Volume 42, Number 4, 2016.

Mobility & Vehicle Mechanics

International Journal for Vehicle Mechanics, Engines and Transportation Systems

ISSN 1450 - 5304

UDC 621 + 629(05)=802.0

UNIVERSITY OF KRAGUJEVAC, FACULTY OF ENGINEERING

SERBIAN SOCIETY OF AUTOMOTIVE ENGINEERS

M V M **M**obility **V**ehicle **M**echanics

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For Publisher: Prof. dr Miroslav Živković, dean, University of Kragujevac, Faculty of Engineering

Publishing of this Journal is financially supported from:
Ministry of Education, Science and Technological Development, Republic Serbia

Mobility & **V**ehicle **M**echanics

Volume 42
Number 4
2016.

Motorna **V**ozila i **M**otori

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SMART SYSTEM FOR VEHICLE COMFORT MONITORING AND ACTIVE SUSPENSIONS CONTROL

Aleksandar Peulić, Željko Jovanović[1]

UDC:629.113;534.015.1

ABSTRACT: Passengers' comfort is one of the most important characteristics of vehicles. Several aspects affects on it but suspension system is most important. Suspension systems demands include a high level balance between comfortable ride, excellent high speed directional stability and cornering performance. These demands are high and sometimes unattainable for passive suspension systems. Active suspension system can solve the problem by affecting on suspension characteristics according to real time measured driving conditions. In this paper, the device for control and prediction of the suspension is proposed. It is based on the "quarter car" model with the observer, designed to reconstruct the immeasurable states from the available output measurement.

KEY WORDS: active suspension system, Android, optimal control, reduced-order observer

PAMETNI SISTEM ZA MERENJE UDOBNOSTI VOZILA I AKTIVNU KONTROLU VEŠANJA

REZIME: Udobnost putnika je jedna od najvažnijih karakteristika vozila. Nekoliko aspekata utiču na udobnost ali sistemi vešanja su najvažniji. Projektovanje sistema vešanja zahteva balans između udobne vožnje, odlične upravljivosti pri velikim brzinama i skretanju. Ovi zahtevi su veoma veliki i ponekad nemogući za pasivne sisteme vešanja. Aktivni sistemi vešanja mogu da reše ovaj problem uticajući na karakteristike sistema vešanja u realnom vremenu u zivisnosti od uslova vožnje. U ovom radu, sistem za kotrolu i predikciju vešanja je predložen. Zasnovan je na „četvrtinskom“ modelu vozila sa observerom, dizajniran da rekonstruiše nemerljiva stanja na osnovu dostupnih rezultata merenja.

KLJUČNE REČI: aktivna kontrola vešanja, Android, optimalna kontrola, redukovani observer

[1] *Received: October 2016, Accepted November 2016, Available on line December 2016*

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1. INTRODUCTION

Vehicle movement over random road surface produces oscillations that impact on passengers and a vehicle. Generally, it is accepted that the vibrations which passengers feel during the ride has the greatest impact on passenger comfort. This field is known as whole-body vibration (WBV). Current standards and regulations for WBV are defined in:

- ISO standard 2631–1 (1997), [1]
- British Standard 6841 (1987), [2]
- ANSI S3.18:2002 [3]
- European Directive 2002/44/EC [4]
- The Control of Vibration at Work Regulations [5].

An overview of current standard and regulations is presented in [6]. The International Standard Organization (ISO) presents a criterion for ride comfort evaluation (ISO 2631) [1] which describes the effects of vibrations on a person.

Both standards and regulations assume that acceleration magnitude, frequency spectrum, and duration represent the principal exposure variables, which account for the potential harmful effects. At the national level in Serbia there is standard ICS 13.160 (SRPS ISO 2631-1:2014 Mechanical vibration and shock: Evaluation of human exposure to whole-body vibration, Part 1: General requirements). Besides vibration exposure, duration and direction of a vibration exposure are important for passengers comfort. According to the ISO 2631-1 standard [1], whole-body vibration exposure is a health risk. Many jobs are exposed to vibrations. Authors of [7] use ISO 2631 standard method for whole-body vibration exposure in comfort determination for haulage truck operators in surface mining operations. They showed that workers were exposed to WBV levels that exceeded safety limits, as dictated by the ISO 2631-1 standard. The authors of [8] showed little match between ISO 2631-1 comfort prediction results and self-reported results during heavy machinery routines for construction, forestry, and mining vehicles. In [9] authors presented a high correlation between whole-body vibration exposure and disability pension retirement, while the authors of [10] concluded that mechanical vibrations affects more on older and lighter drivers .

There are two ways to reduce the oscillations. First one is to build good quality roads, and the second one is development of the suspension systems. Classic suspension systems, produced only with the springs and shock absorbers, cannot change their

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characteristics during the transport. They are created to produce compromise between comfort and vehicle stability.

Linear optimal control [11] is part of the modern control theory which enables the design of specific types of analytical systems. This is applied in [12, 13] for the optimal design of active vehicle suspension system based on the use of the feedback loop. In [12] active suspension system is realized by using multivariate interactive PI control. Problem with this method it that it is necessary to measure suspension stroke, tire stroke and speed of a suspended and unsuspended mass. In [13] is designed regulator with full observer, which in the feedback use estimated states instead the real ones. Measurement of only one parameter, suspension stroke, is needed. By enabling integrators in the feedback loop, per output, by including the state variable which represent the integral of the output (ie. the suspension stroke) of the system, the prime response output in a stationary mode, at constant excitation force acting on the suspended mass and the input from the road surface is achieved.

Nowadays, accelerometers and GPS are part of almost every smart phone. This is the main reason for becoming interesting as mobile sensing devices. Mobile technologies may have the potential in becoming the leader of data gathering in this field. Paper [14] described a mobile sensing system for road irregularity detection using Android OS-based smartphones. Paper [15] considered the problem of monitoring road and traffic conditions in a city using smartphones.

This paper describes the design of the controller which is based on an approach [13], except estimation of the measurable state variable. For testing purposes smart system for acceleration measurement in form of Android application is developed. Nowadays, accelerometers, gyroscope and GPS are part of almost every smart phone. This is the main reason they are becoming interesting as mobile monitoring devices in transportation. The authors of [3] used high-pass filtered accelerometer data in order to detect road potholes. Paper [6] described a mobile sensing system for road irregularity detection using Android OS-based smartphones. Paper [7] also considered the problem of monitoring road and traffic conditions in a city using smartphones. For simulation, two scenarios are created: “ramp” – hitting the surface with angle slope, “step” – hitting the curb.

2. FORMULATION OF THE PROBLEM

We will assume that the active suspension system contains conventional elements (spring and shock absorber) with hydraulic or electro-hydraulic actuator. We look at a simplified, linear "quarter car" model of vehicle presented on the Figure 1. For this model and its dynamic environment, we define the differential matrix equation:

$$\dot{x} = Ax + bu + Zw \tag{1}$$

where the system matrix are:

$$A = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & -1 & 0 \\ -\frac{\lambda_2}{m_1} & \frac{\lambda_1}{m_1} & -\frac{\beta_2}{m_1} & \frac{\beta_2}{m_1} \\ \frac{\lambda_2}{m_2} & 0 & \frac{\beta_2}{m_2} & -\frac{\beta_2}{m_2} \end{bmatrix} \qquad b = \begin{bmatrix} 0 \\ 0 \\ -\frac{1}{m_1} \\ \frac{1}{m_2} \end{bmatrix} \tag{2}$$

$$Z = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & -\frac{1}{m_2} \end{bmatrix} \qquad w = \begin{bmatrix} \dot{x}_0 \\ f \end{bmatrix}$$

x is the state vector of the fourth order, u is the scalar control force, and w is a vector of input.

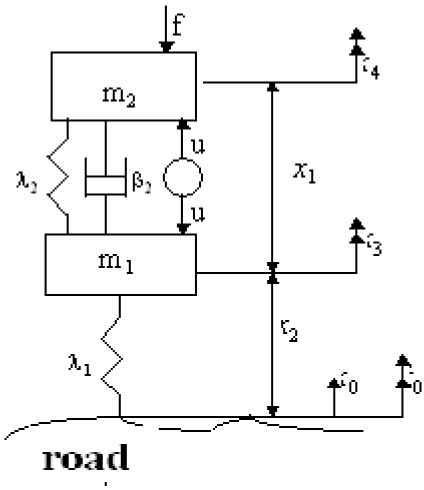

Figure 1 A quarter-car model of suspension system

The output of the system is one variable, suspension stroke:

$y = Cx$ where c is: $C = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}$ (3)

Also, it is necessary to neutralize the constant impact of the system disorders vector w (static force f acting on the suspended weight and "ramp" from the road surface) in stationary mode.

Therefore, it is necessary to expand the state vector of the system (1) and introduce a new state variable, g(t):

$$\dot{g} = y \tag{4}$$

which represents the integral of the output (3) of the system. Extended system can be described with matrix equations:

$$\begin{aligned} \dot{\tilde{x}} &= \tilde{A}\tilde{x} + \tilde{b}u + \tilde{Z}w \\ y &= \tilde{C}\tilde{x} \end{aligned} \tag{5}$$

where the matrix and vectors are formed in the following manner:

$$\tilde{x} = \begin{bmatrix} x \\ g \end{bmatrix} \tilde{A} = \begin{bmatrix} A & 0 \\ C & 0 \end{bmatrix} \tilde{b} = \begin{bmatrix} b \\ 0 \end{bmatrix} \tilde{Z} = \begin{bmatrix} Z \\ 0 \end{bmatrix} \tilde{C} = \begin{bmatrix} C & 0 \end{bmatrix} \tag{6}$$

3. OPTIMAL LINEAR CONTROL

Selection of the Riccati state controller for solving problems of optimization of the complete system provides the analytical solution with a relatively short period of time necessary for the design and calculation. This type of controller takes, calculates and return system state, which is an advantage over some classic regulator structures.

By minimizing the linear quadratic performance index leads to the law of control in a closed loop by state. For expanded system (5) performance index penalizes non-zero status and management, ie. takes into account the limited suspension workspace, stability of the vehicle on the road and ride comfort of passengers.

In matrix form, the performance index is given by the equation:

$$J = \frac{1}{2}\int_0^\infty \left[\tilde{x}^T Q \tilde{x} + \rho u^2\right] dt \tag{7}$$

where is:

$$Q = \begin{bmatrix} q_1 & 0 & 0 & 0 & 0 \\ 0 & q_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & q_3 \end{bmatrix} \tag{8}$$

Different choice of weights coefficients in the index performance (7) can provide different control, ie. different system performance. By solving Riccati algebraic matrix equation:

$$P\tilde{A} + \tilde{A}^T P - P\tilde{b}\rho^{-1}\tilde{b}^T P + Q = 0 \tag{9}$$

which solution is symmetric positive definite matrix P, we get the optimal control equations:

$$u = -\rho^{-1}\tilde{b}^{T} P\tilde{x} \tag{10}$$

and row-matrix of the Kalman amplification in the feedback is:

$$K = \rho^{-1}\tilde{b}^{T} P \tag{11}$$

and can be divided into proportional and integral amplification:

$$K = \begin{bmatrix} K_p & K_i \end{bmatrix} \tag{12}$$

so that the control rules (10) can be written in the form:

$$u = -K_p x - K_i g \tag{13}$$

It is easy to show that the system is in closed loop (when all states are measurable),

$$\dot{\tilde{x}} = \left(\tilde{A} - \tilde{b}K\right)\tilde{x} + \tilde{Z}w \tag{14}$$

asymptotically stable.

4. REDUCED OBSERVER

In the case of a system in which all states measurements are not available in a simple and easy way, very often the state observer is projected that estimate the state of the system based on the measurement and control of outputs [4]. Estimated states are used instead of the real ones for obtaining control (13), which is justified by the separation theorem [1].

In the adopted model, Figure 1, is a fourth order system with the one measurable state variable so is necessary to design a reduced third-order observer [5]. For ease of performing a mathematical relationship, we will simply break down the state vector on:

$$x' = x_1 \qquad x'' = \begin{bmatrix} x_2 & x_3 & x_4 \end{bmatrix}^T \tag{15}$$

and system matrixes (2), so we have:

$$\begin{aligned} \dot{x}' &= A_{11}x' + A_{12}x'' + b_1 u + Z_1 w \\ \dot{x}'' &= A_{21}x' + A_{22}x'' + b_2 u + Z_2 w \end{aligned} \tag{16}$$

Vector of the estimated states is defined by the equation:

$$x_e'' = h + Lx' \tag{17}$$

where h is new 3-dimensional state vector system, and $\boldsymbol{L}$ is the amplifying vector of the reduced observer which need to be calculated. By swapping (17) in (16) instead of the x'', and eliminating disturbance vector, we obtained:

$$\dot{h} = A_{21}x' + \left(A_{22} - LA_{12}\right)x_e'' + b_2 u \tag{18}$$

Figure 2 shows the way of designing the reduced observer. Control is given by equation:

$$u = -K_p' x' - K_p'' x_e'' - K_i g \tag{19}$$

where KP is:

$$K_p = \left[K_p' \quad K_p''\right] \tag{20}$$

Figure 3 shows the realization of complete systems with closed feedback loop.

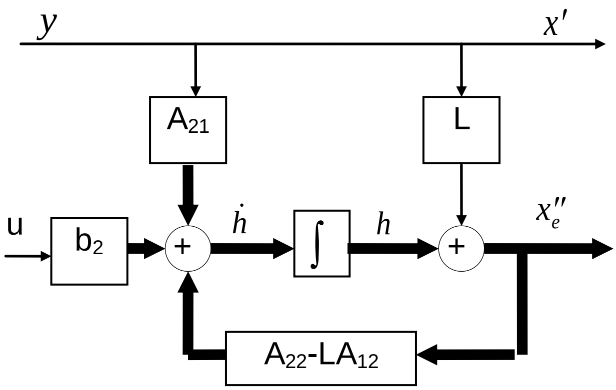

Figure 2 Generating of the immeasurable estimated states

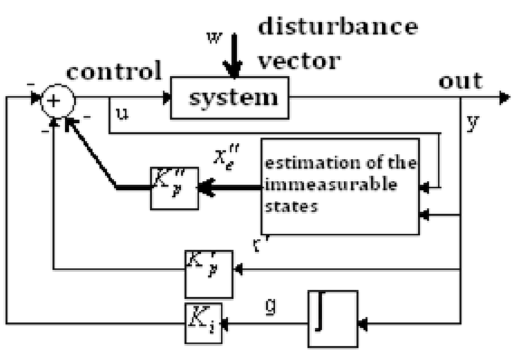

Figure 3 System with the closed feedback loop

Estimation error of the immeasurable states is denoted by the:

$$\varepsilon'' = x'' - x_e'' \tag{21}$$

then from the equations (16) and (17), by subtracting and using equation (18), we get the differential equation for the estimation errors (21):

$$\dot{\varepsilon}'' = \left(A_{22} - LA_{12}\right)\varepsilon'' + Z_2 w \tag{22}$$

According to the separation characteristic, set of values consists of the system values and the reduced observer values which are zeros s_{ir} , i=1,2,3, of polynomial:

$$\det\left(sI - A_{22} + LA_{12}\right) = 0 \tag{23}$$

arbitrarily are set by selecting the appropriate amplifying value of the reduced observer.

If we assume that the system does not operate with disorders and if self-worth values of the observer (23) have negative real parts, error estimation (21), (22) will tend to zero according to an exponential law, and x_e'' will follow the x'' after a certain time (which depends on the observer's values). At first glance, it is best to choose such observer amplification **L** that the observer's own values have high negative real parts:

$$\mathrm{Re}\left(s_{ir}\right) << \mathrm{Re}\left(s_{js}\right) < 0 \tag{24}$$

where s_{js} , j=1..4 are own system values (14), ie. zero polynomial:

$$\det\left(sI - A + bK_p\right) = 0 \tag{25}$$

because then estimated sheet (17) start to follow real states (15), as fast as possible. But, from the other side, higher observer values, in the left half plane, the bandwidth of the observer is higher, and the effect of measurement noise is higher on the result of estimation. Thus, the impact of noise on the measurement system that determines the upper limit of the speed with which the estimated states can approach to the real states. Therefore, the design of the observer consists in seeking and finding a compromise between the estimation speed and performance loss due to noise on the measurement system.

5. ANDROID APPLICATION

Android application is developed to monitor transport parameters using accelerometer and GPS (for storing location). Main application functionalities are developed using RxJava [17] for accelerometer calculations, GPS monitoring, and main application in the separate threads. The developed Android application algorithm is presented in Figure 4.

After application parameters setup, the accelerometer and GPS threads start. Next step is accelerometer calibration, and after that, the comfort calculation is performed. During calculations, the accelerometer axis live signals are plotted on the phone display. After the decision time interval has passed, the user needs to choose subjective comfort level (comfortable, little uncomfortable, and very uncomfortable). Calculated data are stored to files while new calculations starts in the background.

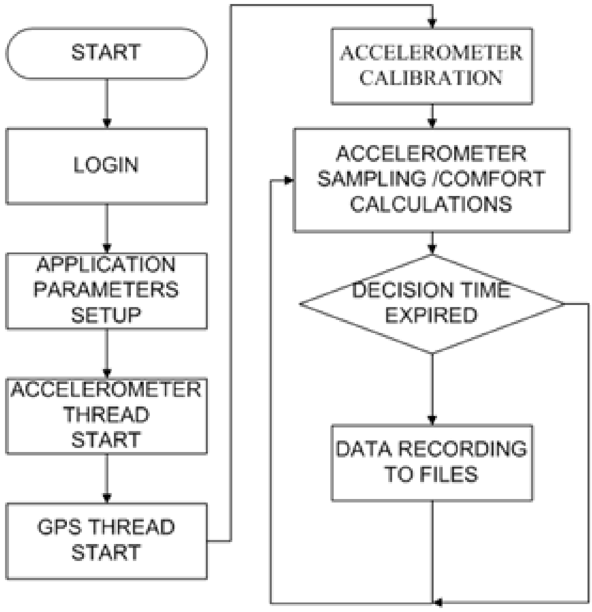

Figure 4 Algorithm of usage for the developed Android application

In order to measure the dynamic accelerations of the device, the influence of the force of gravity must be eliminated. This is achieved by applying a high-pass filter over raw accelerometer data, according to equation (26):

$$HPX_i = HPX_{i-1} - ((RX \cdot fc) + HPX_{i-1} \cdot (1 - fc)) \tag{26}$$

where HPXi is the i-th high-pass-filtered X axis acceleration, RX is raw X axis acceleration data, and fc=0.1 is the filter coefficient that cuts the 10% of the lower frequencies. Raw and filtered data for all three axes are presented in Figure 5.

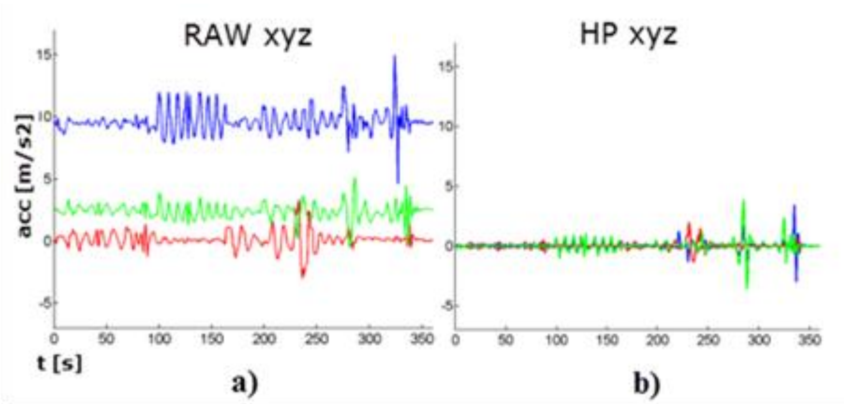

Figure 5 Raw and high-pass-filtered accleration data for all three axes: (a) raw XYZ; (b) high pass XYZ

As presented in Figure 5 the gravity influence is eliminated without loss of informations. Since the phone was almost in an ideal vertical position the gravity impact was largest on the Z axis. The calculation is performed over high-pass-filtered data for the all three axes.

For simulation purposes, smartphone (processor 1.2GHz, Android OS v4.2, accelerometer, GPS) with running application is attached to the windshield using the navigation holder which is presented on Figure 6 a). At this position, suspended mass acceleration is measured. The accelerometer sampling is set to 20ms. Live accelerometer axis signals are plotted on the phone display and stored to files for further analysis. Over vertical (Z) axis calculation (26) is performed in order to calculate interval accumulated vibrations:

$$a_{zRMS} = \sqrt{\frac{1}{n} * (a_{z1}^2 + a_{z1}^2 + \cdots + a_{zn}^2)} \tag{27}$$

where **n** is number of samples, $\mathbf{a_{zi}}$ is Z axis acceleration. During driving locations are saved to KML files, suitable for viewing in GIS software like Google Earth. Marker color represent accumulated vibration level in 10s interval (green < 0.33[m/s^2], 0.33[m/s^2] <= yellow < 0.66 [m/s^2], red >= 066[m/s^2]). Figure 6 b) shows accumulated vibration on Cacak-Uzice relation. Real time calculations were performed beside standard smartphone functions.

a)

b)

Figure 6 Implemented application usage, a) smartphone position, b) created KML file on Cacak-Uzice relation

6. RESULTS AND CONCLUSIONS

In numerical calculations for the "ramp" and "step" test cases the following values are used:

m_1=28.58 kg, m_2=288.9 kg, λ_1=155900 N/m, λ_2=19960 N/m, β_2=1861.9 Ns/m.

With numerous simulations of systems using different selection of weighting coefficients for the index performance (7) and by result analysis next values are chosen:

q_1=1, q_2=10, q_3=5, ρ=2*10^{-10}.

By calculating the *Riccatti* equation (9) amplification is calculated:

K= [-70452 87718 -961   6917 -158110].

Because system values are (14): -2.14, -6.47±j9.79, -57.02±j82.84 according to (24) and the problem of measurements noise with large system bandwidth, we will adopt next reduced observer values: $s_{ir} = -80$, i=1, 2, 3. By solving (23) amplification of the reduced observer is calculated: **L**= [2.52 81.02 -87.42]^T.

At the Figure 5 and Figure 6 responses of the suspension with observer (all states measurable) for excitation "ramp" and the "step" from the road surface, respectively, are shown. It can be seen that the system with the observer has a smaller peak, but in a response to "ramp" negative leap occurs as a result of the new arrangement of zeros and poles of the system. Also, the system response with reduced observer is not significantly better than the response of the system with full observer [4].

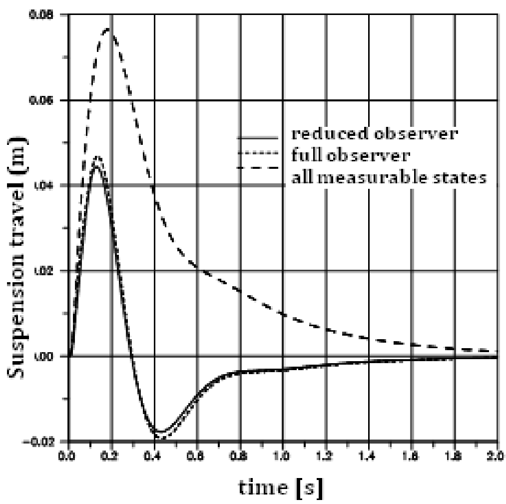

Figure 7 The response of the suspension for the "ramp" from the road surface

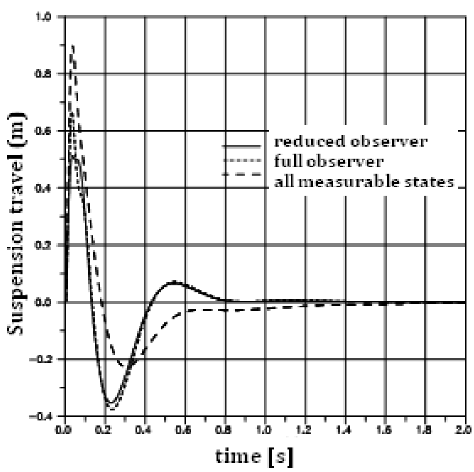

Figure 8 The response of the suspension for the "step" from the road surface

Considering the extremely high sensitivity of the system with reduced observer on noise measurement, we can conclude that the system should be developed with the full observer [4]. Reduced observer in the estimation of the immeasurable states is used less than complete observer because of the output measurement noise (which is random, Gaussian, and which is unavoidable), is not filtered and is even more amplified and directed into the system, as shown in Figure 3. The use of the reduced observer should be avoided because it is better to increase the system with the regulator rather than introducing the system with too big noise.

ACKNOWLEDGMENT

The work presented in this paper was funded by grant no. TR32043 for the period 2011-2016 from the Ministry of Education and Science of the Republic of Serbia.

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THE ANALYTICAL COMPOSITION OF THE BIODEGRADABLE UNIVERSAL TRACTOR OIL BASED ON THE VEGETABLE OILS

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UDC:665.334.9;621.892

ABSTRACT: The basic function of the lubricant is the lubrication i.e. the diminishing of the friction between two surfaces in relative motion. Besides, they are also used to transfer power, heat transfer, cooling, corrosion protection and so on. Lubricating oils and greases are the third tribology element and their use is necessary for the proper function of almost every mechanical system. This paper presents development and testing of the biodegradable universal tractor oil based on the vegetable oils. The agricultural equipment is ideal for the use of biodegradable oils based on vegetable oils because it is used in the very proximity of the environment where the lubricant can come into contact with the soil, water and crops. This is the ideal opportunity to create permanent cycle where the agricultural equipment is lubricated by the oil from the plants grown in the fields cultivated by the very same equipment. Universal tractor oil (UTTO) is the multipurpose oil for the lubrication of the transmission, rear axle, differential, wet brakes, and hydraulic system fed by the common oil reservoir.

KEY WORDS: biodegradable universal tractor oil, oil analysis, physic chemical properties

ANALITIČKA KOMPOZICIJA BIORAZGRADLJIVIH UNIVERZALNIH TRAKTORSKIH ULJA NA BAZI BILJNIH ULJA

REZIME: Osnovna funkcija maziva je podmazivanje, odnosno smanjenje trenja između dve površine koje su u relativnom kretanju. Osim toga koriste se i za prenos snage, prenos toplote, hlađenje, zaštitu od korozije itd. Maziva ulja i masti su treći tribološki element i njihova upotreba je neophodna za pravilno funkcionisanje skoro svih mehaničkih sistema. U radu je prikazan razvoj i ispitivanje biorazgradivih univerzalnih ulja za traktore (UTTO) biljnog porekla. Poljoprivredna oprema je idealna za upotrebu biorazgradivih ulja na bazi biljnih ulja, jer se koristi u neposrednoj blizini okoline gde mazivo lako može doći u dodir sa zemljištem, vodom i usevima. Ovo je idealna prilika za stvaranje trajnog ciklusa u kome se poljoprivredna oprema podmazuje uljem iz biljke koja raste na polju koje se obrađuje tom istom opremom. Univerzalno ulje za traktore (UTTO) je višenamensko ulje za podmazivanje transmisije, zadnjeg mosta, diferencijala, mokrih kočnica i hidrauličnog sistema sa snabdevanjem iz zajedničkog uljnog rezervoara.

KLJUČNE REČI: biorazgradljivo univerzalno traktorsko ulje, analiza ulja, fizičko hemijska svojstva

[1] *Received: November 2016, Accepted November 2016, Available on line December 2016*

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THE ANALYTICAL COMPOSITION OF THE BIODEGRADABLE UNIVERSAL TRACTOR OIL BASED ON THE VEGETABLE OILS

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UDC:665.334.9;621.892

1. INTRODUCTION

Lubricating oils contain up to 80 % of base oils and the properties such as viscosity, oxidation stability, pour and flash point, volatility and others depend on them. Lubricating oils can contain up to 20 % additives which improve base oil characteristics or bring some new properties thus increasing exploitation and technical properties. Lubricants made out of mineral base oils originating from the crude oil, are the most widely used. However, these lubricants are very often toxic and are not readily biodegradable, thus being environmentally aggressive. The annual consumption of lubricants in the world is around 40 million tons out of which less than 40% are collected and properly processed, meaning regeneration, re-refining and controlled incineration, while the rest is disposed without control thus contaminating soil, water and atmosphere. It has been proved that 1 liter of spent oil contaminates 1 million liter of water or one tone of spent oil contaminates the river water as much as waste water from a 40 000 men town.

Due to the aforementioned potential dangers, during some last twenty years the ecologically acceptable oils are more and more used. Ecologically acceptable oils are the oils which in contact with the environment produce the minimum of harmful effects [1-7]. The conditions for the ecological acceptance are biodegradability and no toxicity of lubricants. Besides, ecologically acceptable lubes are produced from the renewable sources (vegetable oil) thus reducing the dependence of mineral oils.

The disadvantages of vegetable oils versus mineral oils are low oxidation stability, low fluidity on low temperatures, low hydraulic stability and the price which is 1.5 to 2 times higher than the price of mineral oils [8-13].

The features of oils based on rapeseed oil, sunflower oil, soybean oil and a mixture of rapeseed oil with mineral oil were, after the corresponding testing, compared with the features of the commercially available mineral-based universal tractor oil, UTTO (Table 1).

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Table 1 Oil Samples

Sample number	Oil name	Oil code
1.	Rapeseed oil without additives	RE
2.	Soybean oil without additives	SO
3.	Sunflower oil without additives	SU
4.	Rapeseed oil with additives	REA
5.	Soybean oil with additives	SOA
6.	Sunflower oil with additives	SUA
7.	Rapeseed oil + additives + 10% SN150	REAM10
8.	Rapeseed oil + additives + 20% SN150	REAM20
9.	Mineral UTTO	MIN

The ASTM D 4951 and ASTM D 4927 AAS methods have been applied to obtain the elemental composition of the additives used in the test oils, as shown in Table 2 and Figure 1.

Table 2 The elemental composition of the additives used in the test oils

	P	Ca	Zn	S
	% m/m			
REA	0.07	0.08	0.13	0.19
SOA	0.06	0.07	0.14	0.19
SUA	0.06	0.07	0.14	0.19
REAM10	0.08	0.15	0.14	0.23
REAM20	0.09	0.18	0.15	0.28
MIN	0.11	0.34	0.15	0.54

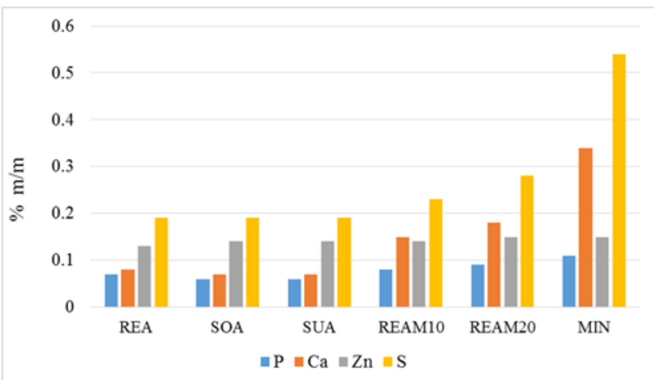

Figure 1 The elemental composition of the additives for the test oils

Vegetable oils are generally less additivated than mineral oils, because they possess good lubricating properties due to their polar nature. This makes them good solvents for sludge and dirt, which would otherwise deposit on metal surfaces [14-17]. Because of these properties, it is possible to reduce the amount of friction modifiers, antiwear additive package, and dispersants, when formulating biodegradable universal tractor oils.

2. PHYSICAL AND CHEMICAL PROPERTIES OF THE TRACTOR OIL

The physical and chemical properties of the vegetable oils were examined in accordance with standard methods (Table 3).

Table 3 Laboratory test methods

Method No.	Physical and chemical properties	Test method
1.	Density, kg/m^3	ASTM D 1298
2.	Kinematic viscosity at 40 °C, mm^2/s	ASTM D 445
3.	Kinematic viscosity at 100 °C, mm^2/s	ASTM D 445
4.	Viscosity Index	ASTM D 2270
5.	Pour point, °C	ASTM D 97 or ISO 3016
6.	Flash point, °C	ISO 2592, ASTM D 92
7.	Foaming, ml/ml 24 °C; 94 °C; 24 °C	ASTM D 892
8.	Deaeration, minutes	DIN 51381
9.	Oxidation stability, minutes	ASTM D 2272
10.	Corrosion on copper, 3 hours at 121 °C	ASTM D130
11.	P content, %	ASTM D 4927
12.	S content, %	ASTM D 2622
13.	Ca content, %	ASTM D 4628
14.	Zn content, %	ASTM D 4628
15.	Wear, (1h; 65 °C; 40 kg and 1500 rpm), mm	ASTM D 4172
16.	4-ball EP test - scuffing, kg	ASTM D 2783

The results of experimental testing of physico-chemical properties are presented in Table 4. Experimental work was carried out in accordance with the manufacturer specifications and proper standards, by using the necessary testing equipment.

Table 4 Physico-chemical properties of oils

Physico-chemical properties	Measuring unit	Methods	RE	SO	SU	REA	SOA	SUA	REAM 10	REAM 20	MIN
Density at 15°C	kg/m³	ASTM D1298	916	918	920	918	921	922	912	907	877
Kinematic viscosity at 40°C	mm²/s	ASTM D 445	34.8	32.7	35.1	42.3	37.7	38.6	42.0	41.0	70.5
Kinematic viscosity at 100°C	mm²/s	ASTM D 445	7.9	7.82	7.93	9.49	9.17	9.27	9.23	9.18	10.05
Viscosity Index		ASTM D2270	210	224	209	218	227	226	211	201	126
Flash point	°C	ASTM D 92	322	326	328	254	260	250	248	246	234
Pour point	°C	ASTM D 97	-8	-13	-11	-23	-25	-24	-26	-27	-36
Foaming, I sequnce, 24ºC II sequence, 94ºC III sequence 24ºC	ml	ASTM D 892	0/0 0/0 0/0	0/0 0/0 0/0	0/0 0/0 0/0	25/0 20/0 20/0	15/0 20/0 20/0	30/0 20/0 10/0	25/0 20/0 10/0	20/0 20/0 10/0	5/0 20/0 5/0
Deaeration	minutes	DIN 51381				6	5	6	5	7	1
Oxidation stability, RBOT	minutes	ASTM D2272	13	8	10	109	60	70	120	149	214
Wear, (1h;75ºC;40kg and 1200 rpm)	mm	ASTM D 4172	0.66	0.69	0.68	0.38	0.39	0.37	0.39	0.39	0.36
4-ball EP test - scuffing	kg	ASTM D 2783				200	200	200	200	160	100
Protection against corrosion, Test B		ASTM D 665	pass	pass	pass	pass	pass	pass	pass	pass	pass
Corrosion on copper, 3 hours at 121 ° C		ASTM D130	1A	1A	1A	1A	1A	1A	1A	1A	1A

2.1 Kinematic viscosity

Most tractor lubricants possess kinematic viscosity between 9 and 11 mm^2/s at 100 °C. This viscosity is found to provide sufficient thickness to promote good protection for the transmission system and anti-squawk performance, yet still to be a suitable viscosity for the hydraulic system.

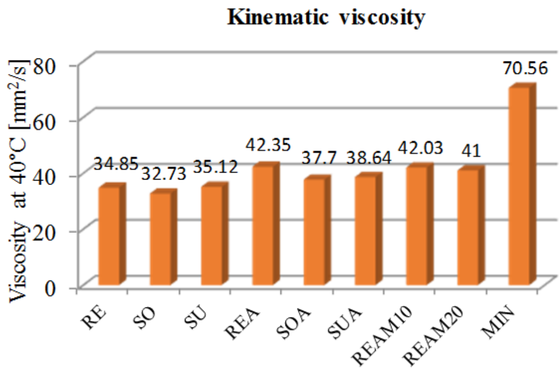

Figure 2 Kinematic viscosity at 40°C, ASTM D 445

As can be seen from Table 4, viscosity of vegetable oils produced from oil seeds falls between 32,7 and 42,3 mm^2/s at 40 °C, and between 7,8 and 9,4 mm^2/s at 100 °C.

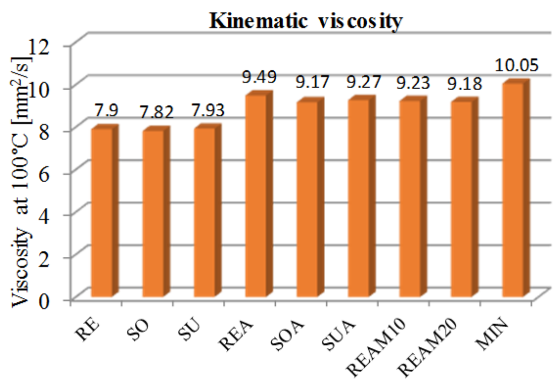

Figure 3 Kinematic viscosity at 100°C, ASTM D 445

2.2 Oxidation stability

Most vegetable oils are triglycerides constituting a complex mixture of fatty acids with different chain length and instauration content [18-24]. The alcohol component (glycerine) is the same in all vegetable oils. The fatty acid components are plant-specific and therefore variable. The fatty acids differ in chain length and number of double bonds. From the fatty acid composition of the oils, it is observed that chain length C18 is dominating (Table 5). Main fatty acids with double bonds are linolenic, linoleic and oleic. The oxygen absorption rate is 800:100:1 respectively, therefore less double bonds in a carbon chain result in better oxidation stability [16]. Generally the oxidation stability of vegetable based oils decreases with the increased level of instauration.

The content of polyunsaturated fatty acids (C18:2) is rather high for soybean (SO) and sunflower (SU) oil. Under thermal conditions, the double bonds in polyunsaturated fatty acids polymerize much faster than monounsaturated (C18:1 and C22:1) or saturated (C16:0 and C18:0) fatty acids. Unfortunately, the saturation of fatty acid degenerates the low temperature behaviour or pour point of the oil.

Iodine value characterizes particular oil on the base of unsaturated fatty acids. Oils with high iodine values are more problematic for oxidation processes, however values fewer than 100 are not recommended since such oils are more problematic for changing the characteristics at lower temperatures.

Table 5 Fatty acid content and iodine value of vegetable base oil

Physico-chemical properties	Unit	Rapeseed oil	Soybean oil	Sunflower oil
Iodine value	$gI_2/100g$	118.41	126.2	131.2
Fatty acid content	%			
C14:0 (Myristic acid)		0.06	0.05	0.04
C16:0 (Palmitic acid)		6.58	10.24	6.35
C16:1 (Palmitoleic acid)		0.36	0.15	0.13
C18:0 (Stearic acid)		2.88	5.24	5.35
C18:1 (Oleic acid)		53.10	29.33	27.13
C18:2 (Linoleic acid)		28.72	47.95	58.53
C18:3 (Linolenic acid)		6.54	5.35	0.16
C20:0 (Arachidic acid)		0.41	0.52	0.41
C20:1 (Eicosenoic acid)		0.73	0.29	0.20
C22:0 (Behenic acid)		0.28	0.65	1.31
C22:1 (Erucic acid)		0.17		
C24:0 (Lignoceric acid)		0.10	0.20	0.35

The oxidation stability of oil samples was examined by the ASTM D2272 test (RBOT - Rotating Bomb Oxidation Test). As concerning the neat vegetable oils (without additives), rapeseed oil (RE) shows better oxidation stability as compared to the soybean (SO) and sunflower (SU) oil. The reason is a high content of oleic acid and a low iodine value present in rapeseed oil. The oxidation stability of vegetable oils without additives is very low.

The improvement of the oxidation stability of vegetable oils was accomplished by adding the antioxidant additives and the mineral base oil. The concentration of the additives was the same for all vegetable oils. The oxidation stability values determined by RBOT method for neat vegetable oils, vegetable oils with additives and vegetable oils with mineral base oil, were compared with the values for commercial UTTO oil, as it is shown in Figure 4.

The best oxidation stability shows sample REAM20 (149 minutes). The oxidation stability is improved by adding the antioxidant additive: for rapeseed oil, the improvement is more than eightfold. The stability is further increased by adding a mineral oil, but the biodegradability is reduced.

A low oxidation stability of newly formulated biodegradable oils limits their use for the production of motor oils and other oils that require high oxidation stability. Therefore, such oils may be used in the fields where the high oxidation stability is not required (flow lubricating oils, hydraulic oils, universal tractor oils), or in the agriculture and forestry, where a low toxicity and biodegradability of lubricants is mandatory [25-29].

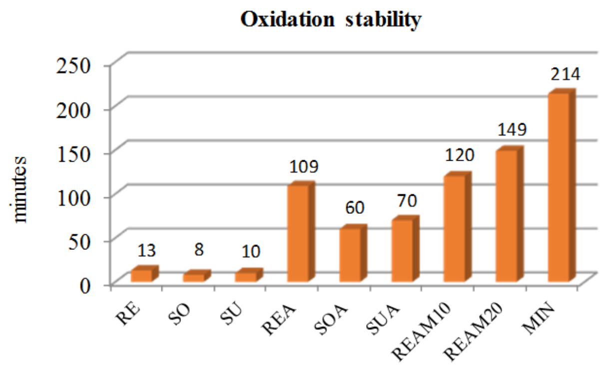

Figure 4 Oxidation stability, ASTM D2272 (RBOT)

2.3 Flash point

Flash point is important in transport and storage due to risk of fire. Vegetable oils have higher flash point values in comparison with mineral oils (Figure 5).

Flash point for vegetable oils is higher than 300 °C. By adding a package of additives and mineral oil according to the formulation, the flash point is reduced, but it is far above the allowed values according to the specifications of tractor manufacturers (Massey Ferguson CMS M1141, Massey Ferguson_CMS M1143; John Deere J20C: Flash point ≥ 200 ^{0}C).

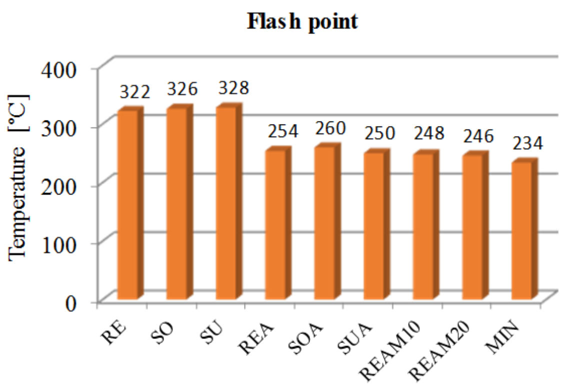

Figure 5 Flash point, ASTM D 92

2.4 Pour point

The flowability of vegetable oils at low temperatures is extremely low, which limits their use at low operating temperatures (Figure 6). Vegetable oils form crystal structures at low temperatures, by agglomeration of triglycerides, wherein the oil flowability is reduced. In order to improve the low-temperature characteristics, vegetable oils are added additives labeled as pour point depressants (PPD). The function of these additives is to prevent the crystallization of the triglyceride molecules at low temperatures and their further grouping. The optimal concentration of additive PPD of 1% in the final formulation of vegetable oils, significantly improves their low temperature properties.

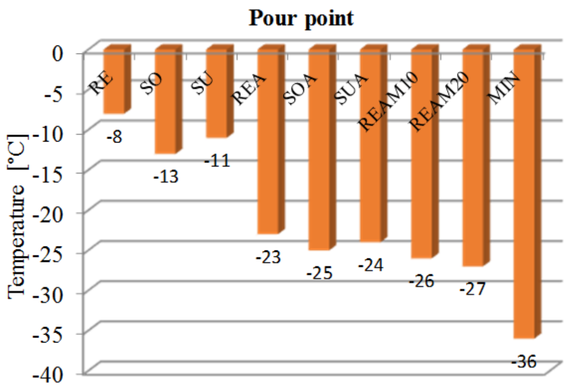

Figure 6 Pour point, ASTM D 97

2.5 Abrasion and high pressures resistance

Tests of the abrasion and high pressures resistance were carried out on the device with four balls ("four ball" test), and the results are shown in Table 6. The wear resistance testing was carried out according to the method ASTM D 4172.

The test conditions were as follows: the pressing force is 392 N, the top ball is rotated at 1200 rpm for 60 min., and the temperature of the test lubricant is regulated at 75°C. The limiting value of the scar diameter worn on the ball is maximum 0.4 mm for UTTO oil, according to the Massey Ferguson MF 1135 specification. The vegetable oil samples without additives (RE, SO, SU) did not pass the standard test, because the wear intensity was 70% higher than allowed. The wear parameters for other samples are presented in Figure 7, and it is seen that they are quite uniform, and within the allowed limits (< 40mm).

The measurement of extreme-pressure properties was performed according to the ASTM D 2783 (Four-ball method). The load is steadily increased until welding occurs, and the welding value of load is recorded as a maximum load which can be carried out by lubricant. The results in Table 6 indicate that vegetable based UTTO oils possess higher load values comparing to mineral oils, which means that they can better withstand extreme pressures and suddenly applied stress. The laboratory tests by using four-ball method have revealed that vegetable oils free of EP additives, possess even better results than mineral oils with the additives, as it is seen in Figure 8.

Table 6 The wear resistance test parameters and results

Characteristics	Unit	RE	SO	SU	REA	SOA	SUA	REAM10	REAM20	MIN
Wear	mm	0.66	0.69	0.68	0.38	0.39	0.37	0.39	0.39	0.39
4-ball EP test	kg	140	140	140	200	200	200	200	160	100

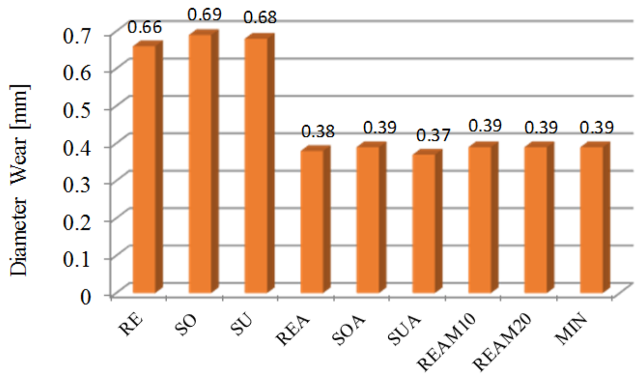

Figure 7 Wear resistance of vegetable oils and their mixtures

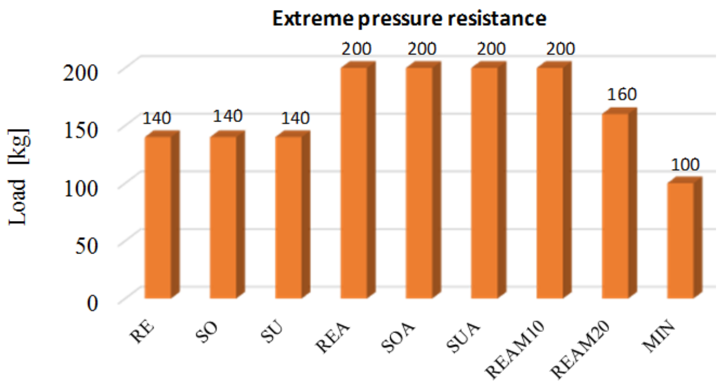

Figure 8 Extreme pressure resistance of vegetable oils and their mixtures

4. CONCLUSIONS

According to the obtained results for physico-chemical properties of various oil samples, it may be concluded that almost all the investigated properties of biodegradable universal tractor oils, satisfy the John Deere and Massey Ferguson specifications, and some characteristics are even better when compared to the properties of universal mineral based oil. The vegetable oils show considerably higher viscosity index (VI > 200) than mineral oils, allowing a reliable tractor operation at wider temperature changes. Flash point is higher for vegetable oils as compared to the mineral. Low temperature fluidity of vegetable oils is far from satisfactory, thus limiting their use at low temperatures. However, PPD additive lowers pour point for these oils to -15 0C or even -23 0C, and these values satisfy most standards. Some of the additives used (PPD and EP) increase foaming above the allowed limits, but after the addition of antifoaming agent, good results are obtained. Oxidation stability of vegetable oils without additives is very low. For instance, the result from RBOT test for additive free soybean oil is only 8 minutes. The improvement of this characteristic of vegetable oils has been accomplished by adding the antioxidant additive and mineral based oil. The mineral oil addition enhances the oxidation stability, but lowers the biodegradability of vegetable oils. The best oxidation stability was found for the rapeseed oil sample (REA=109 minutes), which was the expected result.

The wear resistance tests were performed on "four ball" device. The results from this examination were quite uniform for all samples and within the standard limits (< 40 mm). The extreme pressure (EP) resistance was tested by using "four ball" device. The vegetable UTTO oils show much higher ability to withstand extreme pressures as well as shock loads, in comparison to mineral oils. The laboratory tests give evidence that even vegetable oils without EP additives show better results than mineral oils with the additives.

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IMPROVEMENT OF VEHICLE INSPECTION TECHNOLOGY BY INTRODUCING INTEGRATED INFORMATION SYSTEM

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UDC:629.3;629.113

ABSTRACT: Technical inspections of vehicles represent an important segment of the traffic safety. Therefore, this issue is receiving great attention both in the world and in our country. In particular, given the importance of the exchange of information on technical inspection of vehicles among members of the European Union by introducing a single information system. In the Republic of Srpska since 2009 there was introduced a new concept for the organization of technical inspection of vehicles. This new organization specifically emphasizes the development of the information system. This paper briefly presented the operation of a modern information system as well as the benefits of its introduction not only to raise the quality of technical inspections but also for the wider community.

KEY WORDS: vehicle inspection technology, integrated information system

UNAPREĐENJE TEHNIČKOG PREGLEDA VOZILA UVOĐENJEM INTEGRALNOG INFORMACIONOG SISTEMA

REZIME: Tehnički pregledi vozila predstavljaju bitan segment u bezbednosti saobraćaja. Stoga se ovom pitanju poklanja velika pažnja kako u svetu tako i kod nas. S obzirom na važnost razmene informacija o tehničkim pregledima vozila, u Evropskoj Uniji naročito se poklanja pažnja uvođenju jedinstvenog informacionog sistema. U Republici Srpskoj je od 2009. god. zaživio novi koncept organizacije tehničkog pregleda vozila u kojoj poseban značaj ima jedinstveni informacioni sistem. U informacioni sistem uvezani su, osim stanica za tehnički pregled vozila i Agencija za identifikaciona dokumenta BiH i Ministarstvo saobraćaja i veza Republike Srpske. Putem ovog sistema olakšano se prati rad stanica u realnom vremenu i prikuplja veliki broj podataka: o tehničkim karakteristikama vozila, o načinu obavljanja tehničkih pregleda, vremenu trajanja, radu osoblja i dr. U radu je ukratko prezentovan način rada informacionog sistema kao i prednosti njegovog uvođenja ne samo za podizanje kvaliteta obavljanja tehničkih pregleda već i za širu društvenu zajednicu.

KLJUČNE REČI: tehnički pregled, informacioni sistem

[1] *Received: November 2016, Accepted November 2016, Available on line December 2016*

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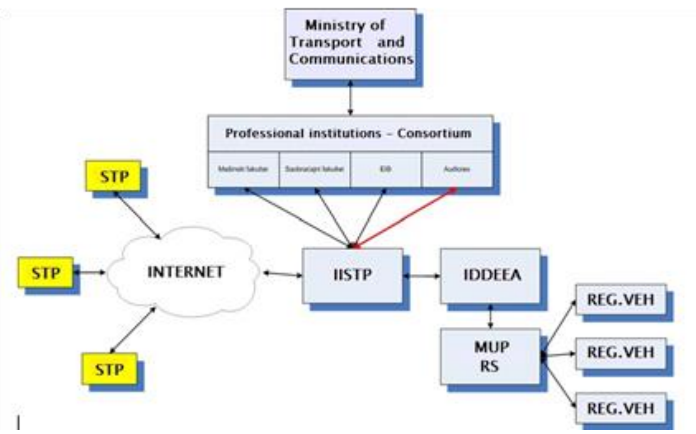
UDC:629.3;629.113

1. INTRODUCTION

Legal regulations governing vehicle inspection in Bosnia and Herzegovina and in the Republic of Srpska are as follows: the Law on the Basic Principles of Road Safety in Bosnia and Herzegovina (Official Gazette of the Republic of Srpska, no. 96/06, 57/07, 97/09, 62/10 and 22/13), the Rulebook on Vehicle Inspection (Official Gazette of the Republic of Srpska, no. 19/07, 95/07, 87/08 and 90/09) [1, 2]. In 2009, the Republic of Srpska introduced a new concept for the operation of vehicle inspection stations. This new concept involved the introduction of the Vehicle Inspection Expert Institution operating under the Republic of Srpska Ministry of Transport and Communications. Organizational chart pertaining to vehicle inspections in the Republic of Srpska is given in Figure 1.



Sending electronic TP-1 FORM will result in immediate delivery to vehicle registration location IDDEEA - Agency for Identification Documents, Registers and Data Exchange of Bosnia and Herzegovina

Figure 1 Organizational chart for vehicle inspection in the Republic of Srpska

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In the Republic of Srpska, the RS Ministry of Transport and Communications issues licences and supervises the operation of vehicle inspection stations, and the RS Traffic Inspection is responsible for the inspection of the stations. The Vehicle Inspection Expert Institution of the RS Ministry of Transport and Communications is a consortium comprising the following institutions: the University of Banja Luka, the Doboj Faculty of Transport and Traffic Engineering, EIB Centar za motorna vozila doo Banja Luka, and Audioteks doo Banja Luka. The Expert Institution is primarily responsible for keeping track of vehicle inspection regulations passed in neighbouring countries, in the European Union, and by international organizations, as well as for the modernization of vehicle inspection technology, the education and licensing of vehicle inspection station staff (supervisors and controllers).

Since 2009, all the vehicle inspection stations, the Agency for Identification Documents, Registers and Data Exchange of BiH (IDDEEA), and the RS Ministry of Transport and Communications have been connected to the integrated information system. This system allows the RS Ministry of Transport and Communications to monitor the operation of vehicle inspection stations in real time, to obtain data on the number and type of vehicle inspections, on the procedure and duration of vehicle inspections, on staff performance, etc. The integrated information system provides information about vehicle characteristics and malfunctions. It is used for the analysis of data relevant for road safety, and also for other analyses (environmental effect of exhaust gas emissions, collection of the public road usage charge that is paid upon vehicle registration, etc.).Since 2009, all the vehicle inspection stations, the Agency for Identification Documents, Registers and Data Exchange of BiH (IDDEEA), and the RS Ministry of Transport and Communications have been connected to the integrated information system. This system allows the RS Ministry of Transport and Communications to monitor the operation of vehicle inspection stations in real time, to obtain data on the number and type of vehicle inspections, on the procedure and duration of vehicle inspections, on staff performance, etc.

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2. STRUCTURE OF INTEGRATED INFORMATION SYSTEM FOR VEHICLE INSPECTION (IISVI)

The following features ensure the functioning of the information system:

- Modern Data Centre with optical link to the Internet
- Robust three-tier software architecture
- Software Micro Strategy BI / ORACLE Warehouse Builder
- Software/hardware encryption.

Flexible access to the information system: cable or wireless, Figure 2. The following programs for vehicle inspection have been developed and tested:

- Regular vehicle inspection: first registration (eVI), roadworthiness certificate (eVI), semi-annual inspection
- Extraordinary vehicle inspection: change of technical data (eVI), roadworthiness test
- Vehicle licencing inspection: for road passenger transport, for road goods transport.

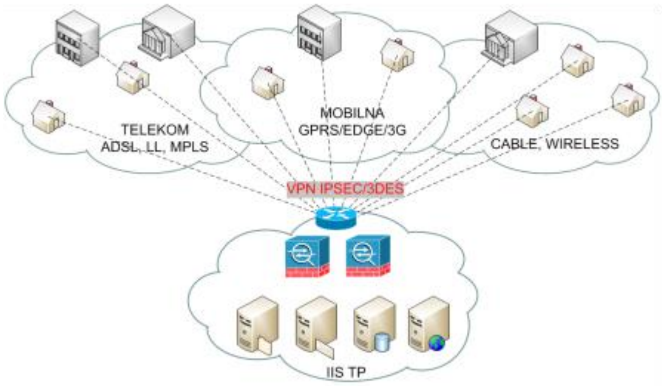

Figure 2 Access to the information system [3,4]

Figure 3 shows the procedure and phases of a regular vehicle inspection that served as the basis for program development.

If a vehicle is registered for the first time in the Republic of Srpska (first registration), vehicle inspection data are saved in the information system (72 different check data from the application form are entered in eVI). The RS Expert Institution checks data accuracy, [3].

In case of a vehicle undergoing other than its first vehicle inspection in the Republic of Srpska (roadworthiness certificate, semi-annual inspection, extraordinary inspection or vehicle licencing inspection), the integrated information system for vehicle inspection (IISVI) will automatically generate technical data on the vehicle based on its VIN. Vehicle inspection station (hereinafter: VIS) supervisor will then check whether vehicle data are correctly entered in the information system, add missing data, or correct the incorrectly entered data during vehicle inspection, if he/she has proper authorization for it.

If the supervisor is not authorized to modify vehicle data, the vehicle will be sent to certification, to identification of vehicle technical data. After certification, the vehicle will be returned to the same VIS to complete the inspection, i.e. to close the item. An extraordinary inspection – change of technical data – will be recorded in the application. The item remains open for 10 workdays, during which period vehicle inspection can be done at some other VIS. If vehicle inspection does not continue within 10 workdays, the vehicle is declared un roadworthy, and the item is closed (eVI electronic vehicle inspection form gets cancelled).

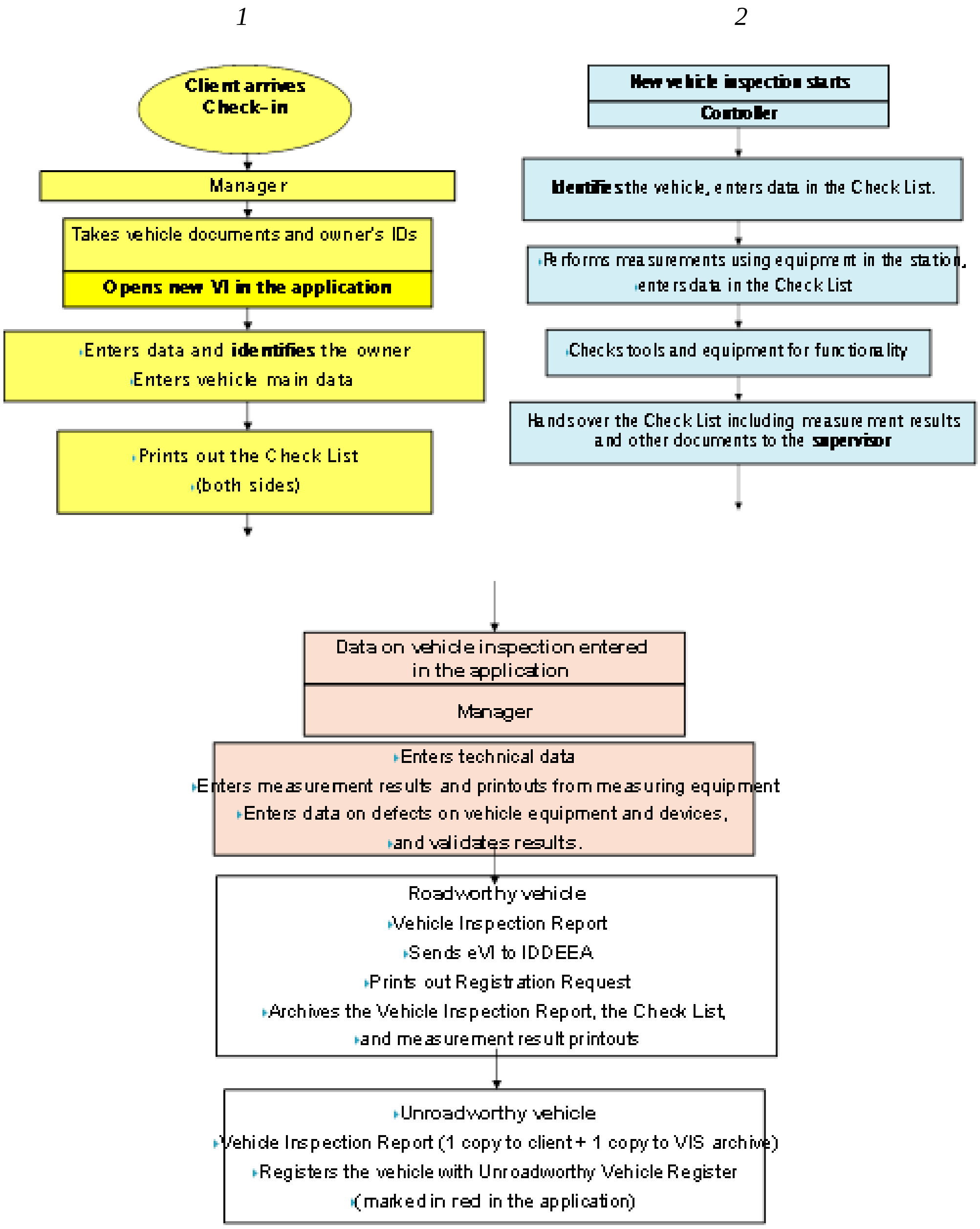

Figure 3 Regular vehicle inspection procedure and phases

Figure 4 shows the data entry application form for each new VI. The same procedure will be followed after detecting vehicle system malfunctions. Within 10 workdays, the vehicle owner must have malfunction repaired and vehicle inspection completed (close the item) at the same VIS (vehicle malfunction application). In that case, the vehicle system with detected malfunction will undergo vehicle inspection phases that were not included previously. The application will display a warning message that the vehicle was inspected at the same VIS and recorded as un roadworthy, or that it was inspected at another VIS after the expiry of the 10 workdays deadline. Figure 5 shows the warning message that appears on screen for a vehicle inspected at another VIS, and recorded as un roadworthy.

(72 data from the application form introduced into eVI)

Figure 4 eVI implementation (regular vehicle inspection – roadworthiness certificate)

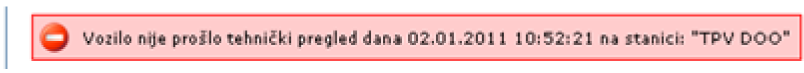

Figure 5 Warning message for vehicle inspected at another VIS and recorded as unroadworthy

Some of 72 vehicle data that are entered in the IISVI application represent obligatory data required during vehicle registration. The data are taken over from eVI form (electronic form compiled during vehicle inspection) to IDDEEA's information system, and further sent from there to relevant vehicle registration point within the Ministry of the Interior of the Republic of Srpska or the Federation of BiH or the Brcko District. IDDEEA's information system has codebooks for most of the data. If some of the data that are identified during vehicle inspection – first registration at VIS - are not in IDDEEA's codebooks (e.g. new vehicle type or brand), the Expert Institution will enter the data in IDDEEA's information system. Upon entry, the data remain inactive until confirmed by counterpart institutions from the Federation of BiH and the Brcko District (electronic authorisation), which makes it active.

3. SUPERVISION AND CONTROL OF VIS OPERATION

The integrated information system for vehicle inspection (IISVI) enables the supervision of all VIS by using search options within VIS modules: ART program for system configuration and maintenance, BI (business intelligence) program within the statistics and reporting module. ART is a web based program that practically processes SQL requests and returns results in real time (instantly or within several minutes).

For the needs of users within the RS Ministry of Transport and Communications, and IISVI administrators, 30 reports have been prepared, necessary for the tracking of activities within VIS (supervision of VIS operation, control of measurements performed at VIS, finances, VIS staff, VIS tools and equipment, aggregate reports).

Fake vehicle inspections used to be frequent before the introduction of the information system. For that reason, the RS Ministry of Transport and Communications, together with the Expert Institution, tried to find a system solution to the issue by introducing time standards for different types of vehicle inspections. The system is designed to disallow the beginning of a new vehicle inspection before the time set within the time standard has expired. Unfortunately, this has not fully eliminated fake vehicle inspections but they have significantly reduced in number. Progress has been achieved in facilitating the work of the Ministry of Transport and Communications and inspection authorities, pertaining to supervision and control. In addition to being able to monitor time standards, there is an option for monitoring the recording of measured values of physical quantities. Figure 6 shows an example of measurement recording control.

Kontrola unosa mjerenja :: tp1 :: Thu Jun 09 18:35:12 CEST 2011

ŠIFRA	STP	NALOG	DATUM	MOTOR	ZAT_GASOVA	CO_2	SL_HOD_UPRAVLJAČA	KOEF_KOČ_RADNE_KOČ	POM_KOČNICA	RADNA_KOČ_D	RADN
001	AUDI CENTAR DOO	1,291	09.06.2011	OTTO	-	7.4	-	64	-	-	97
001	AUDI CENTAR DOO	1,286	09.06.2011	DIZEL	1.1	-	4	60	24	263	252

Figure 6 Monitoring of measurement recording

During scheduled visits to VIS, the Expert Institution controls the possession and quality of measuring equipment. Data on executed controls and control results relating to VIS measuring equipment are saved in the information system. Figure 7 shows a report on the condition of examined measuring equipment, generated by the information system.

Uređaji koji se baždare :: tp1 :: Thu Jun 09 18:42:58 CEST 2011

STP	ŠIFRA	VRSTA_UREĐAJA	PROIZVOĐAČ_TIP	SERIJSKI_BROJ	GOD_PROIZ	MJERNI_OPSEG
AUDI CENTAR DOO	001	KOČNI VALJCI	MAHA, NJEMAČKA-EURO SYSTEM LKW	B102-060405	2003	0-40 kN
AUDI CENTAR DOO	001	DINAMOMETAR	MAHA, NJEMAČKA-PK-100-MA02	0303100788	2003	0-1000 N
AUDI CENTAR DOO	001	MJERAČ USPORENJA	MAHA, NJEMAČKA-VZM 100	B90-010759	2003	0-10 m/s2
AUDI CENTAR DOO	001	REGLOSKOP SA LUXMETROM	MAHA, NJEMAČKA-LITE 1.1	B95-002320	2003	0-64 lx

Figure 7 IISVI report on status of examined measuring equipment

ART reports in real time open up excellent possibilities for creating aggregate reports by selected time periods (report on the number of executed vehicle inspections by VIS, list of un roadworthy vehicles by VIS and by controller, report on registered malfunctions, average age of vehicles by vehicle type, list of pass rates for vehicle license inspection, etc.).

Micro Strategy program is used for statistical data processing. Micro Strategy is a collection of applications, procedures, and methodologies for data management – collection, storage, analysis, and presentation. Such a system allows users to execute advanced data analysis from the integrated information system for vehicle inspection, as well as to have better control of VIS operation.

4. ADDITIONAL USE OF IISVI

The information system for vehicle inspection is used by many other RS institutions. The Hydro Meteorological Institute of the Republic of Srpska makes estimates on air pollution in urban areas by means of COPERT program. Vehicle data that they require are taken from IISVI, [5].

Data from IISVI facilitate the work of the RS institutions responsible for supervision and inspection, as well as the process of forensic expertize.

VIS can issue the "Odometer Reading Report" through IISVI. Data on odometer readings during all regular vehicle inspections (first registration, roadworthiness certificate, semi-annual inspections) are taken from IISVI. Nevertheless, one has to be aware that with some vehicles, odometer readings do not correspond to their actual mileage due to various manipulations, [6].

IISVI may also significantly facilitate the work of traffic police, pertaining to extraordinary vehicle inspections, [7]. It is the reason why the program has been upgraded to match the needs of traffic police. At present, traffic police send vehicles to specified VIS to be able to collect the Vehicle Inspection Report the following day. Due to such complicated procedure, along with the issue of payment for extraordinary VI if the vehicle is declared roadworthy, traffic police end up having a very small number of vehicles undergoing extraordinary VI. Sixty traffic teams send, on average, less than one vehicle per week to extraordinary VI. An advanced information system for the police would allow the use of tablet computers, which would make traffic police work more efficient and more professional. The system would enable access to all relevant data from the IDDEEA's database and the RS Ministry of Transport and Communication's database on vehicle inspections. Such a solution would greatly simplify traffic police work relating to vehicle roadworthiness control. It would create conditions for a larger number of extraordinary vehicle inspections to check vehicle roadworthiness, which would directly result in improved road safety. The advantages of such a system are as follows:

- Extraordinary vehicle inspection can be conducted at any VIS
- Traffic police can conduct on-the-spot check of previous extraordinary vehicle inspections
- Extraordinary VI Report on Unroadworthy Vehicle is printed in the police station, and sent for further processing
- Administrator within the Ministry of the Interior can supervise all traffic teams,
- Real time monitoring
- Reports can be generated for any specified period (day, week, month, etc.) from when IISVI was activated.

Figure 8 shows an option for the implementation of the integrated information system for the police (IISP).

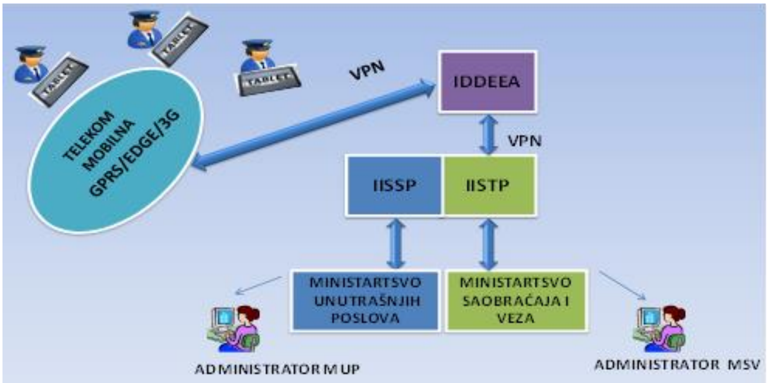

Figure 8 Schematic diagram of police information system implementation

5. CONCLUSIONS

The introduction of the new work system, Expert Institution, and integrated information system for vehicle inspection is important for the following reasons:

- Supervision and control of VIS operation is simplified, thus greatly reducing possibilities for any manipulation during vehicle inspection
- VIS staff ongoing education
- Large amount of data collected during vehicle inspection can be statistically analysed, and they are important for different parts of society: environmental pollution calculations, toll road revenue forecast, fuel consumption forecast, road safety analysis, court proceedings requiring efficient and accurate vehicle data, etc.
- Upgrading of IISVI can facilitate traffic police work and increase efficacy in terms of extraordinary vehicle inspections.
- Special contribution to improving overall road safety.

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COMPARATIVE COMPOSITE AND CONVENTIONAL DRIVE SHAFT ANALYSIS

Marko Denić[1]*, Zorica Đorđević, Vesna Marjanović, Nenad Petrović, Nenad Kostić*

UDC:621.824

ABSTRACT: Composite materials are still not in widespread use in the industry due to their unexplored potential. One of the uses of composite materials can be in drive shafts. Using lightweight materials for propulsion components can potentially significantly decrease their weight in comparison to their metal counterparts, while maintaining performance characteristics. Drive shafts are subjected to torsion and in rare cases they are subjected to bending. This paper explores the angle of twist in case of torsion, deflection in case of bending, mass, and eigenfrequencies (1st mode) in three cases of frequently used composites (E Glass, High Strength Carbon, and Kevlar-49), and compares the results to those of conventional material shafts. Numerical testing of examples was conducted in Autodesk Helius Composites 2016. The research also covers possible variations of composite shafts to include the influence of the number of layers in the composite, their directions, and possible combination of composite and metal in shaft design and their respective influences on shaft characteristics.

KEY WORDS: composite materials, drive shaft, shaft torsion, bending, eigenfrequency

KOMPARATIVNA ANALIZA KOMPOZITNOG I KONVENCIONALNOG KARDANSKOG VRATILA

REZIME: Kompozitni materijali nisu još uvek u širokoj primeni u industriji zbog njihovog neistraženog potencijala. Jedna od primena se može naći u kardanskim vratilima. Upotreba lakih materijala za pogonske elemente može značajno smanjiti njihovu masu u poređenju sa istovetnim čeličnim elementima, zadržavajući, pri tom, iste performanse. Kardanska vratila opterećena su na uvijanje i u ređim slučajevima na savijanje. Rad istražuje ugao uvijanja u slučaju torzije, ugib u slučaju savijanja, masu i sopstvene frekvencije za tri najčešće upotrebljena kompozitna materijala (staklena vlakna, ugljenična vlakna visoke čvrstoće, kevlar) i predstavlja poređenje rezultata dobijenih ispitvanjem konvencionalnih kardanskih vratila. Numerička analiza primera vršena je u Autodesk Helius Composites 2016. Istraživanje, takođe, pokriva potencijalne varijacije kompozitnih materijla uključujući uticaj broja slojeva kompozitnih materijala, orijentacije vlakana u slojevima, i moguće kombinacije kompozitnih i metalnih metarijala kardanskih vratila, kao i njihov respektivni uticaj na karakteristike vratila.

KLJUČNE REČI: kompozitni materijali, kardansko vratilo, uvijanje vratila, savijanje, sopstvene frekvencije

[1] *Received: July 2016, Accepted September 2016, Available on line December 2016*

COMPARATIVE COMPOSITE AND CONVENTIONAL DRIVE SHAFT ANALYSIS

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UDC:621,824

1. INTRODUCTION

The automobile industry has seen a growth in implementation of composite materials in the past years, however it is still a slow process, as the material properties for various load cases is still being researched. Following this trend of using lightweight materials to replace steel components more and more parts are being produced using composites. However composites are still most frequently found in static and cosmetic elements. Drive shafts made of composites have most recently been featured in some BMW M series models. Use of composite materials for propulsion components is still a developing field of study. Drive shafts (cardan shafts) are main driving components for transferring torque in vehicles. The use of composite materials for making drive shafts implies decreasing the mass compared to conventional material shafts. In the use of composite materials the orientation of fibers plays an important role in load distribution and stress characteristics. Depending on the load case, fibers need to be placed at optimal angles to minimize deformation of the shaft. The base of this research is to analyze and compare drive shaft numerical calculations for steel and composite drive shafts in the same loading scenarios.

Kaviprakash et al. [3] conducted research on fiber orientation in laminar composites, as well as the order of layering. Their optimization was done in ANSYS for hybrid shafts made from high strength carbon fibers, high module carbon fibers, Kevlar, and epoxy resins. The results were compared to conventional shafts and showed improvements in decreasing mass of approximately 79%, lowering stress as well as improving fuel economy. Hatwar and Dalu [2] analyzed E Glass and carbon fiber shafts in combination with epoxy resins. Static analyses conducted in ANSYS were compared to analytical results for maximum shear strain, shear stress, equivalent stress, natural frequency, and mass, for steel shafts, carbon, and glass shafts. The results showed a decrease of mass by over 72% for composite shafts with similar deformation and stress characteristics. Rothe and Bombatkar [5] tested a composite shaft made from high strength carbon fibers using static, modal, and buckling analyses. Bhajantri et al. [1] replaced a two-part steel shaft for a single-part composite shaft decreasing the mass by up to 50% and concluding optimal parameters for the orientation of fibers in layering using regression analyses. Ravi [4] analyzed composite

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shafts made from carbon fibers using a combination of tetrahedral and hexagonal finite elements. The results were compared to conventional shafts and showed a decrease in mass by 24%. The analysis covered hollow and full shafts concluding favourable dimension ratios for hollow shafts. Sivakandhan and Prabhu [6] optimized fiber angles in symmetrical layers of equal thicknesses for composite shafts. They optimized composite drive shafts achieving decreases in mass of 15% and 72% respectively compared to conventional shafts.

This paper analyses single-part laminar composite drive shafts, for possible use in heavy duty trucks, and gives a comparison of numerical calculations for both the composite shaft and its steel and aluminium counterparts. Three of the most frequently used composite materials are used in this research, as determined by literature review. Results are shown for all parameters for both composite and metal shafts. Analysed properties are twist angle, deflection, eigenfrequencies, and mass. Additionally variations of the number of layers, their direction and possible combination with conventional materials are also explored.

Test example drive shafts were tested in Autodesk Helius Composites 2016. This new software is easy to use and it is accurate in simple load cases in comparison to other software, which use FEA method, such as ANSYS, Abaqus, and DS CATIA.

2. SELECTION OF MATERIALS

The comparative analyses conducted in this paper aim to show the difference in performance and mass of conventional, metal, shafts and various frequently used composite shafts. Calculations were performed in ANSYS and verified in Helius Composites for both metal and composite shafts.

The conventional materials used for the purposes of this research are S275JR, as it has widespread use in the automobile industry, and 6061-T6 Aluminium. Material characteristics are taken from the standard material library in ANSYS and are given in table 1. A survey of available literature on the subject shows that the most frequently used composite materials for drive shafts are E Glass Epoxy, High Strength Carbon, and Kevlar (Kevlar-49). Material characteristics for E Glass and Kevlar-49 are taken from the material library in Helius Composite and are given in table 1. HSC characteristics were used from [3] and a material with those properties was created in the software manually.

Table 1 Characteristic of steel, aluminum and composite materials

Material	E11, [MPa]	E22, [MPa]	E33, [MPa]	G12, [MPa]	G13, [MPa]	G23, [MPa]	$\nu 12$, [/]	$\nu 13$, [/]	$\nu 23$, [/]	ρ, [kg/m3]
Steel	$2.1 \cdot 10^5$	$2.1 \cdot 10^5$	$2.1 \cdot 10^5$	$8 \cdot 10^4$	$7.6 \cdot 10^4$	$7.6 \cdot 10^4$	0.3	0.3	0.3	7860
Aluminum	$6.83 \cdot 10^4$	$6.83 \cdot 10^4$	$6.83 \cdot 10^4$	$2.62 \cdot 10^4$	$2.62 \cdot 10^4$	$2.62 \cdot 10^4$	0.33	0.33	0.33	2710
E Glass	$4.48 \cdot 10^4$	$1.24 \cdot 10^4$	$1.24 \cdot 10^4$	$5.52 \cdot 10^3$	$5.52 \cdot 10^3$	$3.60 \cdot 10^3$	0.28	0.28	0.36	2080
HSC	$1.35 \cdot 10^5$	$7 \cdot 10^3$	$9.26 \cdot 10^3$	$5.8 \cdot 10^3$	$6.15 \cdot 10^3$	$3.08 \cdot 10^3$	0.31	0.31	0.50	1580
Kevlar-49	$7.58 \cdot 10^4$	$5.52 \cdot 10^3$	$5.52 \cdot 10^3$	$2.07 \cdot 10^3$	$2.07 \cdot 10^3$	$1.54 \cdot 10^3$	0.34	0.34	0.47	1380

3. EXPERIMENT

Literature suggests general dimensions of shafts in the automobile industry as well as their loads. This research will be conducted on a modified version of the example from [2]. The hallow drive shaft is 1000 mm long, 100 mm in diameter, while the wall thickness is 3.32 mm. The shaft is loaded with 3000 Nm of torque on one end, while the other end is fixed. In order to analyze bending of the shaft (deflection) the standard procedure for simulating bending loads was used in three points with a force of 1000 N.

The steel drive shaft was first calculated for maximal shear stresses, twist angle and deflection of the shaft on bending analytically. In order to verify the analytical method, a numerical analysis was conducted under the same loading and constraint conditions in ANSYS. The finite element mesh consists of 15876 tetrahedral elements with 5 mm sides and 108415 nodes. Calculated values as well as the mass of the steel shaft are given in table 2.

Table 2 Analytical and Numerical results comparison for steel shaft

	Analytical	Numerical	Difference [%]
Shear Stress [*MPa*]	63.58	63.917	0.527
Twist angle [°]	0.911	0.947	3.801
Deflection [*mm*]	0.076	0.084	9.524
Mass [*kg*]	7.916	7.916	0

Comparing the calculated values, it can be concluded that the differences in results are less than 10%, and given the magnitude of the values, the numerical results are adopted as valid.

Further calculations of the composite and aluminium shafts, conducted in Autodesk Helius Composites 2016, will be compared to the numerical results from ANSYS for the steel shaft.

4. RESULTS

Numerical calculation resaults are shown and compared graphically to best illustrate the difference in characteristics of the examined materials of shafts. Results attained are mass, twist angle, deflection, and eigenfrequency values for steel, aluminum, E Glass, HSC and Kevlar-49 shafts.

The greatest benefit of using composite shafts in the automobile industry is decreasing the mass of the vehicle. The masses of the examined shafts are given in figure 1.

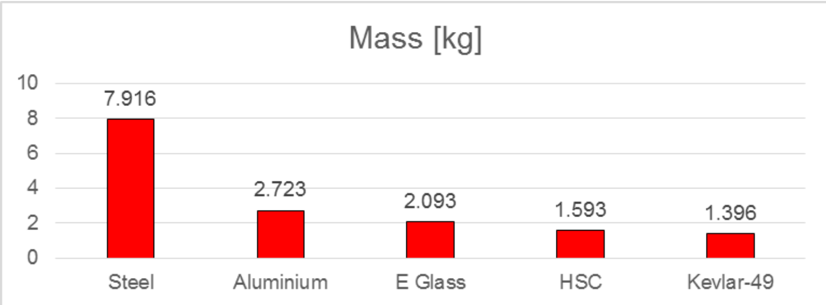

Figure 1 Masses of drive shafts

The twist angle is the other important parameter calculated for the shafts. Figure 2 shows the twist angle values in degrees for all calculated drive shafts.

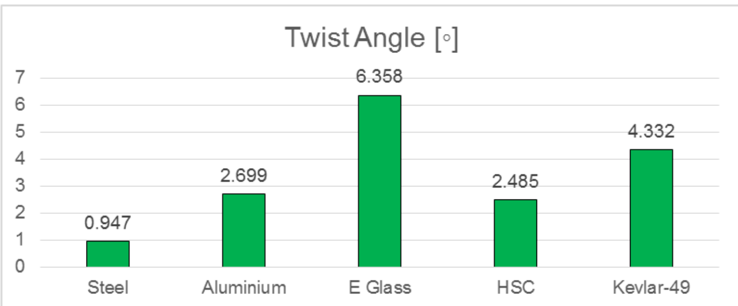

Figure 2 Twist angles of drive shafts

Even though drive shafts in automobiles are most frequently just subjected to torsion, they are also calculated for the case of bending, usually by subjecting them to forces in three points. The maximal deflection is calculated in the middle of the shaft. There are no suggestions stipulated for deflection, however it is best to keep deflection under a few millimetres per meter of length. As the drive shaft has enough clearance to withstand such deformations due to stochastic changes in terrain over which the vehicle is moving these small deflections are acceptable. Figure 3 shows maximal deflection values in the middle of the shaft.

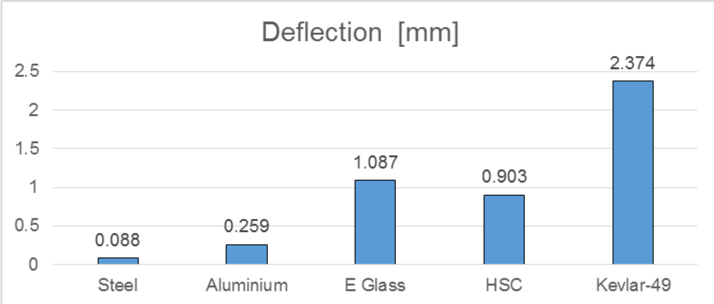

Figure 3 Deflection of drive shafts

Figure 4 graphically shows values of eigenfrequencies (for the 1st mod) for each shaft. One of the main reason for practical implementation of two-part steel drive shafts is that the single-part drive shaft exhibited unfavourable eigenfrequencies due to the length of the shaft. Due to a drastic difference in eigenfrequencies of composite material shafts, two-part metal shafts can be exchanged for single-part composite shafts.

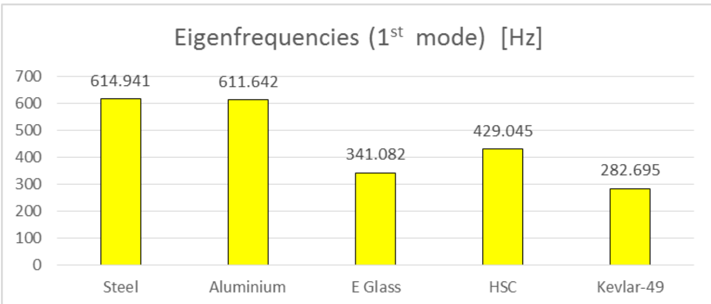

Figure 4 Eigenfrequencies of drive shafts (1st mode)

All fibers for the calculated composite shafts are set at an angle of ±45° in for layers as suggested by literature as being optimal positioning of fibers in the layers of the composite for more than one loading scenarios.

5. COMPOSITE VARIATIONS

Further analysis is directed towards determining the best variation of the composite drive shafts. The variation of the number of layers by doubling the number in every sequential iteration is conducted to determine the influence of the change in the number of layers on the previously calculated parameters. The overall thickness of the layers is 3.32 mm and is constant. All the same calculations were conducted as in the previous section, except that the experiment of the change in the number of layers is only conducted on the E Glass shaft, as it is most frequently used in literature. The results of the varied number of layers are shown in table 3.

Table 3 Influence of the change in the number of layers on deflection, torsion and eigenfrequency for E Glass drive shafts

Number of layers	4	8	16	32
Deflection [mm]	1.0872	1.0739	0.0708	1.07
Angle of Twist [^{0}]	6.039	5.759	5.693	5.676
Eigenfrequency(1st mode) [Hz]	341.082	341.191	343.694	343.819

As the change in the number of layers has been found to not have a big influence on shaft characteristics, the next variation in this experiment is directed towards determining the influence of the layer order. Various orientation of the angle of fibers when the fibers in the layers are oriented from 0^0 to 90^0 is tested for the four layer E Glass shaft. Two variations are tested with layer combinations of -45^0, 0^0, 45^0, and 90^0 in variations and the resulting characteristics presented in table 4, with the first combination being the same as in the first comparison.

Table 4 Influence of fiber direction changes in layers

Directions of fibers combinations in layers	$45^0/-45^0/45^0/-45^0$	$0^0/-45^0/45^0/90^0$	$45^0/0^0/90^0/-45^0$
Deflection [mm]	1.0872	0.926	0.822
Angle of Twist [^{0}]	6.039	8.152	9.873
Vibration (1st mode) [Hz]	341.082	369.584	392.366

Due to the high costs of composite materials, there is a tendency to combine conventional with composite materials in drive shaft design to form hybrid drive shafts. This way the best of both materials characteristics can be exploited. The idea is to start off with a steel or aluminium base and layer over them with composites. The distribution of stress in the layers needs to be accounted for in order to avoid having the metal base from transmitting the greater part of the load, thereby not using the potential of the composite layers. This research tested steel and aluminium base shafts in combination with E Glass composite in four layers 1.66 mm thick oriented in the setup of 45/-45/45/-45. The steel and aluminium bases have thicknesses of 1.66 in both cases. Table 5 gives the characteristics of two hybrid shafts and compares the values to their base metal and purely E Glass shafts.

Table 5 Comparison of hybrid steel/E Glass and Aluminum/E Glass shaft to the metal and E Glass composite drive shaft characteristics

Material	Steel/ E Glass	Steel	Aluminum /E Glass	Aluminum	E Glass
Deflection [mm]	0.342	0.088	0.577	**0.259**	1.087
Angle of Twist [^{0}]	2.594	**0.947**	4.11	2.699	6.358
Mass [kg]	5.01	7.916	2.414	2.723	**2.093**
Eigenfrequency (1st mode) [Hz]	393.018	614.941	436.039	611.642	**341.082**

6. CONCLUSIONS

This paper analysed the use of composite materials and their variations and compared their characteristics (deflection, torsion, eigenfrequency and mass) with those of conventional shafts.

The use of composite materials for creating drive shafts can significantly decrease the mass of this component. The difference in weight among the composite shafts is around 10%, and the composite with the smallest mass is Kevlar-49 with a decrease in mass of 82.36%. Other tested characteristics for composite shafts do not show such drastic differences.

High strength carbon (HSC) showed itself as the least susceptible to torsion, with a twist angle of 2.485^0, which is less than that of its aluminium counterpart, but over 2.6 times greater than that of the corresponding steel shaft. E Glass has performed the worst under these circumstances with a twist angle of 6.358^0 which is still acceptable.

Deflection has the greatest variance in results between the materials. Of the composite shafts HSC performed the best, while Kevlar-49 had the greatest deflection, however all deflection values can be considered acceptable due to their minuscule values. Eigenfrequencies are significantly lower for composite materials than for conventional steel and aluminum shafts, as was expected.

Further variations of the E Glass composite by changing the number of layers made small decreases the twist angle with the increase of the number of layers, and had an overall insignificant influence on the characteristics of the shaft in comparison to the increased complexity of production. The changes in fiber orientation in the layers only slightly improved deflection from the initial setup, while worsening other characteristics. Therefore it can be concluded that the initially calculated setup of composites with 4 layers with angles of fibers changing from +45^0 to -45^0 in each layer to be optimal.

Due to the costliness of composite materials a compromise in the design solution can give favourable results compared to conventional design solutions. The combination of E Glass with steel, and E Glass with aluminium was tested and demonstrated improvements in deflection (around 31% increase for Glass/steel), and twist angle (around 40% decrease for E Glass/steel), while having a greater mass and eigenfrequency compared to a purely E

Glass composite shaft, but a significantly lower mass than their corresponding metal counterparts.

Any decrease of mass in automobiles is in direct correlation with the decrease of fuel consumption. An improvement of fuel economy through further research into, and implementation of composite materials inevitably leads to a decrease of automobiles negative effects on the environment.

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DETERMINATION THE NORMS OF FUEL CONSUMPTION FOR BUSES IN THE PUBLIC TRANSPORTATION IN REAL CONDITIONS OF EXPLOITATION

Slobodan Mišanović[1]

UDC:629.341

ABSTRACT: Determination the norms of fuel consumption for the buses are operating in the public transportation system is an important indicator of exploitation, which should serve as a benchmark when analysing fuel economy of bus. Viewed from a strategic point of business, optimization of fuel consumption is a significant step in the program of measures relating to reducing the financial expenses of the company. Lower consumption of fuel means better environmental performance for vehicles that are manifested through lower emissions as an important issue in terms of environmental protection and sustainable development.

In this paper presents an example of determining the norms of fuel consumption for the largest group of articulated buses ''Solaris Urbino 18", which are in fleet JKP GSP "Beograd" (City Public Transport Company "Belgrade").

The norms were obtained by statistical analysis of the representative sample lines where the buses in operation. Norms of consumption was obtained on the basis of interval estimates of the mean value fuel consumption for selected lines and establishing a correlation dependence of the fuel consumption and exploitation speed of bus.

KEY WORDS: norms of fuel consumption, bus, public transportation

ODREDJIVANJE NORMATIVA POTROŠNJE GORIVA ZA AUTOBUSE U JAVNOM GRADSKOM PREVOZU U REALNIM USLOVIMA EKSPLOATACIJE

REZIME: Odredjivanje normativa potrošnje pogonskog goriva kod autobusa koji se koriste u sistemu javnog gradskog prevoza je važan eksploatacioni pokazatelj, koji je posbno značajan za analizu gorivne ekonomičnosti autobusa. Gledano sa strateške tačke poslovanja, optimizacija potrošnje goriva predstavlja značajan korak u programu mera koje se odnose na smanjenje finansijskih troškova preduzeća. Manja potrošnja goriva daje bolje ekološke performanse vozila odnosno niži nivo emisije štetnih gasova što doprinosi zaštiti životne sredine. U ovom radu predstavljen je primer utvrđivanja normativa potrošnje goriva za grupu zglobnih autobusa " Solaris Urbino 18 ", koji su u voznom parku JKP GSP "Beograd ". Normativi su dobijeni statističkom analizom na reprezentativnom uzorku na linijama gde su autobusi u radu, korišćenjem intervalne ocene srednje vrednosti potrošnje goriva za odabrane linije i uspostavljanjem korelacione zavisnosti eksploatacione brzine kretanja i potrošnje goriva autobusa.

KLJUČNE REČI: normativ potrošnje goriva, autobus, javni prevoz

[1] *Received: July 2016, Accepted September 2016, Available on line December 2016*

DETERMINATION THE NORMS OF FUEL CONSUMPTION FOR BUSES IN THE PUBLIC TRANSPORTATION IN REAL CONDITIONS OF EXPLOITATION

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1. INTRODUCTION

Determination of norms of fuel consumption for different groups of buses that make up the fleet of one company for public transport, stems from the fact of their different tehnical characteristics and different service conditions on the routes where vehicles operate.

In this paper is present a case of determining norms of fuel consumption for a group of articulated buses ’’Solaris Urbino 18’’. The fleet GSP ’’Beograd’’ has 200 buses of this type that were acquired in the period August-December 2013. Of the planned number of 640 buses in operation on work days, this group accounts for about 31% of the vehicles in operation and represents the largest group of buses. At the time when norms determination, vehicles have passed the phase of elaboration of the vehices and their technical condition was optimal. Mileage of tested vehicles is ranged from of 60 000 and 90 000 km.

When were buses purchased an integral part of the documentation of the tender was the test fuel consumption according to the method SORT 1 (urban cycle). The manufacturer has declared consumption for this test of 56 L / 100km. The question is how this result is close to the actual fuel consumption in the real system. In Figure 1 is presented one of the buses from that group with the basic technical characteristics

SOLARIS Urbino 18
Engine: DAF PR 228 Euro 5
Power: 231 KW
Torque 1275 Nm
Volume: 9,186 cm^3
Transmission: ZF-6AP
Length: 18.000 mm
Width: 2,550 mm
Height: 3,050 mm
Vehicle capacity: 159 passengeres
Year: 2013
Number of vehicles in fleet: 200

Figure 1 Articulated bus Solaris Urbino 18 with basic technical data

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2. THE INFLUENTIAL FACTORS ON THE FUEL CONSUMPTION OF BUSES FOR URBAN TRANSPORT

The fuel consumption of buses is a complex function of several independent factors. The most important factors to fuel consumption are:

- Performance vehicles (powertrain features-power, torque, specific consumption, transmission characteristics, weight, aerodynamics)
- Characteristics of road (longitudinal gradients, horizontal curve, adhesion characteristics of road)
- Traffic conditions (traffic flow, number of passengers in bus , keeping at the traffic lights, the number of stations, etc.)
- Period of exploitation (winter, summer - the use of air conditioners)
- Technique vehicle handling.

Fuel consumption of buses for public transport in terms of the characteristics in direct connection with the constructive and exploitation characteristics of the engine, the load of the bus, the size of the resistance movement, the characteristics of transmission of the remaining components.

The density and structure of traffic flow, the level of regulation of intersections and the number of stations on the route of the most important factors when the conditions of the bus in question. These impacts can best demonstrate the value of exploitation speed (Ve) by bus realized on the line [1].

$$Ve = 2Lr \cdot Te\text{-}1 \qquad [km \cdot h^{-1}] \qquad (1)$$

$$Ve = 2L_r \cdot (Tv + Tss + Tts)^{-1} \qquad [km \cdot h^{-1}] \qquad (2)$$

Ve- exploitation speed [km• h^{-1}]

Lr - length of route [km]

Te - the duration of use [h]

Tv - driving time [h]

Tss- time spent waiting at stations [h]

Tts - time spent at a traffic standstill [h].

If we take into account the time a vehicle spends in the terminal while waiting for the departure (Tt - time spent at the terminus), then we have a turnaround time (To = Tv + Tss + Tts + Tt) gives a speed turnaround such as:

$$Vo = 2L_r \cdot To^{-1} \quad [km \cdot h^{-1}] \qquad (3)$$

$$Ve > Vo \qquad (4)$$

From the expressions on the operating speed, we can conclude that as conditions for the movement tends to a greater number of stations, signal intersections, the frequent delays in traffic flow to the lower speed. With the decline of the value of exploitation speed increases fuel consumption which can be show the following picture:

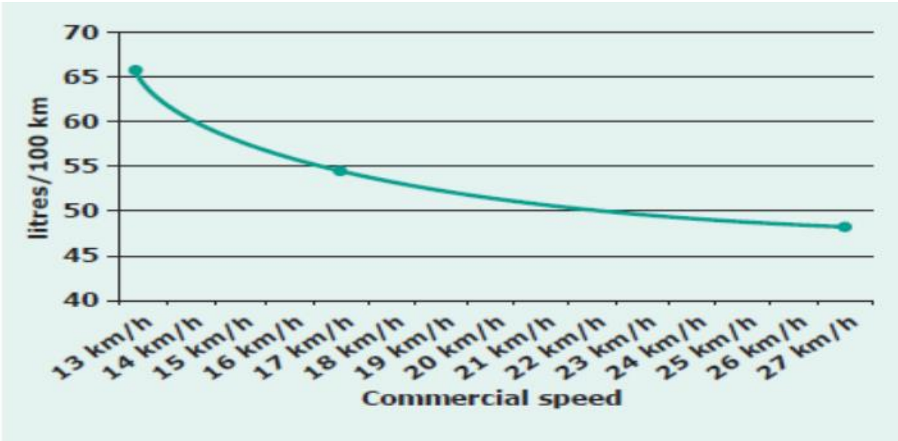

Figure 2 Dependence of fuel consumption and exploitation speed for articulated bus [2]

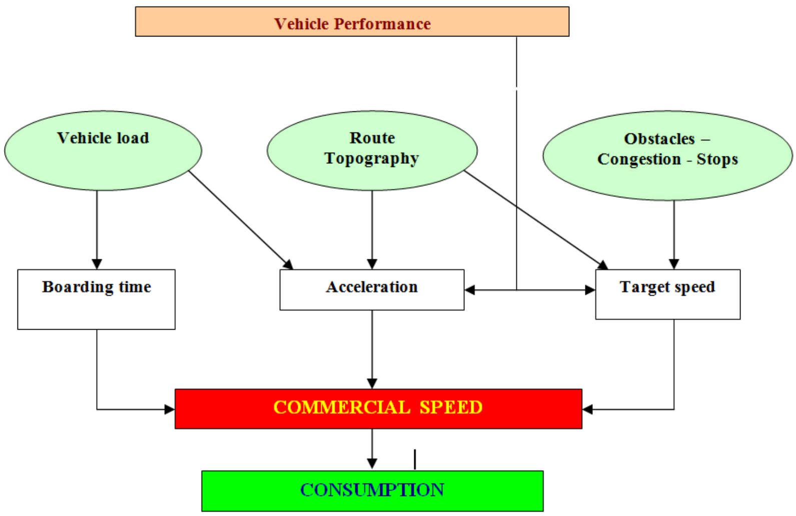

Figure 3 Influential factors on fuel consumption

From Figure 3 [2] it can be concluded that the exploitation speed of movement of buses for public transport in direct dependence on the influencing factors while fuel consumption in inverse proportion with the exploitation speed as already presented in Figure 2. For this reason, the greatest number of empirical models of fuel consumption (Akcelik-Richardson model, CNR-model, Gattuso model) as a base the size of the benefit precisely the exploitation speed of the bus [3].

3. METHODOLOGY OF DETERMINING FUEL CONSUMPTION FOR BUSES SOLARIS URBINO 18

Determining norms of consumption of fuel for vehicle group "Solaris Urbino 18", are done on the basis of the results obtained :

- The statistical method based on the measurement of fuel consumption in real conditions of exploitation by buses and lines [4]
- The research covered the period from 1.3-15.4.2014 and 1.10-31.10.2014.year, given that months: March, April and October are the authoritative period of analysis from the aspect of intensity of passenger flows, traffic conditions and external temperature as the most influential factors affecting fuel consumption in general
- The results obtained on the fuel consumption at the level of the working day, on selected lines for each bus separately. Everyday was measured quantity of fuel through the electronic system to refuel, for each bus separately. Daily mileage is obtained on the basis of reading from tachograph
- Results of the daily consumption of fuel that had extremely high values as a result of disruptions in traffic or discrepancies in the records of refueling were not taken into analysis.

It is known that the fuel consumption of motor vehicles as a stochastic phenomenon is subject to the law of normal (Gaussian) distribution. This law allows the use of statistical methods, it possible for every type of vehicles are given estimate the expected fuel consumption.

Based on a representative sample (Xi, i = 1, n) performed a statistical analysis of the results of the fuel consumption of buses Solaris Urbino 18 on lines using the mean value (Xs) and standard deviation (s).

$$X_s = \frac{X_1 + X_2 + X_3 \ldots + X_n}{n} \tag{5}$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X_s)^2}{n}} \tag{6}$$

The norm of fuel consumption was obtained on the basis of interval estimates of the mean fuel consumption (μ) of the basic set with a probability of 95%, using a normal distribution for the sample n≥ 30th [5].

$$P\left(X_s - 1.96\frac{s}{\sqrt{n}} < \mu < X_s + 1.96\frac{s}{\sqrt{n}}\right) = 0.95 \tag{7}$$

4. EXAMPLE OF MEASURING AND NORMS FUEL CONSUMPTION ON THE LINE NO.17

Line No.17 (Konjarnik-Zemun), according to the spatial position is the tangential line, of medium length (Lr) of 16.1 km. (Figure 5). Average exploitation speed (Ve) is 18.5 km h-1. The number of stations in the direction " A " is 27, in the direction of "B" is 30.

Average distance between stations is 575 meters. Line in terms of the number of passengers is one of the highly loaded lines [7].

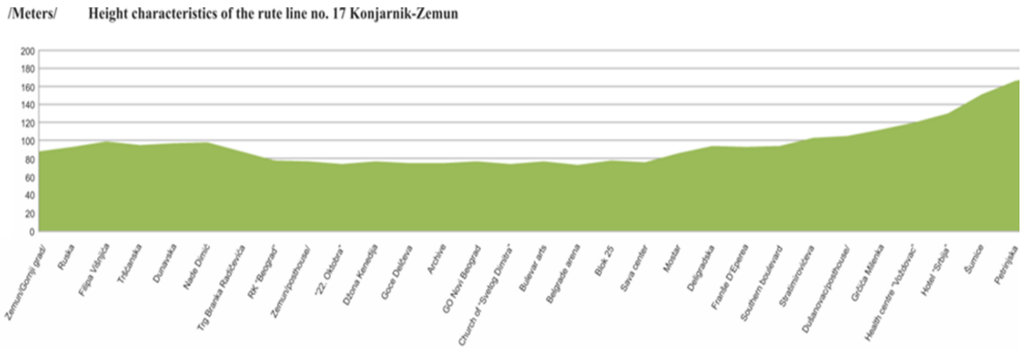

Figure 4 High characteristics of the rute line no. 17 Konjarnik-Zemun

Figure 5 Spatial position and altitude characteristics of the route line No.17

In table 1. presents the results of measurement of fuel consumption on city line No.17 (Konjarnik-Zemun) for 5 buses SOLARIS Urbino18 (Garage Number: 3002,3003,3016,3017,3018) during October 2014 [4].

Table 1 Results of measurement of fuel consumption on the line 17 (October 2014)

Number of measurement	Consumption [L/100 km]	Number of measurement	Consumption [L/100 km]	Number of measurement	Consumption [L/100 km]	Number of measurement	Consumption [L/100 km]
1	**44.03**	21	**52.33**	41	**53.6**	61	**54.92**
2	**46.31**	22	**52.36**	42	**53.63**	62	**55.02**
3	**47.57**	23	**52.46**	43	**53.63**	63	**55.07**
4	**48.56**	24	**52.54**	44	**53.69**	64	**55.2**
5	**48.98**	25	**52.54**	45	**53.69**	65	**55.2**
6	**49.18**	26	**52.6**	46	**53.82**	66	**55.25**
7	**49.23**	27	**52.65**	47	**53.82**	67	**55.33**
8	**49.24**	28	**52.67**	48	**53.85**	68	**55.42**
9	**49.38**	29	**52.8**	49	**53.9**	69	**55.76**
10	**49.74**	30	**52.83**	50	**54.05**	70	**55.88**
11	**50.00**	31	**52.88**	51	**54.24**	71	**56.45**
12	**50.41**	32	**52.88**	52	**54.43**	72	**56.5**
13	**50.71**	33	**52.91**	53	**54.44**	73	**58.31**
14	**51.08**	34	**52.94**	54	**54.51**	74	**58.47**
15	**51.44**	35	**53.04**	55	**54.51**	75	**60.48**
16	**51.53**	36	**53.05**	56	**54.57**	76	**60.82**
17	**51.6**	37	**53.28**	57	**54.58**	77	**61.45**
18	**51.86**	38	**53.28**	58	**54.62**	78	**62.25**
19	**51.87**	39	**53.28**	59	**54.64**		
20	**52.22**	40	**53.36**	60	**54.92**		

Processing of a statistical sample of 78 measurements, obtained the arithmetic average (Xs) 53.36 L / 100 km and standard deviation (s) 3.06 L/100 km.

To verify that the distribution of the test sample is consistent with "Normal"(Gauss) distribution, we will distribute samples of fuel consumption in the class, as presented at the figure 5.

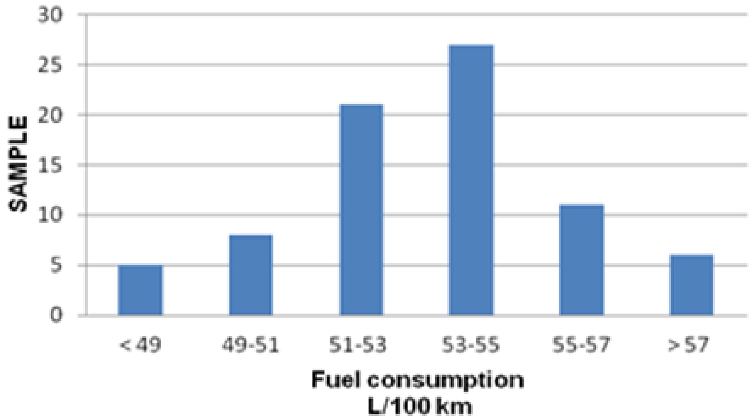

Figure 6 Distribution of fuel consumption samples in the class for Solaris Urbino 18 buses on the line No.17

Using a statistical test "χ^2" (Chi-square test) of the verify accordance the theoretical with empirical distribution of the sample (Figure 7).

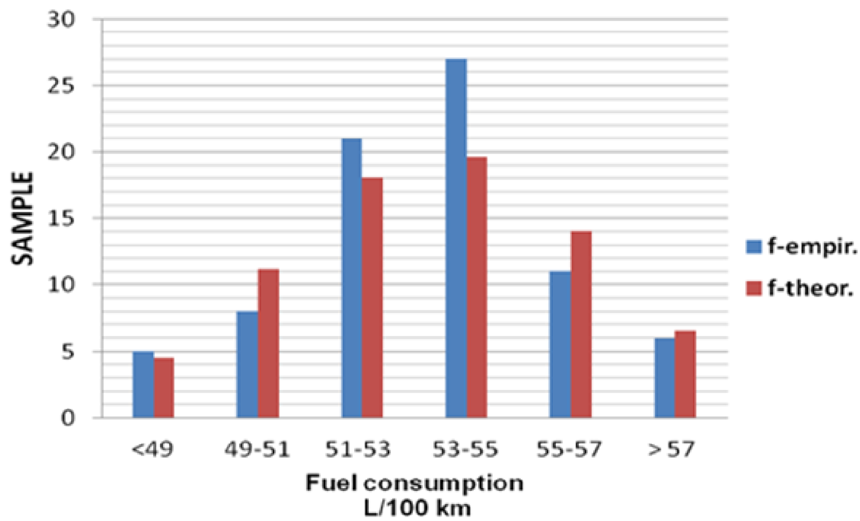

Figure 7 Empirical and theoretical χ^2 distribution sample of fuel consumption on the line No.17

$$\chi^2_{0,05} = 4.929 \quad (8)$$

respectively $\chi^2_{0,05} = 4.929 < 7.815$ (9)

where 7,815 table value $\chi^2_{0,05}$, k = r-m-1 = 3 degrees of freedom (r = number of classes 6, m = 2 number degrees of freedom for ’’normal’’ distribution). Given that the resulting value $\chi^2_{0,05}$ less than the value of the table , has demonstrated compliance with the ’’normal’’ distribution.

Based on the results of measuring the arithmetic value (Xs), standard deviation (s), normative consumption was obtained on the basis of interval estimates of the mean basic set with a probability of 95%, using a normal distribution for the sample n≥ 30 [5].

$$P\left(X_s - 1.96\frac{s}{\sqrt{n}} < \mu < X_s + 1.96\frac{s}{\sqrt{n}}\right) = 0.95 \tag{10}$$

In the present case of P (52.69 <μ <54.05) = 0.95, with a probability of 0,95, we can argue that on the city's line N0.17 for buses Solaris Urbino 18, the average consumption of fuel in the range of 52.69 to 54.05 L/100 km, which is the norm of consumption using the above methodology can be reached the relevant norms of consumption of fuel for other lines where buses SOLARIS Urbino18 are worked. The following figures are examples of the empirical distribution of fuel consumption on the lines No.23;75;83.

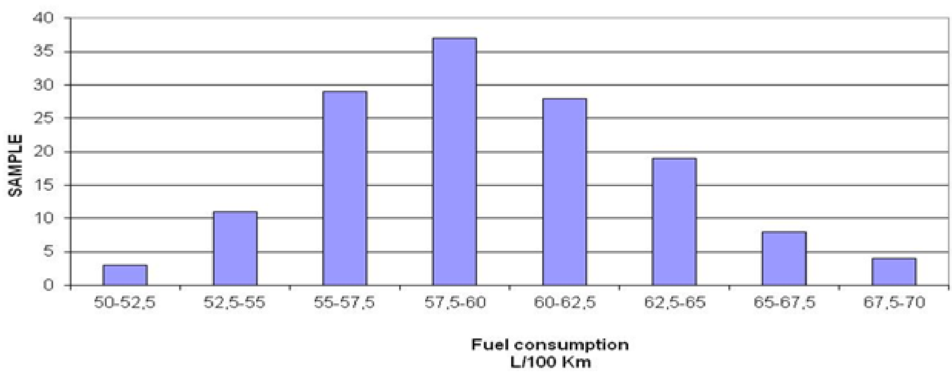

Figure 8 The empirical distribution of fuel consumption for Solaris Urbino 18, on the line no.23

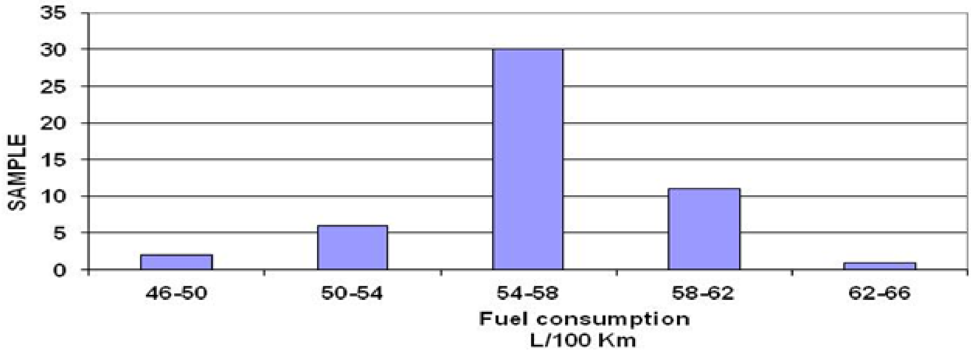

Figure 9 The empirical distribution of fuel consumption for Solaris Urbino 18, on the line no.75

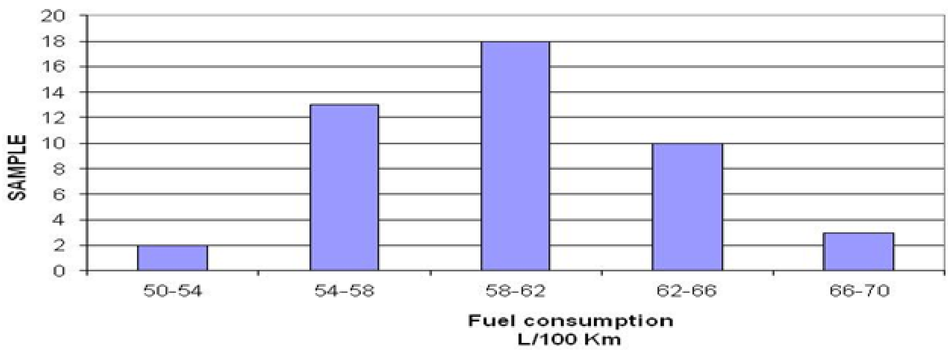

Figure 10 The empirical distribution of fuel consumption for Solaris Urbino 18, on the line no.83

In Table No. 2 presents norms of fuel consumption for buses SOLARIS Urbino 18, on city lines, are included in the research (October 2014).

Table 2 Norms of fuel consumption for buses SOLARIS Urbino 18

No.line	Exploitation speed [Km h^{-1}]	Average consumption [X_s] [L/100 km]	Stan.deviation [s] [L/100 km]	Sample size	Norms of fuel consumption [L/100 Km] ''from''	''to''
16	15.6	59.18	4.09	88	58.33	60.04
17	18.5	53.36	3.06	78	52.69	54.05
18	20.4	54.37	3.76	81	53.55	55.19
23	17.1	59.57	4.07	140	58.90	60.25
27	15.1	59.94	1.93	57	59.44	60.45
27E	16.3	58.80	2.82	51	58.06	59.61
31	13.8	62.43	4.78	84	61.41	63.46
37	16.3	56.01	2.72	76	55.40	56.62
43	16.7	51.30	2.81	72	50.02	52.57
51	15.8	52.86	1.99	77	52.41	53.30
52	16.8	56.34	2.99	46	55.47	57.20
53	18.1	56.32	2.57	31	55.42	57.23
56	19.6	52.88	2.55	32	51.99	53.77
58	17.3	51.98	3.39	35	50.86	53.10
59	18.4	60.71	2.63	52	59.99	61.43
65	16.1	56.31	3.19	63	55.53	57.10
68	17.8	54.66	3.29	42	53.67	55.66
71	16.3	53.21	1.75	43	52.68	53.73
72	23	51.75	3.20	42	50.79	52.72
75	17.3	56.37	3.01	50	55.54	57.21
77	14.9	55.52	2.94	67	54.81	56.22
83	15	60.50	3.60	46	59.46	61.54
85	18.2	52.48	1.57	30	51.92	53.05
88	20.6	52.00	3.05	44	51.10	52.90
89	17.8	53.23	3.65	51	52.23	54.24
95	19.4	53.29	3.72	102	52.57	54.02
96	19.1	51.79	3.17	31	50.68	52.91
101	28.1	44.63	3.40	38	43.55	45.79
531	26.7	39.16	1.65	34	38.60	39.71

Based on the study, results are presented in the table no.2, we can give a correlative relationship between the average fuel consumption and exploitation speed (Figure 11) for some characteristic lines: urban-diametrical (No:31;83;16), urban-radial (No:52;75); urban-tangential (No:17;88) and one suburban line (No.101).

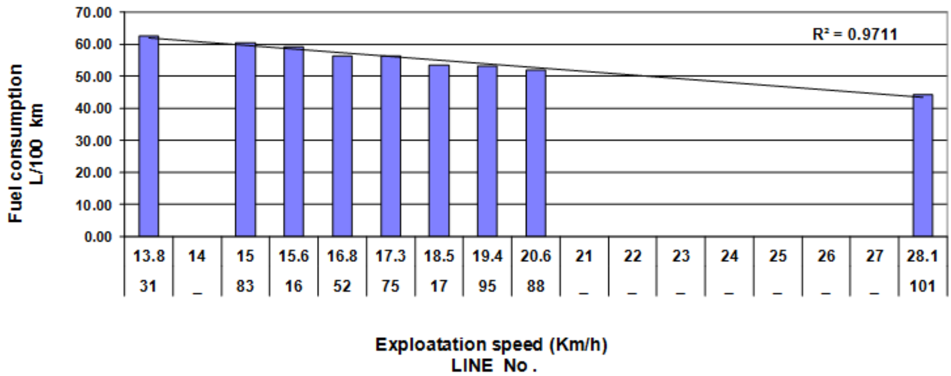

Figure 11 Correlation dependence of fuel consumption and exploitation speed for SOLARIS Urbino 18

Since that the correlation coefficient $R^2 = 0.971$, extremely high, it indicates an extremely strong the linear relationship between fuel consumption and exploitation speed. If in linear regression equation, change the value of exploitation speeds of 12-30 km h^{-1}, which is a realistic range of exploitation speeds and to cover all operating modes: City, combined, suburban, we can reach results norms of consumption as shown in Table 3.

Table 3 Norms of fuel consumption for a group of vehicles SOLARIS Urbino18, obtained from the regression

Exploitation speed [Km h^{-1}]	Expected consumption [L/100km]	Norms of fuel consumption [L/100km] 'from''	'to''
12	63.4	62.14	64.66
13	61.58	60.32	62.84
14	60.46	59.2	61.72
15	59.35	58.09	60.61
16	58.23	56.97	59.49
17	57.11	55.85	58.37
18	55.99	54.73	57.25
19	54.87	53.61	56.13
20	53.76	52.5	55.02
21	52.64	51.38	53.9
22	51.52	50.26	52.78

23	50.4	49.14	51.66
24	49.28	48.02	50.54
25	48.17	46.91	49.43
26	47.05	45.79	48.31
27	45.93	44.67	47.19
28	44.81	43.55	46.07
29	43.69	42.43	44.95
30	42.58	41.32	43.84

If we look at fuel consumption individually for each vehicle SOLARIS Urbino 18, which is the generated in October 2014 in the regular operation in depot " Novi Beograd ", we can conclude the following:

- The average fuel consumption for a group of buses SOLARIS Urbino 18 (a total of 100 buses) is 54.05 L/100 km
- All vehicles operate exclusively on urban or urban-suburban lines and depending on the exploitation of speed and load, the consumption ranges from 49.4 to 62.3 L/100 km
- The results obtained fuel consumption in real terms in October 2014 and norms of consumption that are made on the basis of the sample have a high degree of concurrency
- If the compare values of fuel consumption on the line no.17 which was obtained by statistical method 53.36 L/100 km, with the results obtained in the test using the method ’’SORT 1’’, where the resultant consumption of 56 L/100 km [6], we conclude that it is expected , considering that this is a more difficult driving cycle that has the operating speed of 12.7 km h^{-1}, compared to the exploitation speed on the line No.17 which is 18.5 km h^{-1}
- Fuel consumption during the period when using air conditioning on the bus to be increased by 15% compared.

5. CONCLUSIONS

Determination of norms of fuel consumption for buses operating in the public transportation system is an important indicator of exploitation, which should serve as a benchmark when analysing fuel economy bus. The necessity of defining norms of fuel consumption for each type of city bus, depending on the line where he works in real conditions of exploitation gives all the specifics of the given line. Monitoring of fuel consumption of each bus allows analysis and comparison with the defined standards of consumption. Savko deviation from norms means taking appropriate technical-organizational measures to return consumption within prescribed limits.

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