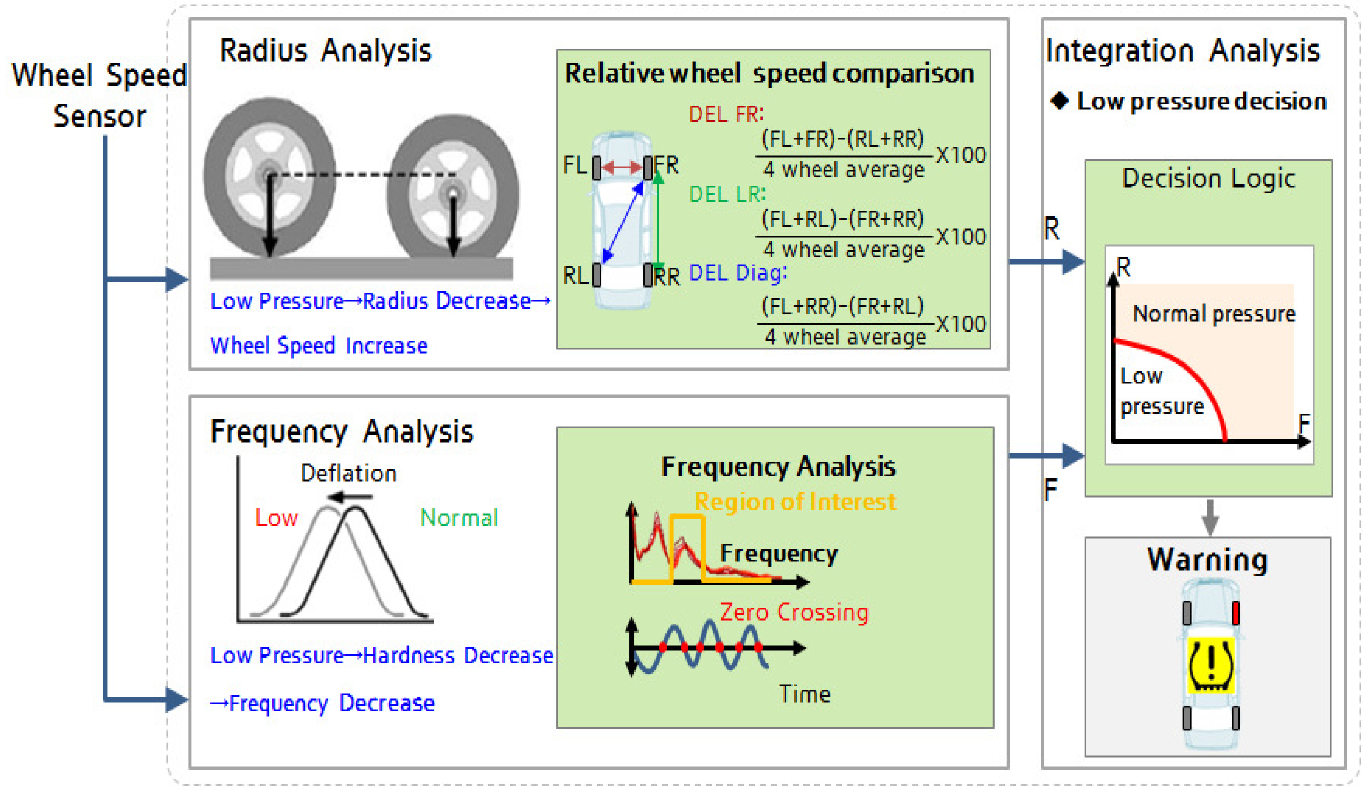

Figure 1. ITPMS Main Concept

2.2. ITPMS evaluation equipment

ITPMS evaluation equipment is divided in two methods such as using the plant model of the vehicle and the tire, using the data acquired from the actual vehicle. The method using the plant model of the tire and the vehicle has the advantage of being able to try a variety of driving environments for validation [11]. However, there is a disadvantage of less validity for vehicles and tires from the actual vehicle development stage. Therefore, in the actual vehicle development step it is required to be the operation for acquiring the verification data from the actual vehicle and the tire.
But there are few related researches.

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3. STRUCTURE OF THE PAPER

In Chapter 4 we brief overview about the process and equipment to verify the ITPMS. Chapters 5 is to learn the system for managing obtained data from the vehicle and in chapter 6, by using the acquired data, we look at the server-based verification and MILS environment for the tuning method. In chapter 7, by using the obtained data, we investigate the simulator to verify ITPMS on the actual hardware.
Finally, chapter 8 shows a tool to support ITPMS verification process and the reliability test result.

4. ITPMS VERIFICATION PROCESS AND EQUIPMENT

4.1. Process

ITPMS is operated based on the vehicle driving data. Analyzing the test results or actual data need no distortion to the experiment, and also requires a lot of time.
An effective development process is necessary in order to develop in a short time.
We made a process and conducted developing according to the process (Figure 2).

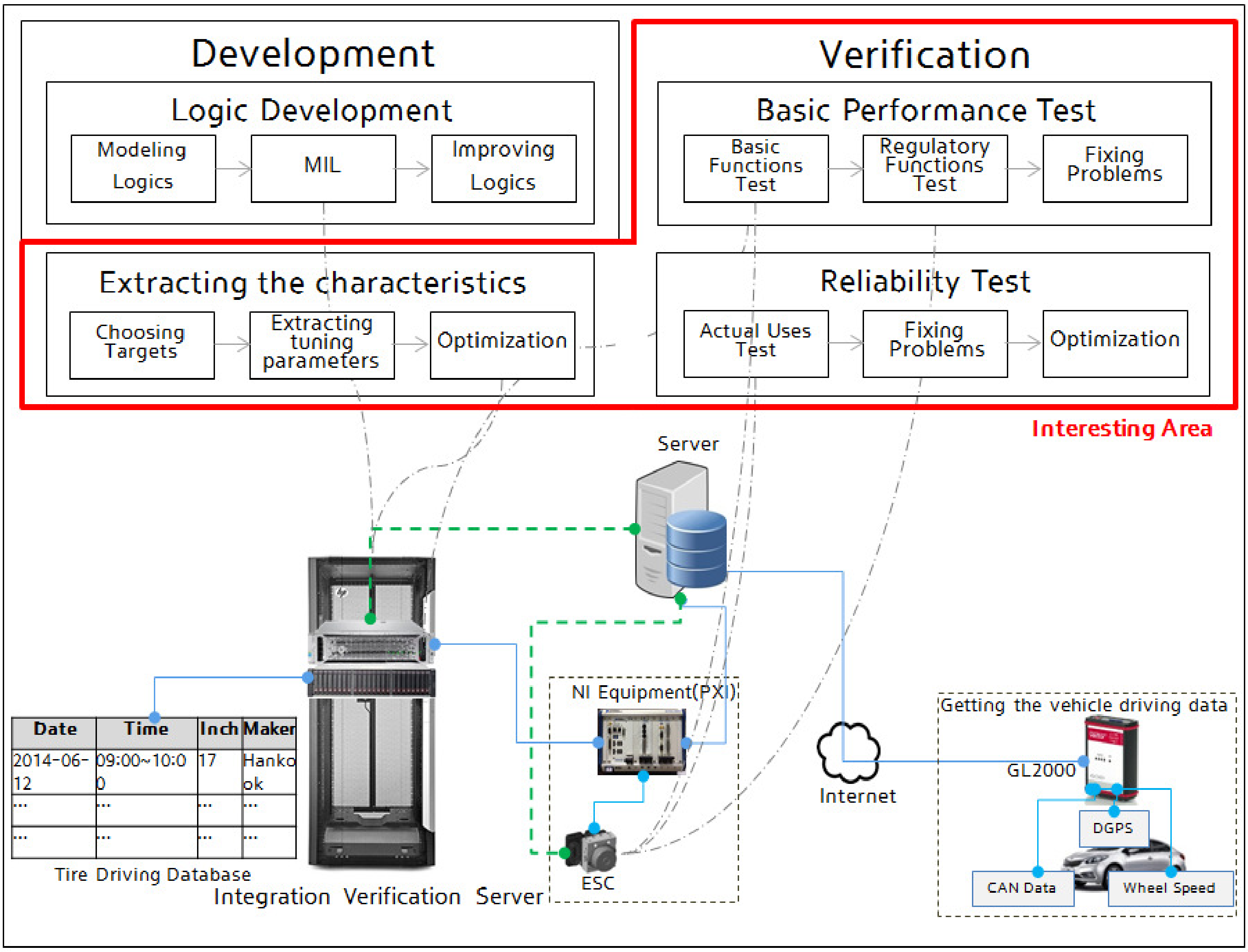

Figure 2. ITPMS Development & Verification Process

ITPMS is developed and validated in three stages:

- Extracting the characteristics: In the test for extracting the characteristic values of the tire, we extract the tuning parameter for all tires mounted on a vehicle. The tuning parameter is used to calibrate the threshold of low pressure decision. For example, if the A vehicle can be equipped with the five kinds of tires, we measure the data from the vehicle through the test mode by mounting each tire in a vehicle to extract the characteristic of the tire. By using the measured data, the tuning parameter optimization based on the verification server to be described later is performed.

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- Basic Performance Test: Once extraction is complete, to confirm the basic performance and regulatory performance a real vehicle test is conducted. Not to test all tires, we choose edge-tiers that mean having insensitive or sensitive characteristics and test them. The test can be performed for all tires mounted on the vehicle. However, because of many resources and time consuming, the test cases are made with respect to the peculiar tire characteristics. If a problem occurs in the basic performance testing, tuning operations carried out again.
- Reliability test: After the basic performance is secured, considering the variety of actual use in real road conditions, we conduct a test for reliability verification.

If a problem occurs similarly in this case, we solve the problem through the tuning. It is difficult to carry out the test again when problems occur because of a lot of resources and time consumption. For this reason, we acquire the vehicle data from each test. If problems occur, using the acquired data without performing again the test is repeated by using the simulator described later and the verification server.

4.2. Equipment

ITPMS verification equipment is consisted of three modules. The first is a data acquisition device attached to the vehicle which transmits data of the vehicle to the server. The second is to manage the data collected by the data acquisition device as ITPMS verification server, and performs tuning and verification based on the data obtained and ITPMS model. Finally ITPMS simulator that uses the obtained data is performed for the verification on the ITPMS hardware.

5. THE DATA ACQUISITION DEVICE

ITPMS necessary data is a counter value of the wheel speed sensors, vehicle driving information (Brake signals, acceleration, engine torque, Yawrate etc.), global positioning system (GPS) information. We use vector GL2000 to obtain all of above information. GL2000 is equipment that can have CAN channel, GPS signal. The driving information of the vehicle is acquired through the CAN, and the wheel speed sensors of the vehicle are obtained at ESC controller via a high speed CAN.

Data acquisition is completed and is transmitted to the ITPMS verification server using the long term evolution (LTE) modem.

6. ITPMS VERIFICATION SERVER

6.1. Data Management Environment

The data from the obtaining apparatus is collected by ITPMS verification server. The collected data with the test information which tester made is recorded into the database. CAN data which has driving information and the wheel counter value of the vehicle after the reading is completed, is respectively converted into a data format that can be performed in the data format that can be implemented with the simulator and the verification server.

6.2. Verification server environment

ITPMS verification server is made of the parallel computing environment to perform the tuning parameters and verify ITPMS functions. The work environment is consisted of MATLAB and Simulink of MathWorks.

In case of a need to use all of the acquired data to perform a tuning or verification, because car data is so much larger data capacity, the efficient parallel processing is required to perform the tuning and verification. For such parallel processing in hardware the verification server is composed of one server and four workstations that perform the verification practically and by using the parallel tool box of MathWorks performs parallel processing in software.

6.3. Tuning and verification

As it described in process, we extracts the necessary data by using the test data to extract the characteristic of the tire. The data to be extracted is a reference value for determining the low pressure and a corrected value that is used in the radius analysis.

We obtain the respective data by each tire and set a representative value that can covers the tire to be mounted on the vehicle by using a statistical technique.

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In this way using the parameters and the acquired data, the basic performance and the reliability test is performed for verifying that the ITPMS accurately determines the low or normal condition.
At this time, using the receiver operating characteristic (ROC) charts we track whether MISS ALARM and FALSE ALARM appear in ITPMS.

7. ITPMS SIMULATOR

7.1. Scope of the simulator

When verifying ITPMS with the 20 ~ 30 thousand km driving data, using the parallel computing takes about 3 hours. Therefore, even when the tuning parameters or ITPMS software is changed, by using the verification server, there is no great burden.
However, in order to verify ITPMS on the hardware, because the simulator has to enter the data in real-time, it cannot be verified for all the input data as ITPMS verification server.
In case of using ITPMS simulator, we make test cases using a limited ITPMS data to verify the malicious running mode or fault diagnosis and verify them.

7.2. Configuration simulator

The ITPMS simulator (Figure 3) was configured using PCI extensions for instrumentation (PXI) of National Instrument (NI). It can perform a simulation with up to two ECUs.
Using the digital board to simulate the wheel speed sensor input data, and uses the CAN card and a digital input/output card to simulate the CAN and IG ON / OFF, Brake signal.
The simulator carries out in the fault diagnosis mode and the verification mode for verifying the general performance.

Figure 3. ITPMS Simulator

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8. CONTROL TOOL AND EXPERIMENT

We can proceed according to the simulator control, data management, test cases generation, validation result management by a tool to support the ITPMS development process.
In the data management mode, it transforms the raw data acquired in the vehicle to the data format for the test environment and stored in the database.
Based on the stored data and generates a test case for the test purpose. Test cases written in the script form can dynamically have a variety of test items.
Once the verification is complete, the report documents are automatically generated and the generated document is written to the database easier to manage history.
Because of the difficulty of the same experiment in the vehicle, a simulator is extremely useful.
However, if the results are different, the simulator cannot be used.
We compared to the output of the vehicle and performed a test of repeatability in order to verify that the output values are same.
Figure 4 shows that the wheel speed value of vehicle and simulator is same.

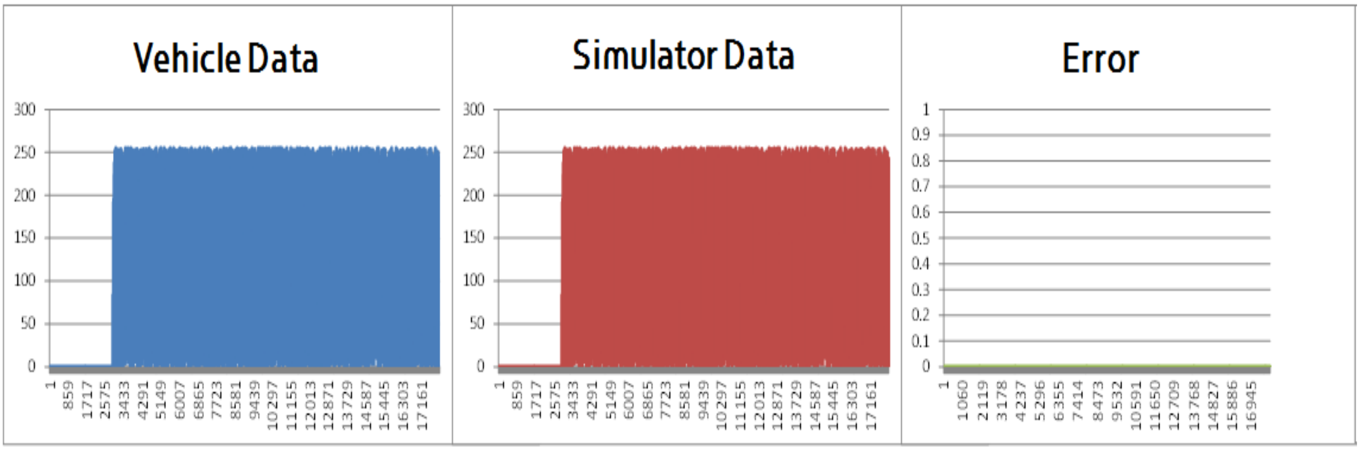

Figure 4. Comparing the wheel speed value of ITPMS simulator and a vehicle

According to the test results, it was confirmed that the simulator outputs the same result.
However, even though we control with the same clock, as a physical limitation between the simulator and the ECU, an error occurs in the portion where the pulse occurs at the same time.
It was confirmed that the range of small errors that do not affect the result.
The following is a data comparing the results of testing important factors for determining the low-pressure value.

Table 1.
Errors between a vehicle and a simulator

	Del FR	Del LR	Del Diag	Fre FL	Fre FR
Vehicle	0.36	0.36	0.19	36.5	44.16
Simulator	0.36508	0.35186	0.20016	36.4827	44.131
Error	0.00508	0.00814	0.01016	0.0173	0.029

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Del FR, Del LR and Del Diag represent the difference of the left/right, front/rear and diagonal of each wheel. Fre FL/FR indicates the frequency value of the front wheel.
By relative standard deviation (RSD) method, factor analysis results show the RSD values of Del FR, Del LR, Del Diag is less than 3%, RSD value of Fre FL/FR that needs for precise comparison is less than 1% (Table 2).
It means that there is no problem as the performance evaluation simulator.

Table 2.
Errors of repeatability tests

	Del FR	**Del LR**	**Del Diag**	**Fre FL**	**Fre FR**
Average	0.36508	0.35186	0.20016	36.4827	44.131
Standard deviation	0.006356	0.002447	0.005914	0.021302	0.033516
Error(100%)	1.741197	0.695535	2.95513	0.05839	0.075947

9. CONCLUSION

By the above construction of process and verification equipment, we can effectively do the ITPMS development and validation.
If we received a simple change requests from OEM or tier1, it takes more than a month without building the verification process and equipment.
We can reduce the development period to a week by the solution about the process and equipment.
Also by utilizing the existing accumulated data, the quality of ITPMS was a remarkably improved by performing verification for the modified software.

This work was presented at the International Congress of Automotive and Transport Engineering, CONAT 2016, Brasov, Romania and it was published in Proceedings of the Congress (ISSN 2069-0401).

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EQUIPMENT AND METHODS USED FOR EVALUATION OF VEHICLE'S SYSTEMS VIBRATIONS ON ROUGH TERRAIN

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Abstract: *Whatever the purpose of research in the automotive area, a decisive role in obtaining relevant and compelling data on research is given by the test equipment, the data acquisition, and methods chosen for their achievement. Mechanical vibrations, especially those arising upon reading this of trails highly rough, in which amplitudes are of very high or are perceived for long periods of time, causes the serious damage to the human body: biological, mechanical and psychical. Obtaining accurate data concerning vibrations and shocks products in an area of rough terrain, as well as understanding thereof, it creates the possibility of establishing new technological approaches which to lead in reduce injuries caused by them on the human body.*

Key-Words: *Vibrations, data aquisition, equipment.cmd*

1. INTRODUCTION

Multiple researches on the influence of mechanical vibrations generated by the road surface and the suspended structures of vehicle that act on the human body, have demonstrated the importance of knowledge as accurate of their manifestations [1].

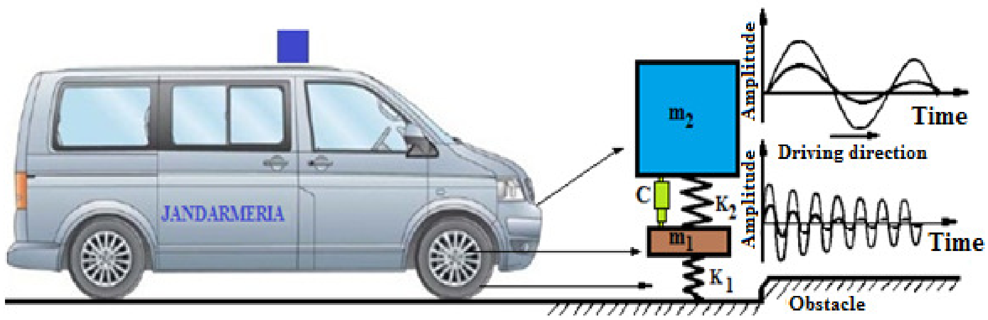

Figure 1. The depreciation's influence over the suspended and unsuspended masses [2]

Research objectives are related to the selection and use of some equipment and programs according to the research activities proposed to be conducted. The intended purpose of the research is to obtain real and cogent data on the vibration values that affect the human body during high speed travel on rugged terrain. In Figure 1 it is presented the theory of operation of a vibration damper on a vehicle.
As a result of approach to some rough trails, the equipment must allow to obtain real values of existing vibration, for the sprung (suspended) and unsprung masses of the vehicle.

2. EQUIPMENT USED FOR AQUIRING THE DATA ON RUGGED TERRAIN

The equipment chosen for the research was carefully selected, in order to serve as much as possible to purposed scope [3][4]. Also, its installation was carried out in accordance with the specific needs of research, so that it can record data about the conformation of the route followed, the accelerations induced by route and the vibration transmitted to the seat and driver.

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Figure 2 illustrates the general layout of the seats and data acquisition equipment (orange markings), installed on the test vehicle - VW T4.

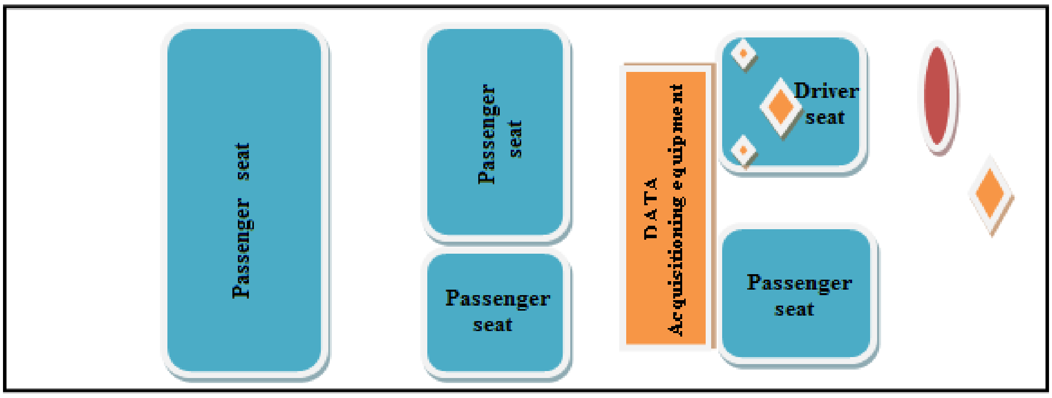

Figure 2. Location of seats and equipment in the vehicle

Figure 3. GPS antennas and their position on the vehicle's roof

The equipment used in experiment is described below:

- To identify the vehicle position and to register the track it was used a "SpeedBox" system produced by Race-Technology - the system consists in a GPS reception with two antennas, an inertial measurement unit and a data processing module. Figure 3 shows the mounting position of the Speedbox unit on the vehicle roof. Speedbox is used also to determine the vehicle attitude, measuring the pitch, yaw and roll rates of the vehicle.
- Two GPS receiver are installed in front and rear of vehicle roof, as a backup solution for Speedbox (type DL-10 [0]) which provides a PVT solution (position, velocity, time).

Figure 4. PicDAQ - Inertial Measurement Unit

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- The accelerations on three axes are measured with PicDAQ systems mounted in front of vehicle and also on the floor, approximately in the vehicle's center (Figure 4). These units are supplemented with another complementary accelerations measurement unit, named Loka [5] (Figure 5).
- To obtain the values of vibrations transmitted to the seat structure and the driver of the vehicle, there were used sensors of type 4504 A mounted on the seat frame structure and a type 4447 sensor positioned on the surface of the chair seat (Figure 6).

Figure 5. PicDAQ, DL-10 and Loka units mounted on vehicle's floor

Figure 6. Installation of vibration sensors type 4504 and 4447

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In any travel regime and also on any type of road, the displacement of vehicle is accompanied by the appearance of vibration and shocks.
The unevenness of the track creates shocks on the wheels, which are converted into oscillations at different frequencies by means of the tires and suspension.
It is subsequently transmitted to the frame of the vehicle and from there to seats and passengers.

3. METHODS FOR VIBRATION EVALUATION

During off-road driving, the speed varies according to the slope, steering angle, existing weather conditions, so that multiple oscillations with different frequencies and amplitudes are perceived.
The route analyzed in the study followed a road with pronounced rough sectors (Figure 7).

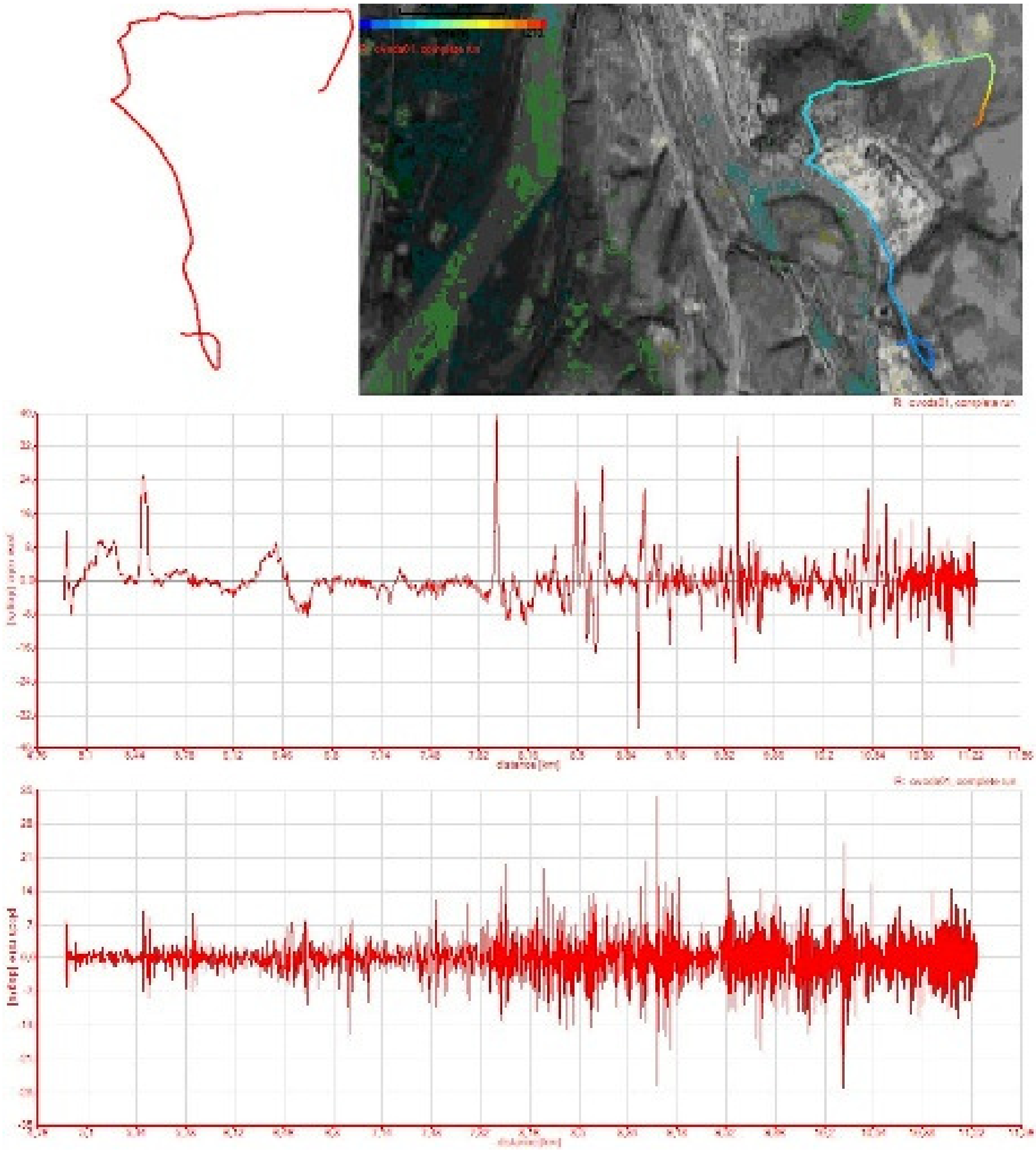

Figure 7. The analyzed route and vertical profile of the track, measured with Speedbox

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The route analyzed in the study followed a road with pronounced rough sectors (Figure 7).
Data received from the GPS antennas allow the correct identification of the route followed during driving and those received from the tri-axial accelerometers have identified the characteristics of the land. Figure 7 shows the route taken and also data related to the variations of terrain characteristics (yaw, pitch) [6]. In Figure 8 it can be observed the level variation of the terrain along the whole length of the route, recorded using the GPS system.

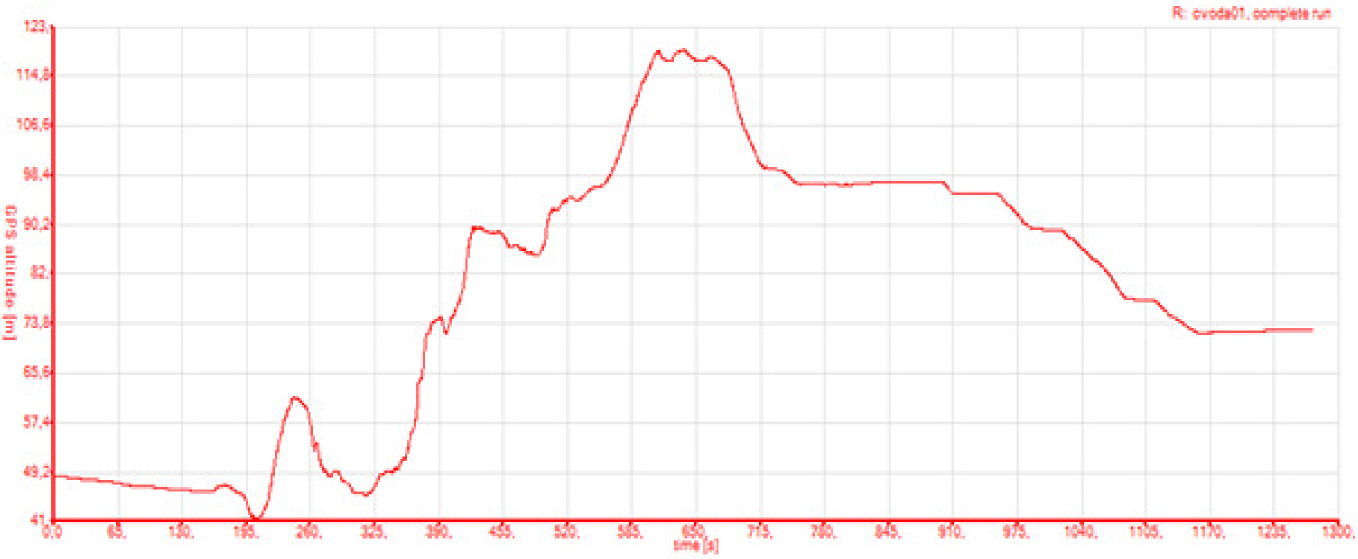

Figure 8. The variations of elevation in terrain, recorded via GPS receivers

Figure 9 shows the high values of vertical accelerations *vs*, the vehicle's speed, measured on the entire length of the route. The information related to the position and speed of the vehicle is collected using the GPS based data acquisition system, DL-10, installed in front and rear of the vehicle roof.

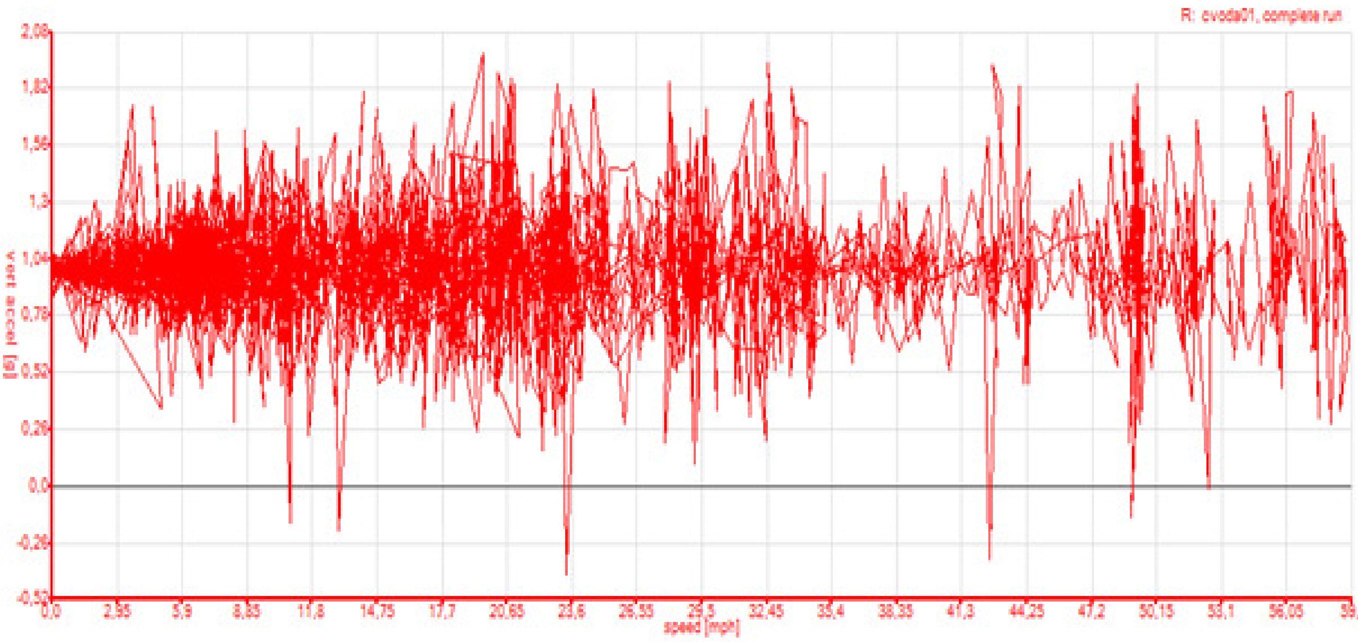

Figure 9. The values of vertical accelerations, as a function of vehicle speed (Speedbox)

Data recorded consist in NMEA sequences, stored in in text files on a SD-card.
The standard NMEA 0183 provides the requirements for the electrical signal and data transmission protocol, on a serial data bus, between the GPS receiver and another device.

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The DL-10 system uses a single type of NMEA sequence: "GPRMC". This sequence contains a minimum data, PVT (position, velocity, time) recommended for determining the solution, based on the received GPS signal.
A sample of the received sequences is given below:
$GPRMC,095145.100,A,4420.0085,N,02804.0713,E,0.00,327.15,130516,,,D*60

Table 1.
GPRMC fields

Field	Description
$GPRMC	The identifier
095145.100	Time (hour, minute, second, milliseconds)
A	Active signal
4420.0085,N	Latitude, North
02804.0713,E	Longitude, East
0.00	Speed in knots
327.15	Course (direction of travel) in degrees, relative to North
130516	Registration date
D*60	Checksum

In order to determine the existing vibrations on the driver's seat and also to find the values transmitted to the driver's body, when driving in rugged terrain, there were used two piezoelectric tri-axial vibration sensors, type 4504-A, mounted on the metal structure of the seat, and a sensor for measurement the vibration transmitted to the human body, type 4447, installed on the seat, under the driver.
Both products are manufactured by Brüel & Kjær.
A sample of data recorded using the sensor 4447 is shown in Figure 10.
As a result of driving the vehicle in rugged terrain, using the carefully selected equipment, there were obtained relevant data for the research. Thus, it was observed a concordance of data measured by the various equipment used and also the accuracy of the information recorded.
Under imposed conditions of travel, it was identified a very wide frequency range of oscillations with different amplitudes, presenting dangerous levels for the human body.
Figure 11 shows the block diagram of the data acquisition process, following the authors' configuration.

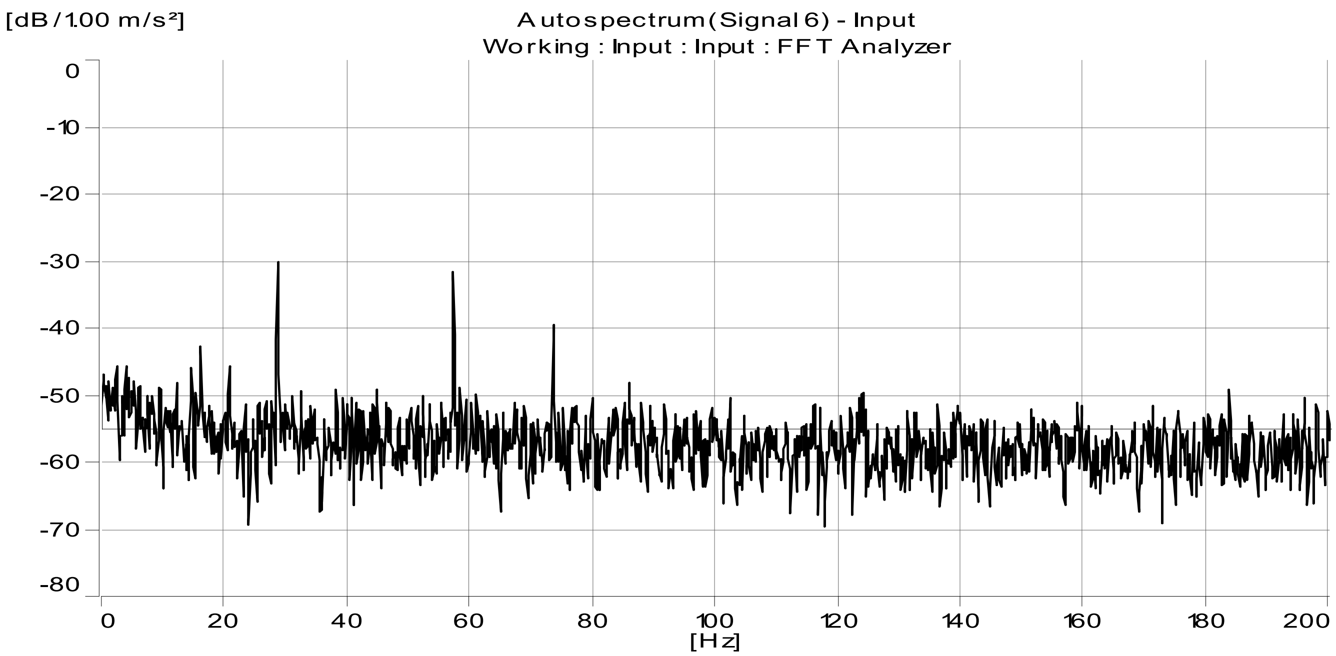

Figure 10. Sample of the signal measured on z axis, on the driver's seat

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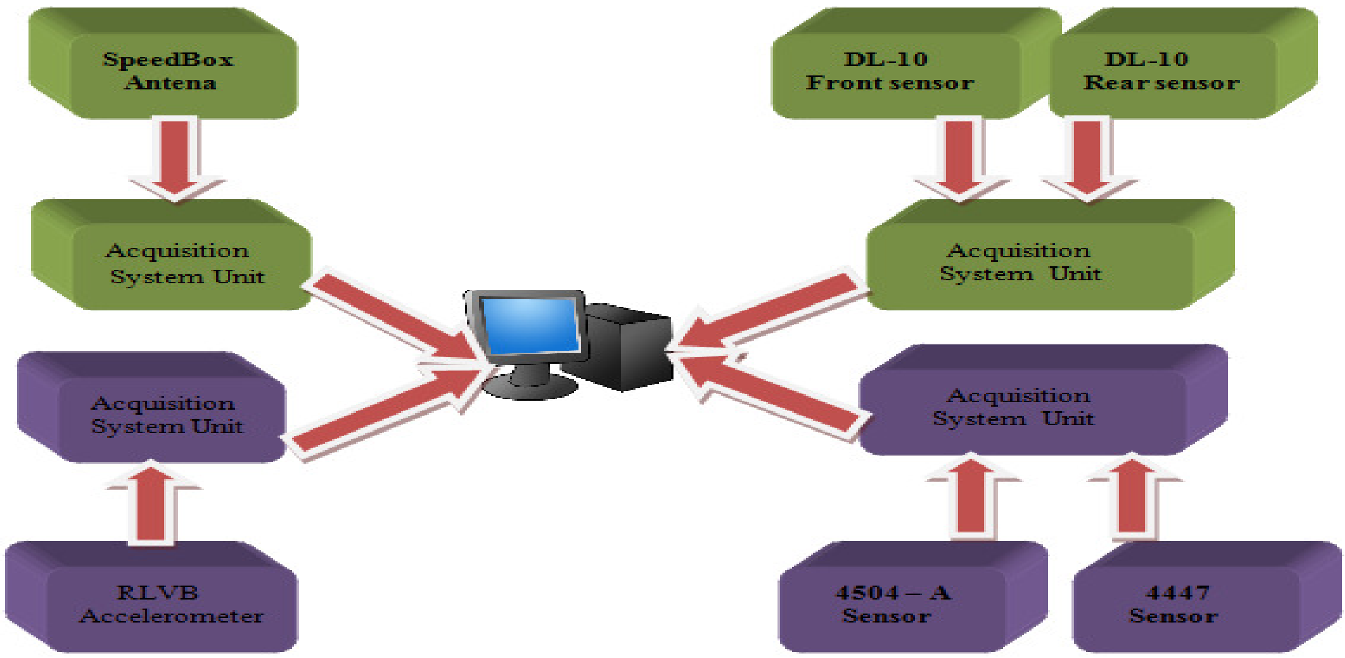

Figure 11. The block diagram of data acquisition process

4. CONCLUSION

The relevance of the research is given by a number of factors, with major importance for the method to approach the analysis of vibration measured on the vehicle structure and also on the passengers, when traveling in rough terrain.
As conclusions, it can be stated that:

- the use of appropriate equipment for the research purpose facilitates the achievement of accurate and real data from field;
- by using equipment based on GPS receivers, it can be obtained a significant correlations between the different devices used for data acquisition - a common time base;
- choice of the right method for installing the equipment that collect the signals at the structure level of the vehicle, makes it possible the achievement of necessary data;
- choice of well-developed programs offers the possibility to achieve the tests and subsequent processing of the received data;
- continuous development of electronic equipment, miniaturization and increase in performances, their opportunities for interoperability, creates great advantages to researchers in all areas of the automotive related fields;
- linking a large number of equipment makes it possible to obtain data as accurate as possible on the pursued phenomena.

This work was presented at the International Congress of Automotive and Transport Engineering, CONAT 2016, Brasov, Romania and it was published in Proceedings of the Congress (ISSN 2069-0401).

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THE STUDY OF THE AERODYNAMIC BEHAVIOR OF AN ELECTRIC KART USING CAD AND CFD METHOD

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Abstract: *This work presents the aspects of modelling, simulation and results using CAD (Computer Aided Design) and CFD (Computational Fluid Dynamics) methods. This simulation was applied to an electric powered kart developed within the research center "Automotive Engineering" of the University of Pitesti.*
Based on the existing kart, a geometrical model was developed using Catia V5 software.
The respective model was used to simulate the aerodynamic behavior with the help of Ansys Fluent software.

Key-Words: *electric kart, aerodynamics*

1. INTRODUCTION

In this paper it is presented a model for studying the aerodynamic behavior of an electric kart. In comparison with a petrol powered kart, the electric kart has batteries placed between the driver's seat and the side bumpers. For the studied case, presented in Figure 1 and Figure 2, due to their flat surface, the batteries could have a negative impact on the karts' aerodynamic performance.
An electric kart was chosen for this study due to the lack of air and sound pollution.
If a large flat plate is inserted into an airstream at right angles to the flow, then air particles moving in the column of air near the center would be decelerated to a stop at the plate and all of their kinetic energy would be converted to an increase in static pressure.
This increase in static pressure is called the "stop" pressure, numerically equal to the dynamic pressure [1].

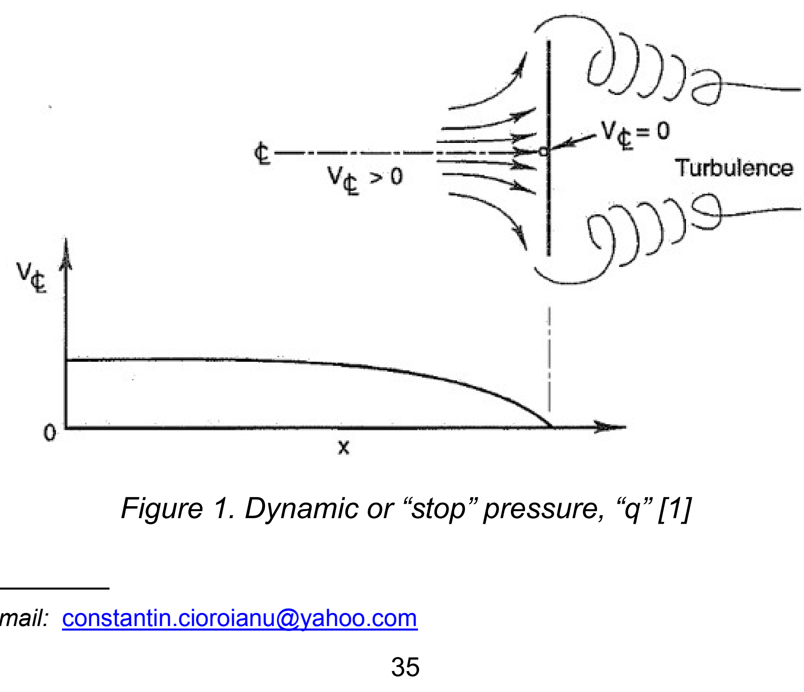

Figure 1. Dynamic or "stop" pressure, "q" [1]

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2. METHODOLOGY

In the first stage, a CAD model was created using CATIA V5 software. The numerical model is generated from the geometrical model. After generating the numerical model, the aerodynamic behavior is simulated by CFD, with the help of ANSYS FLUENT software.

2.1. Geometric Model

With the sets of commands and functions available through CATIA V5 a geometric model of the kart and driver was generated. The geometric model corresponds to a medium-sized individual with a height of 1750 mm. The generated CAD model and components are shown in Figure 2.

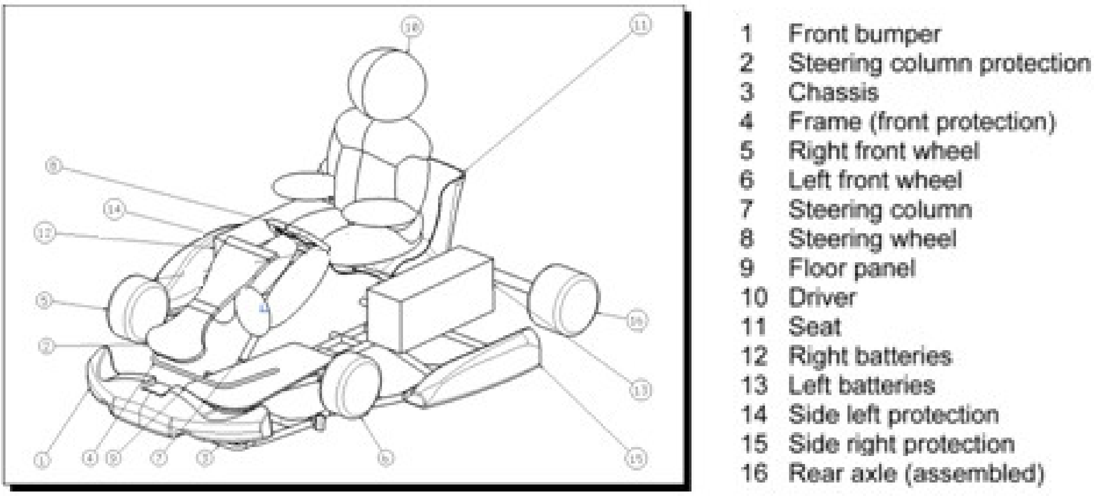

Figure 2. Geometrical model and components

This model was used taking into account the dimensions of the kart and the anthropometric dimensions of the users of this kart. In CATIA V5, model type dummies are used for evaluation of ergonomics performance of various technological operations. A simplified model of the driver will reduce the necessary computational resources. Therefore, an ellipsoid model was developed and it corresponds to a medium-sized individual with a height of 1750 mm.

2.2. Numerical Model

The computational grid (Figure 3) is defined by taking the geometrical model as a carrier defined above. The numerical model defines the computing grid necessary for numerical solving of the set equations describing the fluid flow.
At this stage, the boundary conditions are defined (wall, interaction area, entrance area, output area) and the conditions necessary to establish the set of equations describing fluid flow are also created.
The geometric model of the electric kart and driver represents the structure – defined as a wall – around which airflow is studied. The outer faces of the geometric body representing air are defined as the borders of the field of computing. These borders can be associated with different properties such as wall, input or exit. The numerical values that are initialized to these areas are the air flow rate that gives the speed of the vehicle and pressure. If the output value of the surface pressure is equal to atmospheric pressure thereby defining a free flow conditions.
Solving numerical model provides the user with a series of results necessary for evaluating the aerodynamic performance.

2.3. Conditions of simulation and turbulence model

The influence of the ground on the main aerodynamic characteristics of the car, drag and lift, is studied in two ways, commonly used in wind tunnels, respectively without ground effect (fixed wheels and no relative motion between car and road), and with the moving wall approach [2].
This study is carried out considering fixed wheels and no relative motion between kart and road for three velocities of 15, 20 and 25 m/s.

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Analyses were performed in steady state, for a reference pressure of the air p=1 At. The SST (Shear Stress Transport) turbulence model is used to solve the simulation process.

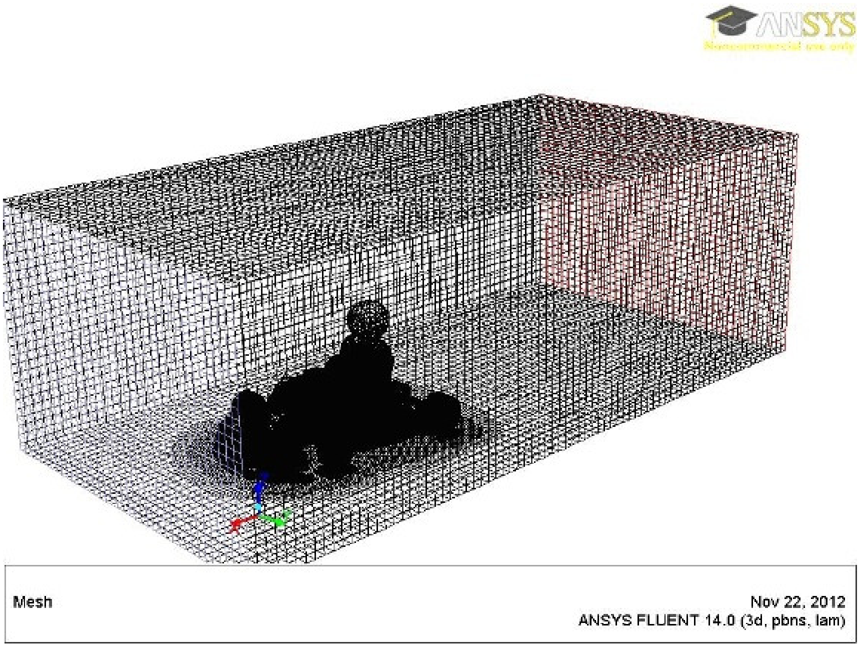

Figure 3. Computational grid

3. RESULTS

The pressure diagram plots the pressure values obtained by solving the numerical model. Information about total, static and dynamic pressure and pressure coefficient is available.
Figure 4 shows the variation of total pressure for the studied kart.
Figure 5 shows the calculated value of the pressure coefficient.

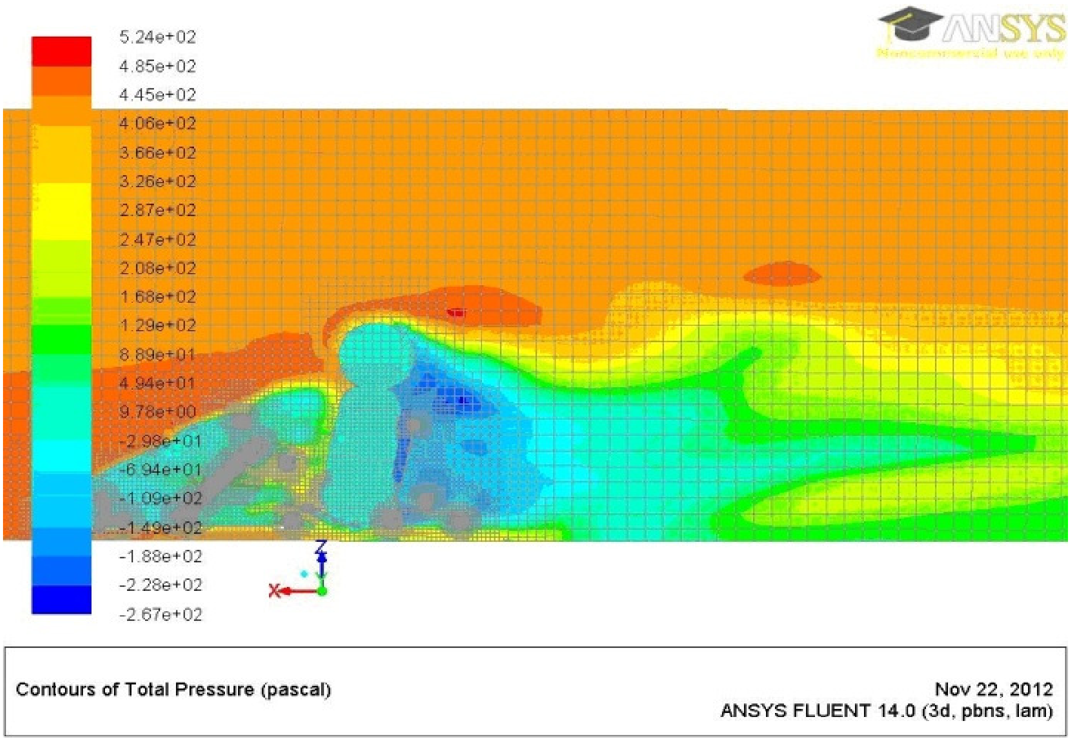

Figure 4. Numerical results of total pressure (velocity 25 m/s)

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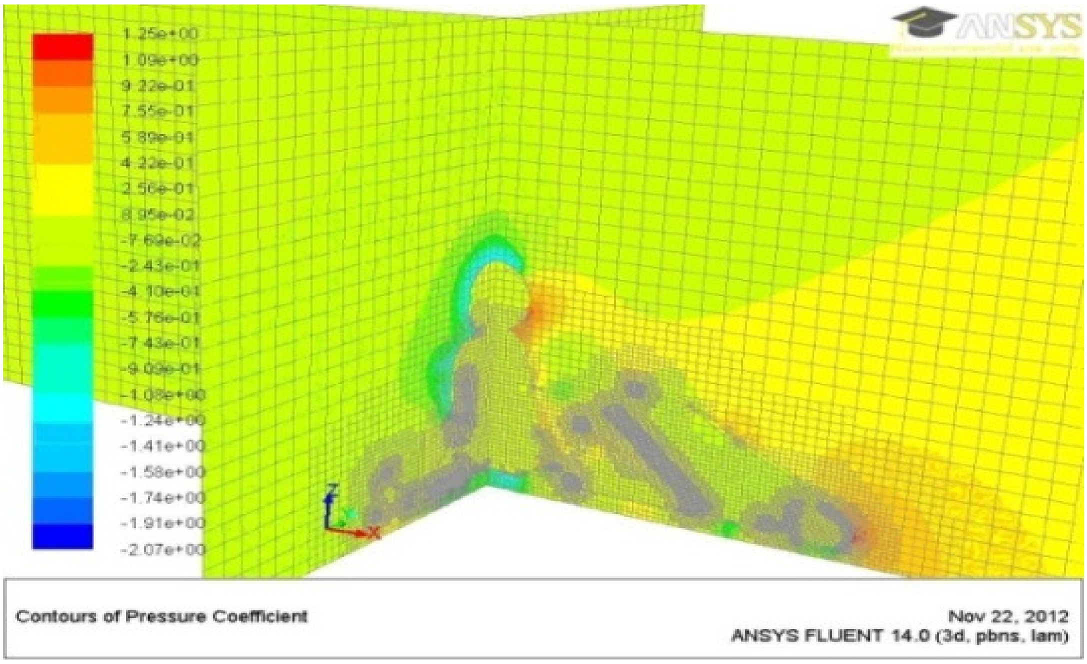

Figure 5. Numeric results of the pressure coefficient

4. CONTRIBUTION OF THE KART'S COMPONENTS IN GENERATING DRAG

In order to evaluate the contribution of the kart's components to the aerodynamic force, a set of 3 numerical tests were made at speeds of v_∞=15 m/s, 20 m/s and 25 m/s. Table 1, Table 2 and Table 3 show the results of calculated aerodynamic drag forces that each component generates.

Table 1.
Calculated aerodynamic drag forces for fluid speed v=15 m/s

Zone	Pressure	Viscous	Total
Front bumper	-8.564	-0.047	-8.611
Steering column protection	-4.549	-0.011	-4.560
Chassis	-3.627	-0.050	-3.677
Frame (front protection)	-0.006	0.000	-0.006
Right front wheel	-0.811	-0.020	-0.831
Left front wheel	-0.810	-0.021	-0.830
Steering column	0.080	0.001	0.081
Steering wheel	-0.812	-0.004	-0.816
Floor panel	-0.100	-0.012	-0.111
Driver	-22.050	-0.051	-22.101
Seat	-1.274	-0.005	-1.279
Right batteries	-7.910	-0.012	-7.922
Left batteries	-9.096	-0.013	-9.109
Side left protection	-0.866	-0.041	-0.907
Side right protection	-2.027	-0.046	-2.073
Engine	-3.947	-0.003	-3.950
Rear axle (assembled)	-8.321	-0.055	-8.376
Net	-74.689	-0.391	-75.079

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Table 2.
Calculated aerodynamic drag forces for fluid speed v=20 m/s

Zone	Pressure	Viscous	Total
Front bumper	-15.396	-0.063	-15.458
Steering column protection	-8.328	-0.015	-8.343
Chassis	-7.441	-0.068	-7.509
Frame (front protection)	-0.072	-0.001	-0.074
Right front wheel	-0.736	-0.027	-0.763
Left front wheel	-1.401	-0.025	-1.425
Steering column	0.049	0.000	0.049
Steering wheel	-2.144	-0.005	-2.148
Floor panel	-0.170	-0.017	-0.186
Driver	-38.546	-0.067	-38.613
Seat	-3.408	-0.006	-3.414
Right batteries	-14.208	-0.017	-14.225
Left batteries	-15.720	-0.018	-15.739
Side left protection	-3.926	-0.061	-3.987
Side right protection	-2.637	-0.044	-2.682
Engine	-4.793	-0.005	-4.798
Rear axle (assembled)	-14.728	-0.071	-14.799
Net	-133.605	-0.510	-134.115

Table 3.
Calculated aerodynamic drag forces for fluid speed v=25 m/s

Zone	Pressure	Viscous	Total
Front bumper	-24.04	-0.08	-24.11
Steering column protection	-11.86	-0.02	-11.88
Chassis	-10.12	-0.07	-10.19
Frame (front protection)	-0.09	0.00	-0.09
Right front wheel	-2.33	-0.03	-2.36
Left front wheel	-3.39	-0.03	-3.42
Steering column	0.34	0.00	0.34
Steering wheel	-1.44	-0.01	-1.45
Floor panel	-0.26	-0.01	-0.28
Driver	-70.30	-0.08	-70.38
Seat	3.28	-0.01	3.27
Right batteries	-22.65	-0.02	-22.67
Left batteries	-23.87	-0.02	-23.89
Side left protection	-4.17	-0.08	-4.25
Side right protection	-4.64	-0.06	-4.69
Engine	-6.37	-0.01	-6.37
Rear axle (assembled)	-21.03	-0.09	-21.12
Net	-202.94	-0.61	-203.54

In order to highlight the results, the figure 6 shows, in percentages, the geometric elements with significant contribution in generating the aerodynamic drag force.

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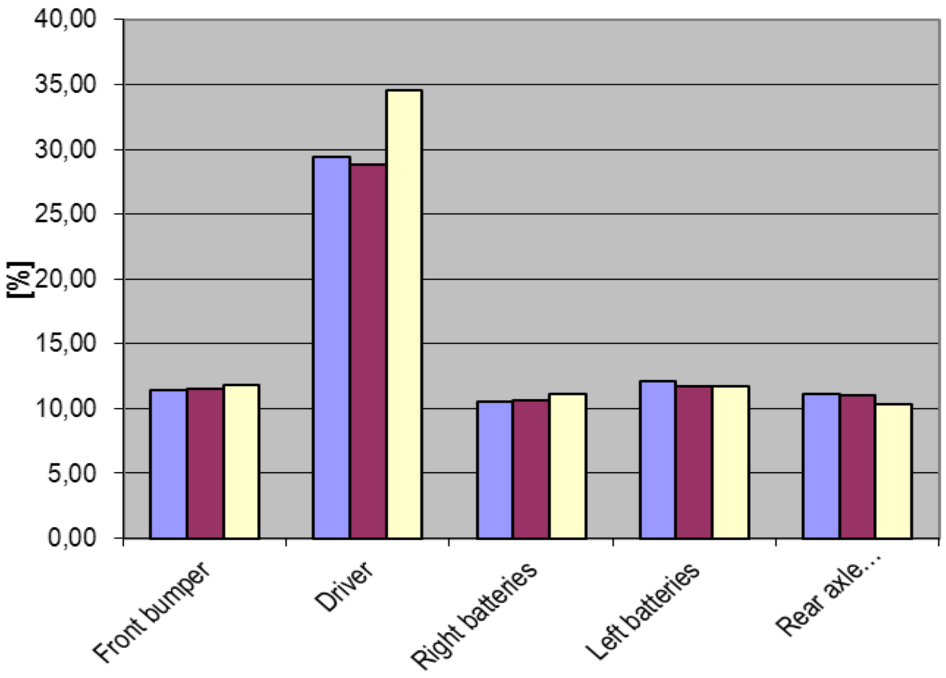

Figure 6. Geometric elements with significant contribution in generating aerodynamic drag force

5. CONCLUSION

Analyzing the results presented in Figure 6 one can see that within reasonable limits of + / -2% the batteries have about 25% contribution in generating drag at various speeds. It is quite significant and it is a negative impact on aerodynamic behavior. This happens due to the front vertical flat surface of the batteries. The problem may solved by placing wind deflectors in front batteries or use protective covers with a shape that would have less contribution in generating drag. Another possibility would be to place the batteries in the middle of the kart, between the steering column and the seat.
This computational model allows further investigation of the influence of driver size and can be used to optimize vehicle outer shape for improved aerodynamics.

This work was presented at the International Congress of Automotive and Transport Engineering, CONAT 2016, Brasov, Romania and it was published in Proceedings of the Congress (ISSN 2069-0401).

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DIAGNOSIS OF THE UNIT INJECTION PUMP'S ELEMENTS

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Abstract: *The paper presents the experimental and technical steps for diagnosis and optical investigation of the unit injection pump's elements for light and heavy diesel trucks, in order to establish the causes of malfunctioning and decision of replacing and/or repairing them. There will be presented some of the most usual damages and technical explanations and interpretation of the diagnosis tests.*

Key-Words: *Unit injection pump, diagnosis, fuel quality, light truck, heavy truck*

1. INTRODUCTION

The day by day exploitation of the light and heavy trucks, equipped with diesel engines, encounters many problems most of them being produced by fuel quality and incorrect repairing or maintenance technology. Few problems could be assigned to material's quality of the unit pump parts that comes from production or remanufacturing facility, but these are replaced, most of the time, through the warranty policy of the manufacturer or, in fewer cases, after an appropriate investigation, through assurance indemnification.

The most usual origin of the malfunctioning of the diesel engine is the contamination of the fuel with dust, rust, water and improper fuel, in the last case taking in consideration the higher percentage or quality of biodiesel in a blended fuel, with, more or less immediate deterioration of the working conditions of the engine, power reduction, heavy cold or hot starts and increasing of the pollutants.

The immediate diagnosis of the injection system must occur in order to avoid the imposed air quality regulations and exploitation costs due to the increasing fuel consumption and working regimes. Due to the high technology of the unit injection system's parts and high pressure of the injection cycle (more than 1800 – 2500 bar to full charge regime of the engine), the correct diagnosis and interpretation of these could be performed only on dedicated equipment and with proper devices.

In this paper will be presented the two situations and commonly damages that could be identified on the unit injection pumps (UIP), the first case being associate with the Bosch's UIP and in the second case being associate with the Delphi's UIP, these being the most usual injection systems on european/romanian diesel trucks fleets.

2. EXPERIMENTAL INVESTIGATIONS

2.1. Testing equipment

The testing of the injection equipment consists of a high technology, accurate and clean preparation and direct investigation of the parts, for each major component (injection pump, injection unit, nozzle, valve, spring etc.) being a dedicated device and/or a dedicated procedure.

Because there were tested injection pumps manufactured by Bosch and by Delphi, there were necessary both type generic testing equipment, and these equipment were [1][2][3]: Diesel testing device EPS 100 (Bosch), Diesel components test bench EPS 815 (Bosch), Diesel testing bench AVM2-PC-20hp (Hartridge), stereo microscope SZX 7 (Olympus), hypobaric niche, ordinary and special dynamometric wrenches and other specific tools (tools, diagnosis interfaces and software) and materials. During the tests was used the special calibration oil 4113 (Castrol) in order to fulfill the testing operation and condition demands.

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2.2. Bosch UIP

The first analysis consists is focused on the six unit pumps that equipped the OM 502 LA-542 engine of an MB Actros 1840 LS truck (11946 ccm, 290 kW, Euro 2, 1998 year).
The engine of the vehicle presents heavy start, either in cold or warm conditions and has altered performances (power, torque, speed stability). The suspicions lead to the injection systems, for instance also for the unit pumps and/or the injector's nozzles (Figure 1 and 2). The separately testing of the injectors, including nozzles, by visual observation under the microscopic procedure and on specific test bench, reveals that there are no obstructions or leaks and no abnormal geometry of the nozzle's holes and corresponding injection parameters (injection pressures, opening times, injection periods, a.o.), thus excluding the injector units as responsible of the malfunctioning of the engine.

Figure 1. Bosch Unit Injection Pump (UIP)

Figure 2. Delphi Electronic Unit Injector (EUI)

In these conditions, the whole attention was concentrate on the six unit pumps, as the most important part of the injection system that could generate working inaccuracies.
In Figure 1 is presented one of the injection pump unit (UIP), which was tested for working parameters (injection pressure, pressure drop, leaks, flow, etc.). All the six UIP were tested individually, in order to precisely identify the whole problems of the injection system. Because the working condition refer also to the flow measurement, there were performed such tests on EPS 815 test bench and were followed up multiple parameters and demanding conditions requisites, for example fuel/conditioning oil temperature, pressure, flow on different conditions (start up point, warm up, clean run, conditioning, rated point, cooling). All these parameters were directly acquired and analyzed through specific interface of the test bench and some of this information, for rated point measurements, is presented in Figure 3.
The faults identified on the valve-seat assembly of the six UIP, through microscope visualization, were similar and consist of many erosion marks caused, most probably, to the impurities in the fuel and compromising of the fuel filter, due to long time exploitation between changes.
Thus are presented images captured on valve seat, Figure 4, valve, Figure 5, and valve pin, Figure 6, respectively, with the erosion spread marks on the jointed surfaces (in these pictures the parts were separated, after dismounted, for direct investigation).

2.3. Delphi UIP

The tested D12D diesel engine of the Volvo FH 42 truck (12.130 ccm, 309 kW, Euro 3, 2005 year) was equipped with six Delphi E3 Electronic Unit Injectors (EUI), Figure 2, and the symptoms claim by the owner consists of impossible normal start (only with additional volatile substances injected/sprayed in intake pipe), variable idle speed and poor performances (power/torque). The injection system works at high pressure (maximum around 2500 bar) and the "mechanical" parts are controlled through an electronic control unit (ECU) of the diesel management structure. As a whole assembly, consisting either of high pressure pump but also with the valve-nozzle injector unit, the possible damages that distort the working parameters must be separated, and each part must be distinctly diagnosed.
T1. Nozzle Opening Pressure – NOP, that must be around 250 – 300 bar. The precise value is recorded only in the technical documentation of each specific type of nozzle/injector, and is not directly presented in this article;
T2. Seat Tightness – ST, presume the direct observation of possible leak of fuel/calibration oil that could occur on the nozzle hole's surface, when the pressure inside the injector are maintained at least 10 s, at a pressure with 15 bar less than the pressure prescribed for NOP;

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T3. Back Leakage – BL, that reveal the period of maintaining the drop of pressure between 170 to 140 bars, inside the nozzle. Optimum period of the pressure drop must be in 3 – 30 s range;
T4. Testing of the EUI in the Hartdrige AVM 2 – PC – 20hp test bench
Figure 7 presents the testing device for pressure drop measurement of the nozzle, Figure 8 presents the special unmounting/mounting device of the EUI and a EUI body (consisting of hydraulic body, valve, electric coil, a.o.) and Figure 9 presents the Hartdrige AVM 2–PC-20hp test bench, prepared for EUI test.
Table 1 presents the values obtained for the T1 – T3 test items, applied to all six EUIs, and also some comments abot the status of each injector/part when was unmounted.
Following technical specification of the EUI manufacturer (Delphi), the units were tested for:

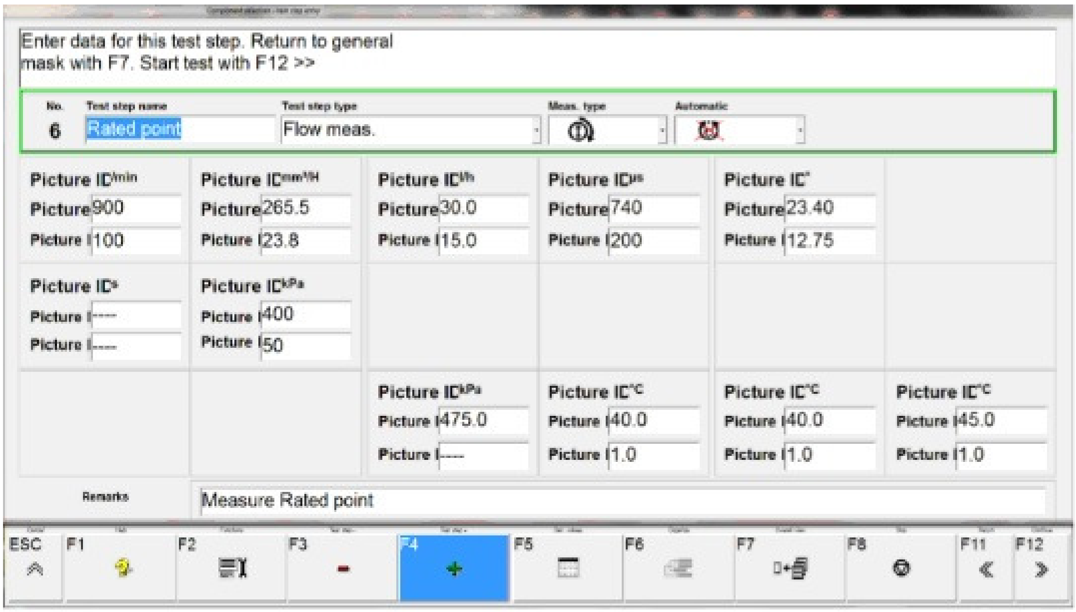

Figure 3. Working parameters for flow measurements

Figure 4. Valve seat erosion

Figure 5. Valve erosion

Figure 6. Valve pin erosion

2.4 Results and Discussions

According to Table 1 results it can be observed that all the EUI's nozzles present proper values for the NOP and only the first two EUIs (1 and 2) present appropriate values for the BL test. Because only these two/three types (T1 – T3) of results are not enough for validate the testing operation of the EUIs, all the units will be tested also on the Hartridge AVM 2 – PC -20hp test bench. After the complete tests of the EUIs on the test bench, also the EUI 1 and 2 were rejected ("Out of Limits" results, see Figure 16 and 17), because internal testing procedure consisting on "Peak Pressure" – line 9, "Rated Delivery" – line 10 and "Peak Torque Delivery" – line 11, were not passed.
Thus it was necessary supplementary investigation on the internal damages of the hydraulic assembly of the EUI that were performed on the stereo microscope.
The visualization of the corresponding joint surfaces reveals pronounced erosion marks (micro grooves, Figure 18 and micro abrasive marks Figure 19) on the high pressure valve linens and pins, all of these as consequences of the impurities in the fuel or compromising of the fuel filtration.

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Figure 7. Pressure drop test

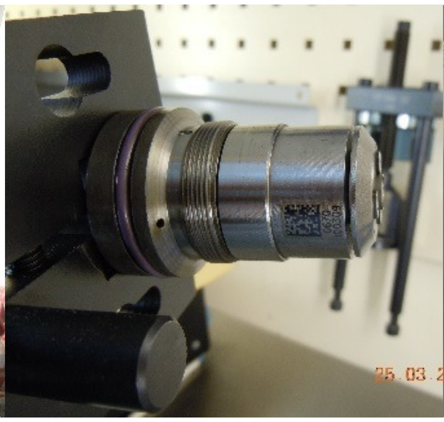

Figure 8. EUI body

Figure 9. Hartdrige test bench

Table 1.
Results of the tests on the Delphi EUI

EUI	T1 [bar]	T2 [10 s]	T3 [s]	Valve Figure	Observations
1	335	yes	10.5	Figure 10	stuck nozzle
2	342	yes	5.2	Figure 11	stuck valve
3	341	yes	1.3	Figure 12	unidentified small part
4	339	yes	1.35	Figure 13	
5	342	yes	2.5	Figure 14	
6	339	yes	1.7	Figure 15	

Figure 10. Valve EUI 1

Figure 11. Valve EUI 2

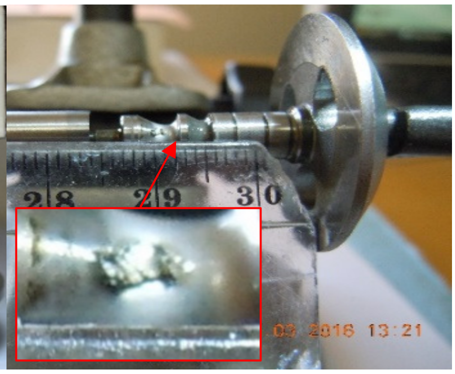

Figure 12. Valve EUI 3

Figure 13. Valve EUI 4

Figure 14. Valve EUI 5

Figure 15. Valve EUI 6

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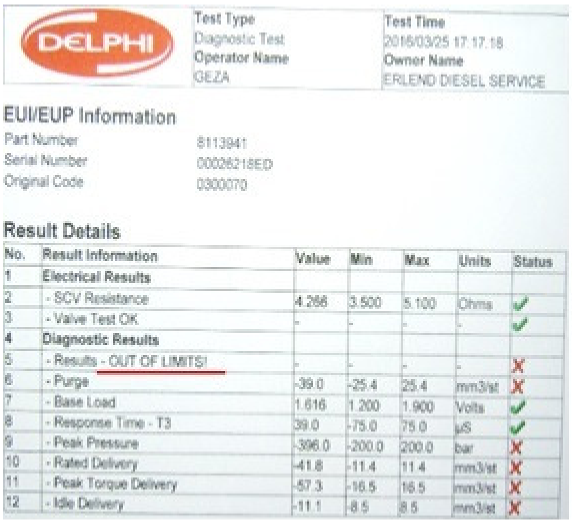


Test Type: Diagnostic Test
Operator Name: GEZA
Test Time: 2016/03/25 17:17:18
Owner Name: ERLEND DIESEL SERVICE

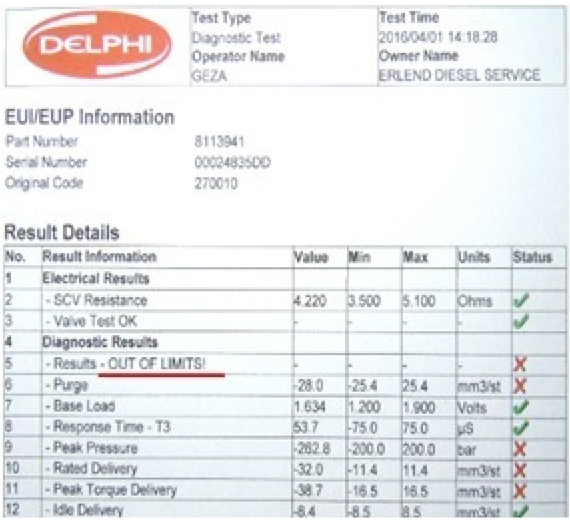
EUI/EUP Information

Part Number: 8113941
Serial Number: 00026218ED
Original Code: 0300070

Result Details

No.	Result Information	Value	Min	Max	Units	Status
1	Electrical Results					
2	- SCV Resistance	4.268	3.500	5.100	Ohms	✓
3	- Valve Test OK	-	-	-	-	✓
4	Diagnostic Results					
5	- Results - OUT OF LIMITS!	-	-	-	-	✗
6	- Purge	-39.0	-25.4	25.4	mm3/st	✗
7	- Base Load	1.616	1.200	1.900	Volts	✓
8	- Response Time - T3	39.0	-75.0	75.0	µS	✓
9	- Peak Pressure	-396.0	-200.0	200.0	bar	✗
10	- Rated Delivery	-41.8	-11.4	11.4	mm3/st	✗
11	- Peak Torque Delivery	-57.3	-16.5	16.5	mm3/st	✗
12	- Idle Delivery	-11.1	-8.5	8.5	mm3/st	✗

Figure 16. Rejection of EUI 1



Test Type: Diagnostic Test
Operator Name: GEZA
Test Time: 2016/04/01 14:18:28
Owner Name: ERLEND DIESEL SERVICE

EUI/EUP Information

Part Number: 8113941
Serial Number: 00024835DD
Original Code: 270010

Result Details

No.	Result Information	Value	Min	Max	Units	Status
1	Electrical Results					
2	- SCV Resistance	4.220	3.500	5.100	Ohms	✓
3	- Valve Test OK	-	-	-	-	✓
4	Diagnostic Results					
5	- Results - OUT OF LIMITS!	-	-	-	-	✗
6	- Purge	-28.0	-25.4	25.4	mm3/st	✗
7	- Base Load	1.634	1.200	1.900	Volts	✓
8	- Response Time - T3	53.7	-75.0	75.0	µS	✓
9	- Peak Pressure	-282.8	-200.0	200.0	bar	✗
10	- Rated Delivery	-32.0	-11.4	11.4	mm3/st	✗
11	- Peak Torque Delivery	-38.7	-16.5	16.5	mm3/st	✗
12	- Idle Delivery	-8.4	-8.5	8.5	mm3/st	✓

Figure 17. Rejection of EUI 2

Were excluded the inappropriate material quality because on these surfaces were not identified point-size regions where pitting occurs and also there was no thermal hardening or chemical treatment of these surfaces applied.

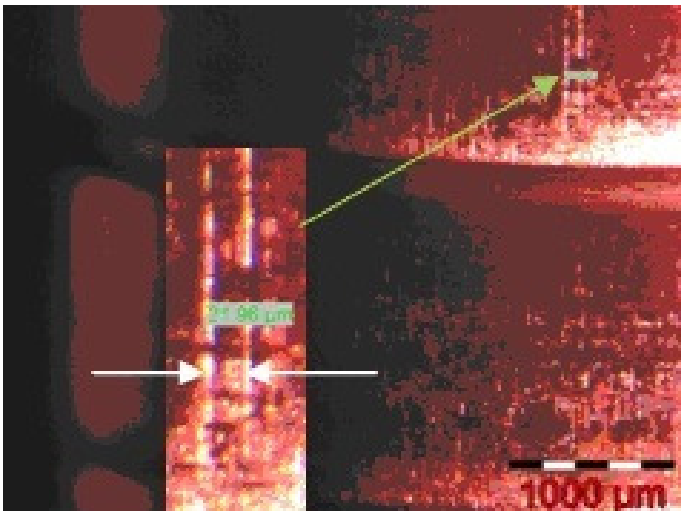


Figure 18. Valve pin micro groove

Figure 19. Valve pin erosion

The micro groove presented in Figure 18 reveal the action of some abrasive particles (the dimension of the groove is 21.96 µm, see details in Figure 17) which generate axial wear on material and Figure 19 present the spreading of the wear surface to up to 35 – 45% of the lateral surface of the sealing/joint surface of the valve, that generate the inappropriate working conditions of the whole EUI.

Due to these advanced erosion of the valve linen – valve pin joint, for all the EUIs, the high pressure "sealing" are compromised, the leaks and pressure drop are high and the EUI were rejected by the Hartdrige testing equipment, and the only possibility too fix the claims of the malfunctioning of the engine is to replace all these EUIs.

In the same time, for all the six injectors visual analysis was performed, on the stereo microscope, to identify possible alteration of the nozzle's holes.

For each of the fifth holes of each nozzle the optical measured dimensions, using an internal light source (see Figure 21) were in the 220 – 240 µm range, Figure 20 and 21.

According to this visual inspection were observed compromising of the nozzle's surface and was established that these defects occur as consequences of the steel-brush cleaning of the injectors, in order to remove the soot and unburned hydrocarbons deposits on EUI.

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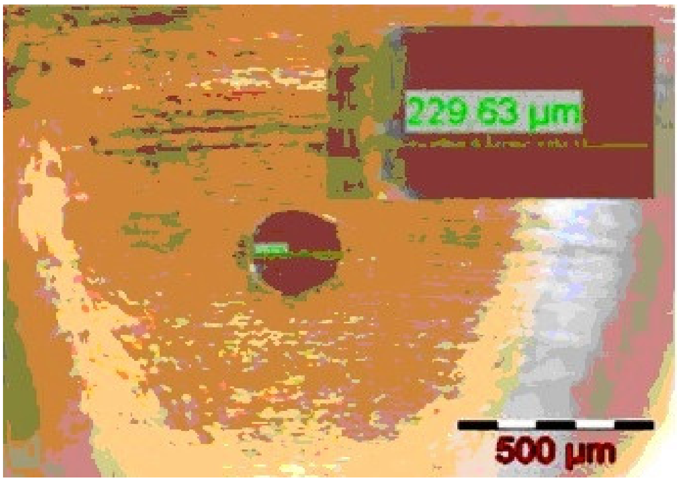

Figure 20. Measured nozzle's hole

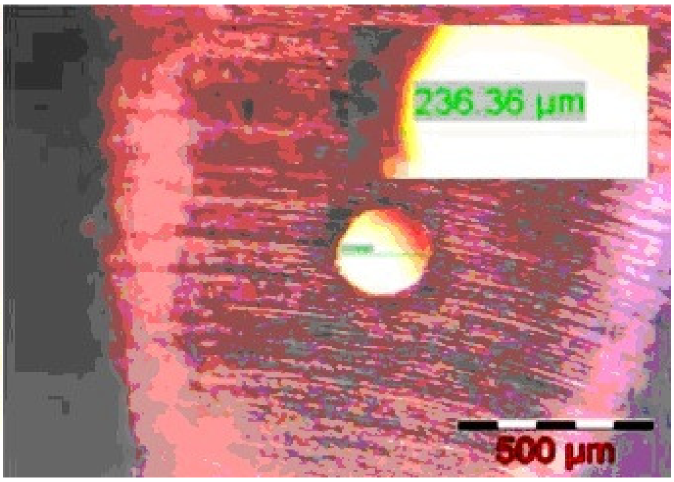

Figure 21. Nozzle's hole with internal light source

3. CONCLUSION

The diagnosis of the injection system of a Diesel engine is a high technology operation due to the high level of the testing equipment demands. Thus, only in specialized laboratories or facilities, on dedicated devices and following specific and coded information (not open/explicit values), these tests applied on injection system parts, for validating their performances, could be applied.

The testing equipment manufacturer could offer the possibility to test not only the same brand/manufacturer parts but also to test some other parts from other manufacturer, but, in most of the cases, the validation and coding of the injector assembly, in order to be installed on the Diesel engine, could be performed exclusively on some dedicated equipment.

The tests made on the Bosch's injection pump units that were claimed for malfunctioning on an Euro 2 heavy truck 12 liters engine, reveals the erosion marks and grooves on the valve assembly (valve seat and joint surfaces), these damages being produced as consequences of fuel impurities and fuel filtration alteration. In this case the injector assembly performed on specific parameters and only the injection pump units are responsible for engine's malfunctioning.

For the Euro 3, 12.1 liters tested Diesel engine, that were equipped with Delphi's Electronic Unit Injectors (EUI), only the whole diagnosis, on separate parts and for the whole assembly of each EUI, reveals all the troubles of these equipment.

Because the general leaks and pressure drops are considered only as guided information, there were necessary direct testing of each EUI, performed on the special test bench, and all of the tested EUIs were rejected, in direct accordance with the technical specification of the manufacturer.

Supplementary investigations performed on the hydraulic assembly identified also massive erosion marks and grooves, produced by the same fuel contamination and fuel filtering discredit.

This work was presented at the International Congress of Automotive and Transport Engineering, CONAT 2016, Brasov, Romania and it was published in Proceedings of the Congress (ISSN 2069-0401).

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1. RIA – Revista inginerilor de automobile (in English: ***Journal of Automotive Engineers***)
ISSN 1222 – 5142
Period of publication: 1990 – 2000 — Format: print, Romanian
Frequency: Quarterly — Electronic publication on: www.ro-jae.ro
Total number of issues: 30 — Type: Open Access
The above constitutes series nr. 1 of SIAR scientific magazine.

2. Ingineria automobilului (in English: ***Automotive Engineering***)
ISSN 1842 – 4074
Period of publication: as of 2006 — Format: print and online, Romanian
Frequency: Quarterly — Electronic publication on: www.ingineria-automobilului.ro
Total number of issues: 42 — Type: Open Access
(including the March 2017 issue)
The above constitutes series nr. 2 of SIAR scientific magazine (Romanian version).

3. Ingineria automobilului (in English: ***Automotive Engineering***)
ISSN 2284 – 5690
Period of publication: 2011 – 2014 — Format: online, English
Frequency: Quarterly — Electronic publication on: www.ingineria-automobilului.ro
Total number of issues: 16 — Type: Open Access
(including the December 2014 issue)
The above constitutes series nr. 3 of SIAR scientific magazine (English version).

4. *Romanian Journal of Automotive Engineering*
ISSN 2457 – 5275
Period of publication: from 2015 — Format: online, English
Frequency: Quarterly — Electronic publication on: www.ro-jae.ro
Total number of issues: 9 (March 2017) — Type: Open Access
The above constitutes series nr. 4 of SIAR scientific magazine (English version).

Summary – on March 31, 2017

Total of series:	*4*
Total years of publication:	*23 (11=1990 – 2000; 12=2006-2017)*
Publication frequency:	*Quarterly*
Total issues published:	*72 (Romanian), out of which, the last 25 were also published in English*