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UNIVERSITY OF KRAGUJEVAC, FACULTY OF ENGINEERING

SERBIAN SOCIETY OF AUTOMOTIVE ENGINEERS

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

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VIBRATION COMFORT OF THE VEHICLE EXPRESSED BY SEAT EFFECTIVE AMPLITUDE TRANSMISSIBILITY

Valentina Golubović-Bugarski [1*], *Snežana Petković* [2], *Željko Đurić* [3], *Goran Jotić* [4]

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RESEARCH ARTICLE

ABSTRACT: Research of the human body vibrations, carried out under controlled laboratory conditions, shows that human body is the most sensitive to vibrations in the frequency range that matches the biomechanical resonance. In the vertical direction, the resonance of the body is approximately 5 Hz, while in the horizontal direction the resonance occurs at frequencies less than 2 Hz. The vibrations of the vehicle have been transferred to the driver and passengers over the seats, which have the ability to attenuate or to amplify vibrations which human body is exposed to while driving. One way to determine the vibration behaviour of the seat is to measure the SEAT (seat effective amplitude transmissibility) factor, which represents the ratio between the vibrations measured on the seat and vibration measured directly on the floor under the seat. Measurement of vibrations in these two positions must be performed simultaneously. If the value of SEAT is less than 1, a seat attenuates vibrations and meets vibrational comfort, the value of SEAT greater than 1 indicates that a seat amplifies vibration, reducing vibration comfort. This paper gives results of SEAT factor investigation done on a hybrid vehicle, for different types of road surface and different modes of driving (electric power and internal combustion engine).

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KEY WORDS: vibration comfort, seat effective amplitude transmissibility SEAT, hybrid vehicle

VIBRACIONA UDOBNOST VOZILA IZRAŽENA EFEKTIVNIM VREDNOSTIMA AMPLITUDNE KARAKTERISTIKE FUNKCIJE PRENOSA SEDIŠTA

REZIME: Istraživanje vibracija tela čoveka, realizovano u kontrolisanim laboratorijskim uslovima, pokazuje da je telo čoveka najosetljivije na vibracije u frekventnom opsegu koji odgovara biomehaničkoj rezonanci. U vertikalnom pravcu, rezonanca tela je približno 5 Hz, dok se u horizontalnom pravcu rezonanca javlja na frekvencijama manjim od 2 Hz. Vibracije vozila se prenose na vozača i putnike preko sedišta, koja imaju sposobnost da ublaže ili pojačaju vibracije kojima je telo čoveka izloženo tokom vožnje. Jedan od načina za određivanje vibracionog ponašanja sedišta je merenje SEAT faktora (efektivna vrednost amplitudne karakteristike funkcije prenosa sedišta) koji predstavlja odnos vrednovanog ubrzanja merenih na sedištu i ubrzanja merenih direktno na podu ispod sedišta. Merenje vibracija u ova dva položaja mora se vršiti istovremeno. Ako je vrednost SEAT-a manja od 1, sedište slabi vibracije i zadovoljava vibracionu udobnost, vrednost SEAT-a veća od 1 pokazuje da sedište pojačava vibracije smanjujući vibracionu udobnost. U radu su prikazani rezultati istraživanja faktora SEAT za hibridno vozilu na različitim tipovima kolovoza i u različitim režimima vožnje (električna energija i motor sa unutrašnjim sagorevanjem).

KLJUČNE REČI: vibraciona udobnost, efektivna vrednost amplitudne karakteristike funkcije prenosa sedišta SEAT, hibridno vozilo

VIBRATION COMFORT OF THE VEHICLE EXPRESSED BY SEAT EFFECTIVE AMPLITUDE TRANSMISSIBILITY

Valentina Golubović-Bugarski, Snežana Petković, Željko Đurić, Goran Jotić

1. INTRODUCTION

Seat is a primary point of contact between the human body and the vehicle structure which generates the vibrations, therefore its role in the isolation of the whole-body vibrations is a very important. Proper design of a seat contributes largely in reduction of the vibration levels. Seat should be designed in such a way that the driver can drive the vehicle safely and effectively, it should have strength enough to protect the occupant in the event of an accident, it should have good static and dynamic comfort properties [11]. It is important to point out that the seat which is better in term of static comfort may be worse in the case of dynamic comfort. Figure 1 shows Ebe’s model of seat discomfort which includes a consideration of both static and dynamic factors [3, 11]. This model shows overall comfort characteristics of two different seats, one being good at rest and the other being good for driving case. In first case, static comfort is high and dynamic comfort is less. However in second case, initial static comfort is less but its dynamic comfort is high. Therefore, seat „a“ will be better for environments with large magnitudes of vibration but seat „b“ will be better for environments with low magnitudes of vibration. It is up to the manufacturers to optimize the comfort for both cases.

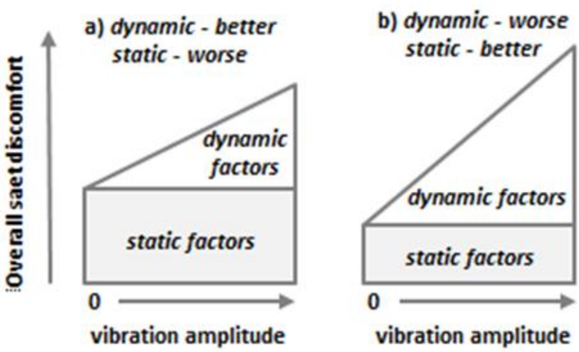


Figure 1. Ebe’s model of the overall seat discomfort [3, 11]

Investigation of seat comfort showed that the ideal seat in any situation is a function of the seat static properties, the seat dynamic properties, the vibration to be controlled, and the human perception characteristics. It can be found in [11] that investigation of static parameters was done, for example driver posture [14, 13], contact pressures [15, 7], and thermal properties [12]. When it comes to dynamic comfort, laboratory studies of whole-body vibration have established a relationship between the magnitude, duration, frequency content, and waveform of the signal. The nature of the seat dynamic response is much complex than its static performance. The dynamic response of the seat is influenced by the dynamic properties of the human body, so the real occupant cannot be replaced by an inert mass as in static investigation. The transmissibility of a seat measured with one occupant will be slightly different when tested with a different occupant [17]. Also, the transmissibility of the seat measured while driving on a smooth surface will be slightly different when tested on a rough surface [4]. Present studies are mostly devoted to investigation of damping properties of the suspension seats in working machines, such as tractors [1, 5] and construction machines [2, 10].

2. THE EFFECTS OF VIBRATION ON COMFOR AND PERCEPTION

Thresholds of perception for continuous whole-body vibration vary widely among individuals. Approximately half of the people in a typical population, no matter standing or seated, can perceive a vertical weighted peak acceleration of 0.015 (m/s^2). A quarter of the people would perceive a vibration of 0.01 (m/s^2), but the least sensitive people would only be able to sense a vibration magnitude of 0.02 (m/s^2) or more, as it is described in ISO 2631-1 [8]. Regarding the vibration comfort in vehicles, a particular vibration condition may be considered to cause unacceptable discomfort. Many factors combine to determine the degree to which discomfort may be noted or tolerated. Acceptable values of vibration magnitude for comfort depend on passenger expectations with regard to trip duration, type of passenger′s activities during trip (reading, eating, writing) and many other factors (acoustic noise, temperature, etc.). However, comfort reactions due to vibration amplitudes may be classified as follows [8]:

- Less than 0,315 m/s^2 not uncomfortable
- 0,315 m/s^2 to 0,63 m/s^2 a little uncomfortable
- 0,5 m/s^2 to 1 m/s^2 fairly uncomfortable
- 0,8 m/s^2 to 1,6 m/s^2 uncomfortable
- 1,25 m/s^2 to 2,5 m/s^2 vary uncomfortable
- Greater than 2 m/s^2 extremely uncomfortable.

3. SEAT EFFECTIVE AMPLITUDE TRANSMISSIBILITY FACTOR

The vibration isolation efficiency of a seat may be expressed by means of The Seat Effective Amplitude Transmissibility factor (SEAT) [11]. This dimensionless factor is dependent on the vibration spectrum, seat transmissibility and subject response frequency weighting. It shows the capability of a seat design to attenuate the vibrations generated in a vehicle, i.e. to protect the driver from excessive vibrations. The SEAT value is defined as:

$$\text{SEAT\%} = 100 \times \frac{\text{ride comfort on seat}}{\text{ride comfort on floor}} \tag{1}$$

A seat would improve ride comfort when SEAT factor is smaller than 1 or, expressed in percentage, when SEAT% is less than 100%. If the value exceeds these limits, the seat actually amplifies vibrations and, thus, worsens ride comfort. According to ISO 10326-1 Mechanical vibration – laboratory method for evaluating vehicle seat vibration [9], the measurement of the SEAT involves determination of the vibration magnitudes at two positions, as depicted in Figure 2:

- on the seat pan, which represents the interface between the human body and the seat
- at the base of the seat, that is at the place of vibration transmission to the seat, Figure 2.

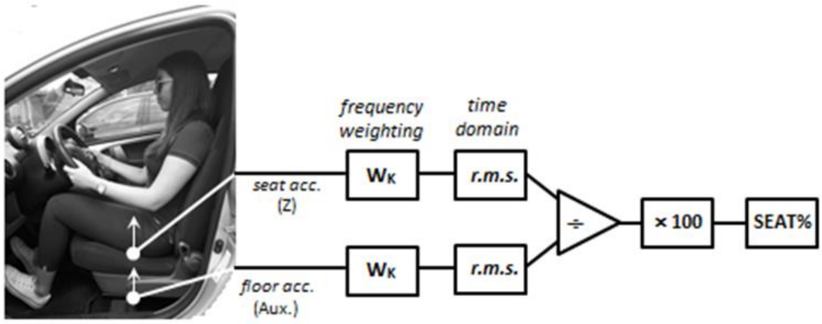


Figure 2. Graphical representation of the SEAT measurement

Measurements at these two points are done simultaneously and the SEAT is computed as the ratio between these two magnitudes. The magnitude of the vibrations is measured in terms of weighted acceleration root mean square values (r.m.s) or vibration dose values (VDV). Therefore, the SEAT expression becomes either:

$$SEAT_{rms}\,\% = 100 \times \frac{a_{w,seat}}{a_{w,floor}} \tag{2}$$

$$SEAT_{VDV}\,\% = 100 \times \frac{VDV_{seat}}{VDV_{floor}} \tag{3}$$

The r.m.s. is expressed in (m/s2) and defined as:

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2(t)\,dt\right]^{\frac{1}{2}} \tag{4}$$

where:
$a_w(t)$ is the frequency weighted acceleration (using W_k weighting) as a function of time in (m/s^2),
T is the duration of measurement in (s).

The VDV is expressed in $(m/s^{1,75})$ and defined by the relation:

$$VDV = \left[\int_0^T a_w^4(t)\,dt\right]^{\frac{1}{4}} \tag{5}$$

where:
$a_w(t)$ is the frequency weighted acceleration (using W_k weighting) as a function of time in (m/s^2),

T is the duration of measurement in (s).

Whether to use r.m.s. or VDV depends on the vibrations encountered during the measurement. If the vibration history is rather smooth, then RMS vibration magnitude is preferable. If, however, the vibrations included transients and shocks, it is recommended to compute SEAT based on VDVs.

The SEAT factor measurement belongs to the category of whole-body vibrations measurement. The way in which humans perceive vibration depends on different factors, including the vibration frequency content and direction. People are most sensitive to whole-body vibration within the frequency range of 1 to 20 Hz, but there are different human sensitivities to vibration in different directions of excitation. When measuring whole-body vibration at the seat, ISO 2631 requires the use of *Wk* weighting in the Z-direction, whereas *Wd* is used for the acceleration in the X- and Y-directions.

When assessing a seat′s ability to attenuate vibrations, it is important to keep in mind that seat and driver must be seen as one system. The driver will add mass to the seat, which preloads the seat springs, and changes the resonance behavior. Further, depending on posture, the seat-driver combination will lead to a more or less stiff system (e.g., vibrations will be different if the driver sits relaxed or if feet are pressed against the floor). Thus, depending on the driver’s body and posture, the performance of seats can be very different. What constitutes a “good” SEAT value depends on the vehicle type [6, 14]. For example, vibration in cars usually has substantial components at about 10 Hz, which can be easily isolated by conventional seats. Car seats therefore often have SEAT values in the range of 60 to 80%.

4. MEASUREMENT METHODOLOGY

The research task in this paper was to evaluate the vibration (dynamic) comfort of a hybrid vehicle by measurement of the Seat Effective Amplitude Transmissibility factor (SEAT). A hybrid vehicle efficiently combines the internal combustion engine (ICE) and electric power (EV) from the battery.

In this investigation, Toyota C-HR (1,8 l Hybrid Petrol) was used, Figure 3, having performances as follows: engine power 98 Hp or 72/5200 kW/rpm, max torque 142/3600 Nm/rpm; electric motor power 53 kW, max torque 163 Nm, max voltage 600 V; battery type Ni MetalHibrid, nominal voltage 201,6 V, number of battery modules 28, battery capacity 6,5 Ah.

a) b)

Figure 3. a) test car, Toyota C-HR, b) energy monitor in the car showing driving mode

The final goal of investigation was to find out how vibration comfort depends on the type of vehicle power mode, i.e. whether driving in electric mode provides better vibration comfort compared to driving in internal combustion engine mode. Also, our intention was to find out the effect of the road surface quality to the vibration comfort, the influence of the driving speed, as well as the influence of the driver′s weight.

The measurements were made by driving the car on the four roads, with different conditions:

- the new motorway (Laktaši – Gradiška), Figure 4a: straight, well maintained smooth road surface without any damage; the car was driven at about 50-60 km/h in EV mode and 70-120 km/h in ICE mode; the driver′s weight was about 100 kg
- the fast road (Banja Luka-Laktaši): straight and little bumpy due to ruts; the car was driven at about 50 km/h in EV mode and 70-100 km/h in ICE mode; the driver′s weight was about 100 kg
- the city street (in Banja Luka): well-maintained surface of the road, but the driving was with a lot of slowing down and braking, at about 40-50 km/h in EV and 60 km/h in ICE mode; two drivers, A (100 kg) and B (60 kg), participated in the experiment
- the suburban street (in Banja Luka), Figure 4b: the road surface is in a poor condition and characterized by a series of pot-holes and bumps; the car was driven at about 40-50 km/h in EV mode and 60 km/h in ICE mode; two drivers, A (100 kg) and B (60 kg), participated in the experiment.

a)

b)

Figure 4. Roads where measurements were done. a) motorway, b) suburban street

Each of the measurement sessions durated about 3 minutes. As mentioned before, for evaluation of the SEAT factor it is necessary to simultaneously measure the vibration signals on the seat and on the vehicle's floor. To perform two channels measurement, we used following equipment, Figure 5:

- Human Vibration Analyser type 4447
- Seat pad, with built in triaxial accelerometer type 4506
- Uniaxial accelerometer type 4507 (all by Bruel&Kjaer).

a) b) c)

Figure 5. a) The analyzer 4447, b) seat pad strapped to the cushion, c) uniaxial accelerometer on the floor

The Human Vibration Analyzer Type 4447 complies with the technical requirements of ISO 8041:2005 Human responses to vibration - Measuring instrumentation, and can perform measurement compliant with the standards pertaining to human vibration [16]. The instrument possessed the pre-set frequency weightings for hand-arm (W_h) and whole-body (W_d and W_k) vibrations. Uniaxial and triaxial accelerometers are the piezoelectric vibration sensors which capture the measured signals and deliver it to the analyzer for processing. The uniaxial accelerometer is mounted on the floor, at the place of the vibration transmission to the seat, Figure 5c. The accelerometer is best mounted on a rigid part of the floor using glue, a strong magnet or double-sided thin adhesive tape. In this investigation, we used double-sided adhesive tape. The triaxial accelerometer is mounted in the seat pad which is located on the seat cushion, Figure 5b. It is necessary to tape or strap it to the cushion in such a way that the accelerometer is located midway between the ischial tuberosities of the seat occupant. The analyzer 4447 is only set up to evaluate SEAT in the vertical direction, i.e. it compares the vertical vibration at the floor (vibration signal marked by Auxiliary) with vibrations along the Z-axis of the Seat Pad (vibration signal marked by Z), as depicted in Figure 2. The whole-body weighting W_k is applied for the Z and the Auxiliary signals when carrying out SEAT measurements.

5. DISCUSSION OF THE MEASUREMENT RESULTS

The r.m.s. vibration magnitudes (expressed in m/s^2) measured along the Z-axis of the Seat Pad (marked by Z) and at the vehicle's floor (marked by Aux), together with the values of the SEAT factor are presented in the Table 1.

Table 1. Results of vibration measurement at the seat and at the floor of the vehicle and SEAT factor

	Type of road	Drive mode/ driver	Velocity (km/h)	r.m.s. (m/s^2)		SEAT	SEAT %
				Z	Aux		
1	new motorway	EV / A	55	0,1253	0,1631	0,7684	76,84
2			60	0,1208	0,1640	0,7363	73,63
3			60	0,1137	0,1591	0,7149	71,49
4		ICE / A	70	0,1221	0,1710	0,7142	71,42
5			90	0,1441	0,1995	0,7225	72,25
6			110	0,1830	0,2392	0,7652	76,52
7	fast road	EV / A	60	0,1759	0,2181	0,8066	80,66
8		ICE / A	70	0,2028	0,2606	0,7784	77,84
9		ICE / A	90	0,2768	0,3429	0,8071	80,71
10	city street	EV / A	60	0,2091	0,2888	0,7239	72,39
11		ICE / A	50	0,2569	0,3327	0,7721	77,21
12		EV / B	40	0,3116	0,4034	0,7726	77,26
13	suburban street	EV / A	35	0,4102	0,5593	0,7334	73,34
14		EV / B	40	0,4826	0,6443	0,7491	74,91
15		ICE / A	45	0,4305	0,5726	0,7518	75,18

Analysing the measurement results, the SEAT factor takes values between 71.42 % and 80.71%. For all measurement conditions, it can be seen that the increase of the vibration amplitude measured on the vehicle's floor results in increase of the vibration measured on the seat, giving the Seat Effective Amplitude Transmissibility average value of 75.44%. This means that 75.44% of vibration generated by driving is transmitted from the vehicle's structure to the driver's seat.

It is interesting to analyze vibration amplitudes measured at the seat and on the floor of the vehicle for different driving conditions. For the approximate values of driving speed (40-60 km/h for EV; 45-70 km/h for ICE), vibration amplitudes are lowest for measurements done along the new motorway. This is expected due to the excellent quality of the road surface, which is well maintained and smooth, and the road is relatively in a straight line, with minimum curvatures. The level of vibration is noticeably increasing with the decline in the quality of the driving surface (motorway / fast road / city streets / suburban streets), for both drive modes, EV (Figure 6a) and ICE (Figure 6b).

a) b)

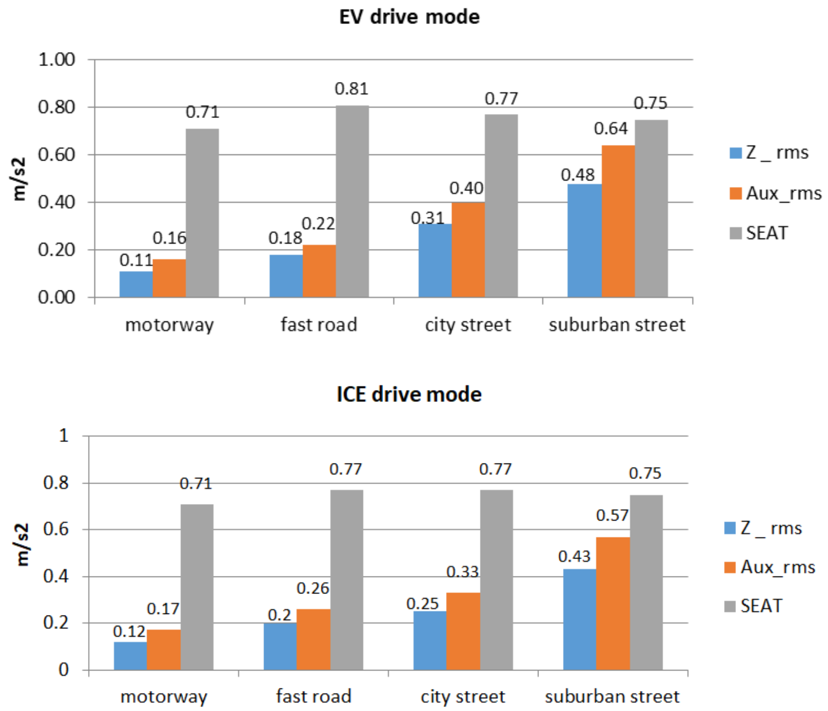
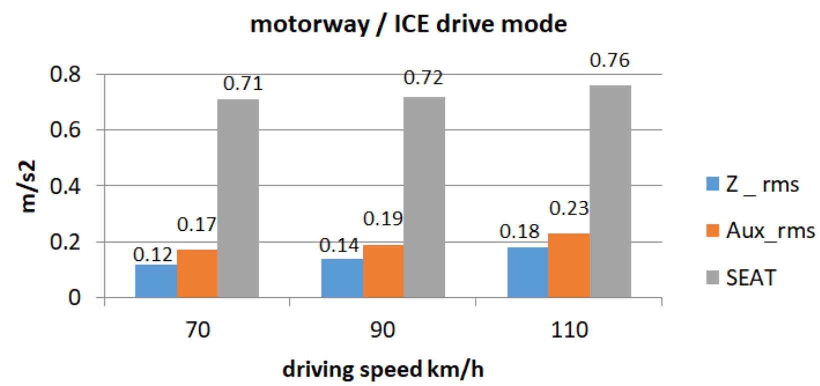


Figure 6. Vibration amplitude values (Z and Aux) and SEAT factor for different type of roads: a) EV drive mode, b) ICE drive mode

Comparing the vibration values measured for the same type of road and drive mode, but different driving speeds, one can conclude that there is no significant difference between vibration values for EV mode (due to insufficient difference of driving speeds, 55 – 60 km/h). However, regarding ICE drive mode, it can be seen that vibration values increase as driving speed increases, Figure 7a (driving on the motorway) and 7b (driving on the fast road).

a)



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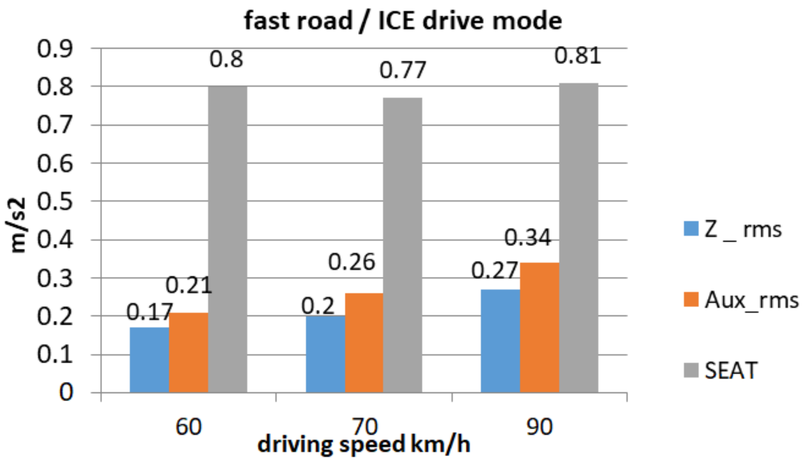
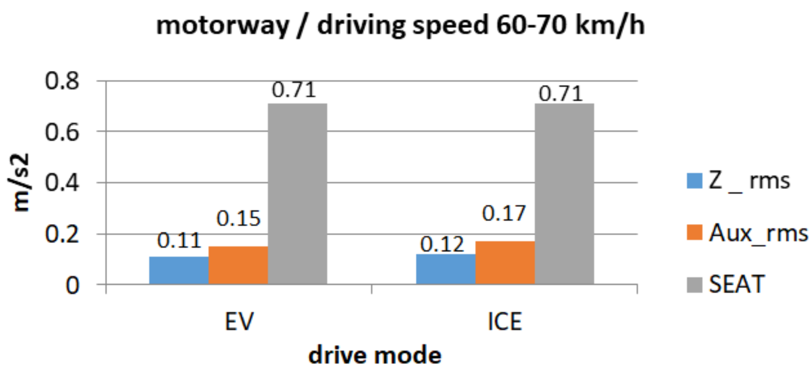


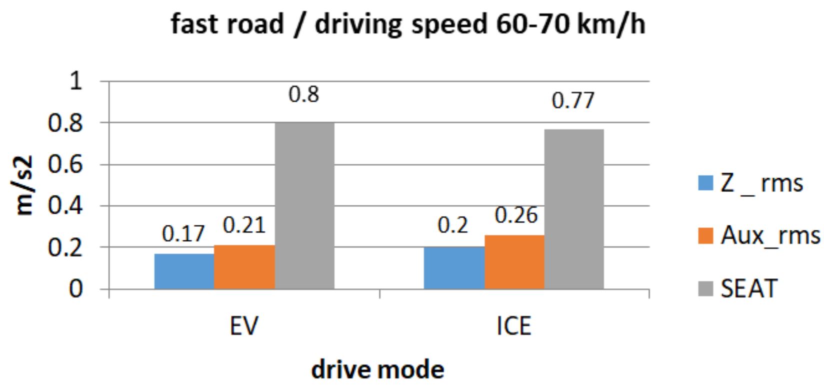
Figure 7. Vibration amplitude values (Z and Aux) and SEAT factor for ICE mode and different driving speeds: a) driving on the motorway, b) driving on the fast road

Comparing the vibration values measured for the same type of road and approximately equal driving speed, but for the different drive modes, it can be concluded that EV mode produces lower vibration than driving in ICE mode, as shown in Figure 8a (driving on the motorway), 8b (driving on the fast road) and 8c (driving on the city street).

a)



b)



c)

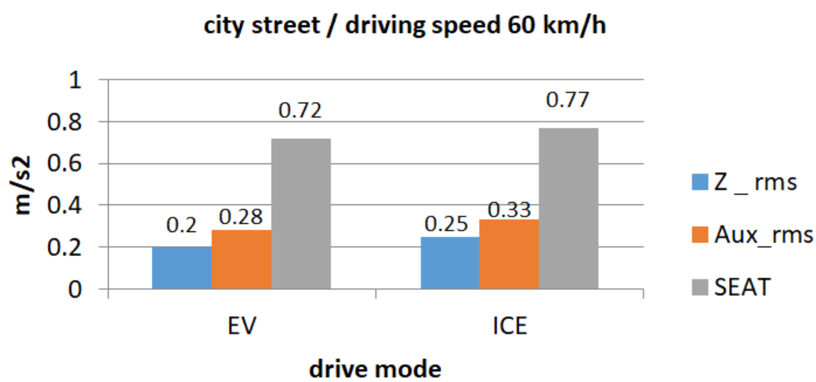
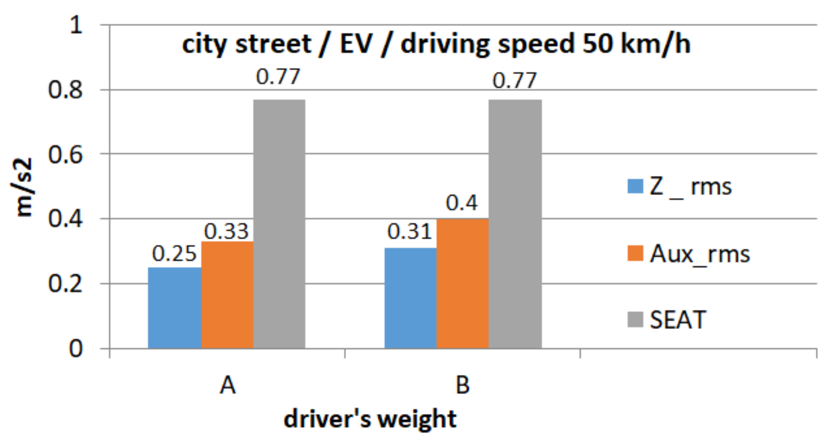


Figure 8. Vibration amplitude values (Z and Aux) and SEAT factor for different drive modes: a) driving on the motorway, b) driving on the fast road, c) driving on the city street

Regarding the influence of the driver's weight, it can be seen that greater driver's weight (A - 100 kg, B - 60 kg) produces lower vibration transmission to the seat pan, Figure 9a (driving on the city street) and 9b (driving on the suburban street).

a)



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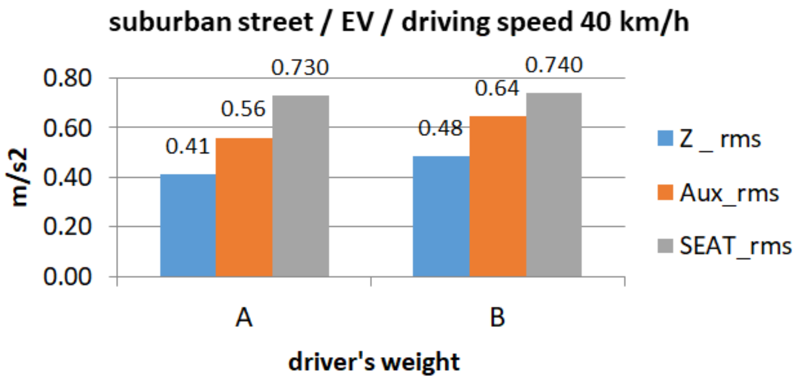

Figure 9. Vibration amplitude values (Z and Aux) and SEAT factor for different driver's weight: a) driving on the city street, b) driving on the suburban street

6. CONCLUSIONS

An investigation of the vibration comfort of a hybrid vehicle Toyota C-HR was done in this paper. A total of 16 measurements were performed and the measured Seat Effective Amplitude Transmissibility factor, expressing vibration seat comfort, was in the range between 71.42% (vehicle rides over new motorway with smooth road surface) and 80.71% (vehicle rides over fast road with a lot of ruts). Although the measured SEAT values varied within 10%, the average value of the SEAT for all performed measurements is around 75%, which can be considered as good dynamic comfort estimation for this category of vehicles (passenger cars). Vibration amplitudes measured on the vehicle's floor and at the driver's seat show that the vibration comfort can be rated as "not uncomfortable" (vibration amplitude less than 0.315 m/s^2), except for driving over the suburban streets where the vibration comfort is rated as "a little uncomfortable" (for vibration amplitude between 0.315 m/s^2 to 0.63 m/s^2).

Regarding the measured vibration amplitudes on the vehicle's floor and the driver's seat, we can conclude following:

- The vibration amplitude depends on the type of road the vehicle is riding on and the quality of its surface. The best vibration comfort is achieved by driving on a motorway where the road surface is smooth, with no damages. This applies to driving modes, electrical power and internal combustion engine mode. For some environments, a major contributor to the vibration is the roughness, or tidiness, of road. So, keeping the road in good condition and repairing the damages would improve the mechanical (vibration) environment for the vehicle
- Increasing the driving speed increases the vibration amplitudes, which reduces dynamic comfort. For many vehicles, lower vibration is received by passengers if the speed of the vehicle is limited
- At the same driving conditions, i.e. the same type of road and approximately the same speed, EV drive mode gives a lower vibration level (for about 15 %) than drive in ICE mode. Even though the engine of the vehicle can be the main contributor to the vibration exposure, we concluded that the lower vibration generated in EV mode is associated with the lower driving speed, since the hybrid vehicle activates the EV mode at lower driving speeds

- At the same driving conditions (the same type of road, the same driving mode and approximate speed), it was shown that the driver of the lower weight was exposed to higher vibrations. Conventional foam seats, such as car seats, have a resonance at 4 to 5 Hz, which coincides with the frequency where the human body is most sensitive to vibration. However, the drivers weight generally has only small effect to vibration response. Several other factors, such as subject size, posture, backrest contact and backrest angle, foot-support position and support for the arms can have significant effects on seat transmissibility.

Commonly cars are purchased on the basis of comfort evaluation just in the showroom, whereby attention is paid only to static comfort, neglecting the dynamic and temporal aspects of seating comfort. It is much better for purchasers to test-drive the vehicle for an extended period of time and evaluate the vehicle's dynamic comfort, which is especially important for high-mileage business drivers.

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TWO-YEAR SUCCESSFUL EXPLOITATION OF THE ELECTRIC BUSES IN BELGRADE

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RESEARCH ARTICLE

ABSTRACT: Since, September 1, 2016, new line EKO 1 is established in Belgrade, where are five E-buses in operation. What are the experiences in exploitation in terms of realized transport, maintenance, electric consumption, environmental benefits as well as the satisfaction of passengers, who use the line EKO 1, are the subjects of this paper. In paper will also present future plans for further expansion of the network line in Belgrade, where the electric buses will operate.

KEY WORDS: e-bus, exploitation, development

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DVOGODIŠNJA USPEŠNA EKSPLOATACIJA ELEKTRIČNIH AUTOBUSA U BEOGRADU

REZIME: Od 1. septembra 2016. godine u Beogradu je osnovana nova linija EKO 1, u kojoj radi pet električnih autobusa. Kakva su iskustva u eksploataciji u smislu realizovanog transporta, održavanja, potrošnje električne energije, ekoloških efekata kao i zadovoljstva putnika koji koriste liniju EKO 1, su predmet ovog rada. U radu će se takođe predstaviti i budući planovi za dalje proširenje mrežne linije u Beogradu, u kojoj će raditi električni autobusi.

KLJUČNE REČI: e-bus, eksploatacija, razvoj

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1. INTRODUCTION

City Transport Company "Belgrade" (JKP GSP "Beograd"), is the bearer of public transport in Belgrade and one of the largest public transport companies in South East Europe. Every day in the operation is: 609 buses, 150 trams and 94 trolleybuses and 5 buses electrically powered. From 1st September 2016, introduced a new line of EKO 1 where operate buses exclusively on electric power. In this way, Belgrade is included in the map of cities in Europe and the world that have begun using electric buses as a long-term strategy for using this concept of drives, which will be the main alternative to diesel-powered buses.

The choice of the electric bus concept came after several years of activity in monitoring the development and application of these buses in many cities in Europe and the world, as well as successful cooperation with many bus manufacturers (Higer, BYD, Solaris, Siemens-Rampini). Also, City Transport Company "Belgrade" has been active in many EU projects related to electric buses (ZEEUS, Hybrid user forum, Civitas, UITP bus committee ...). Specificity of using electrically powered buses can be seen in terms of line on which they work, vehicle concept, charging systems, maintenance, exploitation indicators and environmental suitability.

2. CITY LINE EKO 1 (VUK'S MONUMENT – BELVIL)

The choice of a new line (Figure 1) on which electric buses operate, comes after a detailed analysis of the fulfilment of the following criteria [1]:

- A central city line, so that the environmental impact of the "0" emission is the biggest
- The high attractiveness of line from the aspect of passenger requirements
- Suitability of the line or terminal from the aspect of providing energy requirements for chargers
- Line length, such that at the end of the journey there is a minimum of 20% of the available power in the supercapacitors.

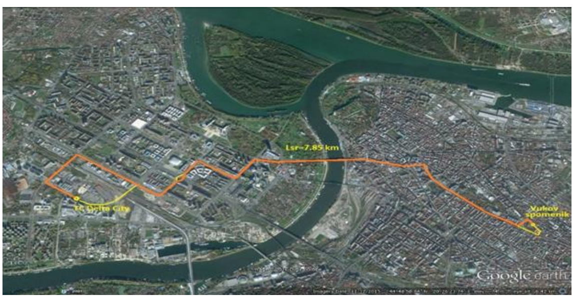

Figure 1. Route of line EKO

Figure 2. E-bus HIGER KLQ6 at the “Vuk's monument’’ charging station

The mean length of the EKO 1 line is 8 km. The line is with a flat configuration with a slight climb. On the line work 4 buses "Higer KQL6" City E-bus bus, with an average interval of 20 minutes.

"Higer KQL6" (Figure 2), City E-bus bus has the capacity of minimum 80 passengers. E-bus is equipped with two traction asynchronous motors “Siemens IPV5135’’, 2x67 kW nominal power, 2x90 kW peak power. System for storing electricity realized by supercapacitor “Aowei“, 20 kWh capacity [2]. Chargers for fast charging have the power of 150 kW. The charging station on “Vuk’s Monument” terminus is connected to the DC voltage (DC) from the tram contact grid and the charging station on “Belvil’’, to the three-phase AC voltage from the public power grid. The charging time at the terminals is 5-10 minutes.

3. EXPLOITATION INDICATORS ON THE LINE EKO 1

Analysing the period of operation of buses on electric power from 01/09/2016 to 1/9/2018, E-buses have had the following results [3]:

- Working hours per vehicle per day: 16÷18 h
- Average daily mileage per vehicle: 190÷215 km
- Exploitation speed: 14.8 $km \cdot h^{-1}$
- Daily number of passengers transported per vehicle: 900÷1200 passengers
- Reliability of work on the line: 97.5%
- Depending on operating mode, number of passengers, traffic conditions, driving style, impact of the system for heating and air conditioning of the vehicle), electric consumption may vary
- In the spring/autumn period, direction "A" 0.82÷1.15 $kWh \cdot km^{-1}$, direction "B" 1.2÷1.45 $kWh \cdot km^{-1}$
- In the summer period average consumption is higher by 23.3%, than the transition period
- In the winter period average consumption is higher by 45.4%, compared with transition period
- Loss of electricity in the charging phase (network, charger, pantograph, super capacitor): about 5%
- E-bus realized recovery of electricity in the braking phase of about 25-30% compared to the energy consumed to drive.

An example of the exploitation indicators of the operation of the E-bus (garage number 2103) on the line EKO 1, for the day 18 April 2018, is presented in Tables 1 and 2. The outside temperature was min 12 ˚C, max 18 ˚C [4].

Table 1. Direction''A" (Vuk's-Belvil)-Expoloitation indicators, 18 April 2018

Timetable [hh:mm:ss] start	Timetable [hh:mm:ss] end	Electric energy-charging [kWh]	Loss in the charging phase [kWh]	*SOC [Vuk] [%]	SOC [Belvil] [%]	ΔSOC [%]	Electric consumption (ΔSOC+loss) [kWh]	Electric consumption [kWh·km^{-1}]	Driving time [hh:mm:ss]	Exploatation speed [km·h^{-1}]
5:14:00	5:45:00	5.00	0.25	98.00	62.00	36.00	7.38	1.02	0:31:00	14.46
7:13:00	7:45:00	10.87	0.54	99.00	62.20	36.80	7.54	1.08	0:32:00	14.01
8:46:00	9:21:00	10.17	0.51	99.60	55.20	44.40	9.10	1.29	0:35:00	12.81
10:20:00	10:49:00	9.86	0.49	99.00	69.00	30.00	6.15	0.89	0:29:00	15.46
11:55:00	12:27:00	10.70	0.54	100.00	66.00	34.00	6.97	1.00	0:32:00	14.01
13:31:00	14:05:00	9.75	0.49	94.75	55.00	39.75	8.15	1.16	0:34:00	13.18
15:04:00	15:40:00	11.30	0.56	99.00	62.60	36.40	7.46	1.07	0:36:00	12.45
16:39:00	17:14:00	10.21	0.51	88.00	49.70	38.30	7.85	1.12	0:35:00	12.81
18:12:00	18:42:00	11.34	0.57	94.00	55.00	39.00	8.00	1.15	0:30:00	14.94
19:46:00	20:18:00	11.69	0.58	98.00	70.00	28.00	5.74	0.85	0:32:00	14.01
21:19:00	21:46:00	10.25	0.51	98.00	65.00	33.00	6.77	0.97	0:27:00	16.60

*SOC (State of charge supercapacitor)

Table 2. Direction''B" (Belvil-Vuk's)- Expoloitation indicators,18 April 2018

Timetable [hh:mm:ss] start	Timetable [hh:mm:ss] end	Electric energy-charging [kWh]	Loss in the charging phase [kWh]	*SOC [Belvil] [%]	SOC [Vuk] [%]	ΔSOC [%]	Electric consumption (ΔSOC+loss) [kWh]	Electric consumption [kWh·km-1]	Driving time [hh:mm:ss]	Exploatation speed [km·h-1]
6:22:00	6:53:00	8.18	0.41	101.90	48.00	53.90	11.05	1.35	0:31:00	16.45
8:01:00	8:37:00	7.79	0.39	100.00	46.00	54.00	11.07	1.35	0:36:00	14.17
9:34:00	10:06:00	7.54	0.38	99.00	50.00	49.00	10.05	1.23	0:32:00	15.94
11:09:00	11:42:00	9.39	0.47	101.00	50.90	50.10	10.27	1.26	0:33:00	15.45
12:44:00	13:20:00	6.36	0.32	100.00	47.80	52.20	10.70	1.30	0:36:00	14.17
14:18:00	14:52:00	7.18	0.36	101.00	47.20	53.80	11.03	1.34	0:34:00	15.00
15:52:00	16:28:00	9.43	0.47	101.00	43.90	57.10	11.71	1.43	0:36:00	14.17
17:26:00	18:05:00	7.67	0.38	100.00	38.20	61.80	12.67	1.54	0:39:00	13.08
18:59:00	19:37:00	10.31	0.52	100.00	38.70	61.30	12.57	1.54	0:38:00	13.42
20:33:00	21:07:00	9.23	0.46	100.00	41.00	59.00	12.10	1.48	0:34:00	15.00
22:08:00	22:37:00	6.15	0.31	100.00	48.00	52.00	10.66	1.29	0:29:00	17.59

*SOC (State of charge supercapacitor)

Realized mileage per vehicle a given period is presented in table 3.

Table 3. Mileage per vehicle

E-bus	Period [1/9/2016 - 1/9/2018]* Mileage [km]
2101	104.400
2102	106.320
2103	109.050
2104	100.350
2105	103.100

* In the period 14/8-6/10/2017, E-buses not in operation because of the works in Roosvelt's street.

4. MAINTENANCE OF E-BUSES

Buses on an electric drive as a relatively new concept of buses used in public transport are characterized by certain specifics when maintenance is concerned [3]. Some of these specificities compared to diesel buses are:

- Simpler maintenance compared to the diesel bus
- Vital parts of the electrical components (inverters, converters, air compressors, steering pump, supercapacitor) are a modular type (Figure 3,4)
- Lower maintenance costs (compared to a diesel bus about 3 times, E-bus 3000 Euros per year, Diesel 9000 Euros per year)
- Diagnosis of defects are identified on the instrument panel
- Short replacement time.

Figure 3. Traction inverters

Figure 4. Compressor, steering pump

In Table 4, shows the components and systems on the buses with a diesel-powered and electric-powered bus.

The electrically powered bus has a significantly smaller number of components and systems, which makes it more efficient and cheaper in terms of regular and corrective maintenance. In E-buses, regular servicing is performed according to the defined checklist at every 20,000 km.

5. ECOLOGICAL EFFECTS ON THE LINE EKO

One of the main reasons for introducing E-buses on the line EKO 1 is the environmental effects compared to diesel buses [3]. This relates primarily to:

- The smaller the level of noise, compared to a diesel bus lower by 13 dB(A) [3]
- "0" emission of harmful gases. Comparison of the emissions of harmful gases of one E-bus and diesel buses on the line ECO 1 for annual mileage 60,000 km, consumption 44 L/100 km, present in Table 5.

Analyzing the period of operation of buses on electric power from 01/09/2016 to 15/5/2018, E-buses have had the following results [3].

Table 4. Components and systems on the buses with a diesel-powered and electric-powered bus

Component	Diesel bus	E-bus
Motor IC (internal combustion)	Yes	No
Engine lubrication system	Yes	No
Oil motor	Yes	No
Oil filter	Yes	No
Air filter	Yes	No
Belts	Yes	No
Engine cooler	Yes	No
Antifreeze	Yes	No
Intercooler	Yes	No
Starter	Yes	No
Turbocharger	Yes	No
Fuel injection system	Yes	No
Fuel tank, installation	Yes	No
Fuel filter, separator	Yes	No
Exhaust system	Yes	No
SCRT system	Yes	No
AD-blue,	Yes	No
Ad-blue reservoir tank, installation	Yes	No
Gearbox / Retarder	Yes	No
Front axle / Suspension / Steering system	Yes	Yes
Chassis	Yes	Yes
Rear axle	Yes	Yes
Brake system	Yes	Yes
Wheels and tires	Yes	Yes
Air conditioning, Heating	Yes	Yes
The door	Yes	Yes
Signalization, Display	Yes	Yes
CAN, On-Board	Yes	Yes
Power steering pump, compressor	Yes	Yes
Differential, Kardan	Yes	Yes/No
Drive Electric Motor /Reducer	No	Yes
Inverter	No	Yes
High-voltage installation DC / AC	No	Yes
Low voltage equipment DC / DC	No	Yes
Batteries for power supply	No	Yes
Pantograph / Plug inn	No	Yes
Cooling system for super capacitors / batteries	No	Yes

Table 5. Comparison of the emissions of harmful gases from one E-bus and diesel buses on the line ECO 1

Pollutant	E-bus	Emissions of diesel buses [Euro 3]	Emissions of diesel buses [Euro 4]	Emissions of diesel buses [Euro 5-EEV]	Emissions of diesel buses [Euro 6]
	[kg/year]	[kg/year]	[kg/year]	[kg/year]	[kg/year]
CO	0	206	147	147	147
CxHy	0	64.7	45.2	24.3	12.75
NOx	0	490.4	342.1	195.7	39.2
PM 10	0	9.8	1.96	1.95	0.95

6. E-BUS LINE- USERS SATISFACTON

Three months after the EKO1 line started its operation; a survey of the route's passengers was conducted in order to get acquainted with their opinions and first impressions. The survey was conducted in November 2016, during vehicles operation and lasted for three days [5]. The largest group of the EKO1 line passengers composed of employed users and the largest percentage of the passengers have been using the line daily.

Questions from the survey related to the satisfaction of passengers from the EKO1 line included the following:

- line route
- arrival interval of vehicles
- features of e-buses
- comfort and e-bus equipment

(interior and exterior design, noise and safety and other information in a vehicle, wi-fi ...).

Around 80% of the passengers are satisfied with the line route, and 2% of the passengers are completely dissatisfied with it.

The vehicles interior and exterior design, air conditioning and heating system and the noise level in them got a similarly high score. Even 99% of the passengers feel completely safe in the vehicles with purely electric drive and over 90% of the passengers are satisfied with the information system.

The EKO1 line passengers give it the highest grades. Even 73% of the passengers give it to grade 5, and 25% of them give it a high grade 4. Thus, the average grade for the EKO1 line in the opinion of its users is 4.7.

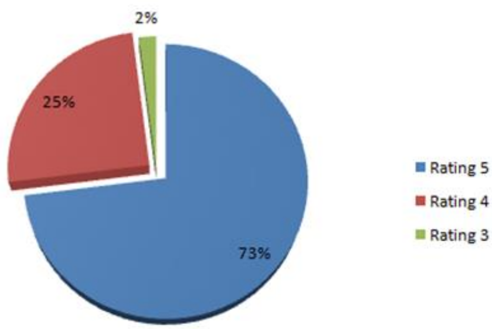

Figure 5. The total grade score for the EKO1line

7. FUTURE PLANS

After two years of successful exploitation of E-buses in Belgrade and satisfactory results, JKP GSP ''Beograd'' and the City of Belgrade are planning to develop the concept of the city electric bus drive on city lines [6].

The plan is to purchase of 80 E-buses in the next 3-4 years, which will replace trolleybuses that work on lines: 19,21,21,29. These lines pass through the city centre and the idea is to dismantle the contact network, due to the high costs of maintenance and frequent failures that initiate large congestion and crowds in the centre of the city. For the realization of this project, it is necessary to complete the construction of the new central city terminal in Dunavska Street (work in progress), ensuring sufficient capacity of the electric network for the operation of chargers than 360 kW. The spatial position of the lines: 19, 21, 22, 29 on which electric buses will operate as well as the required number of chargers at the terminals is presented in Figure 6.

Figure 6. New E-bus lines in Belgrade

It is planned that E-buses will replace diesel buses on line 77 (Zvezdara-Bezanijska Kosa) that passes through the city center in order to reduce the emissions of harmful gases in the city center, as well as the introduction of new E-bus line will be connected the airport ‘’Nikola Tesla’’ with the central city zone.

8. CONCLUSIONS

The introduction of buses with electric drive in the regular operation is a significant step in the development of public transport system in Belgrade. The concept of E-buses with the pantograph charging system on the termini completely meets the conditions of exploitation in terms of electricity supply, the daily autonomy, and the passengers’ transport demands.

The new EKO 1 bus line with E-buses will enable the full effect of the use of this concept in terms of environmental requirements. Tracking the results of the use of electric buses on the EKO 1 line will serve as the best argument for defining future strategies of public transport in Belgrade, regarding this concept of buses and its mass application.

The introduction of electric buses on lines: 19, 21, 22, 29, 77 is compliance with the EU transport policy, which determines that participation of "clean" buses in the cities of Europe will be 50% by 2025 (amendment of the directive EC/33/2009) or 30% for cities from EU countries with less economic power.

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AUTOMATED SELECTION OF ANALYTICALLY CALCULATED GEARBOX CONCEPTS ACCORDING TO DIMENSIONAL CRITERIA

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RESEARCH ARTICLE

ABSTRACT: This research allows for a selection of gearbox according to minimal dimensional criteria from automated analytical calculations. An automation of the calculation process for four different analytical approaches from literature. The results achieved in the software are compared according to various criteria, minimal length, height, width, and volume. The automation of the process allows for a selection of gearbox concept depending on the chosen criteria. For specific input values, a verification of the automated software operation was conducted, and the resulting values are compared and discussed. Differences in calculated volumes of gearboxes, depending on choice of calculation, reach over 50%. This approach allows for adequate choice of gearbox for specific cases and speeds up the calculation process.

KEY WORDS: gearbox volume, comparative analysis, automated selection, analytical calculation

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AUTOMATISKI IZBOR ANALITIČKI ODREĐENIH KONCEPTA MENJAČA NA BAZI DIMENZIONALNOG KRITERIJUMA

REZIME: Ovo istraživanje omogućava izbor menjača na osnovu kriterijuma minimalnih dimenzija na bazi automatskih analitičkih proračuna. Automatizacija procesa proračuna obrađuje se za četiri različita analizička pristupa iz literature. Rezultati dobijeni softverom upoređuju se prema različitim kriterijumima, minimalnoj dužini, visini, širini i zapremini. Automatizacija procesa omogućava izbor koncepta menjača u zavisnosti od izabranih kriterijuma. Za specifične ulazne vrednosti izvšena je verifikacija rada automatizovanog softvera i dobijene vrednosti su upoređene i diskutovane. Razlike u izračunatim zapreminama menjača, koje zavise od izbora proračuna, dostižu i preko 50%. Ovaj pristup omogućava adekvatan izbor menjača za specifične slučajeve i ubrzava proces proračuna.

KLJUČNE REČI: zapremina menjača, komparativna analiza, automatska selekcija, analitički proračun

AUTOMATED SELECTION OF ANALYTICALLY CALCULATED GEARBOX CONCEPTS ACCORDING TO DIMENSIONAL CRITERIA

Nenad Kostić, Nenad Petrović, Vesna Marjanović, Nenad Marjanović

1. INTRODUCTION

Recent research in the field of development and application of gearboxes is oriented on achieving better working characteristics, decreasing mass, volume, used material, as well as decreasing the number of different elements used in the construction. This allows transmissions to be more cost-effective from a production and maintenance standpoint. Also, these transmissions have useful exploitation characteristics in terms of performance. Improving gearboxes boils down to an engineer's vast knowledge and experience in this field and the use of alternate approaches, in order to allow for progress.

A lot of research is directed towards the development of reducers and their improvement. Marjanovic et al. [1] developed a practical approach to optimizing gear trains with spur gears based on a selection matrix of optimal materials, gear ratios and shaft axes positions. Researchers in [2] compared optimization results to analytical calculations comparing the performance of these processes. Kostic et al. [3] presented a new approach for solving gearbox optimization using the mimicking of natural processes to achieve layout solutions comparable to optimization results without using computerized optimization methods. Clearances between cycloid gearbox elements were optimized in [4] in order to provide a realistic picture of contact and machining tolerances. Golabi et. al [5] presented gear train volume/weight minimization optimizing single and multistage gear trains' gear ratios. Mendi et al. [6] aimed to optimize gear train component dimensions to achieve minimal volume comparing GA results to analytic method parameter volume. Savsani et al. [7] described gear train weight optimization comparing various optimization methods to genetic algorithm (GA) result values. Gologlu and Zeyveli [8] performed preliminary design automation through optimization of gear parameters and properties using a GA based approach.

The motivation behind this research is based in the desire to determine the real influential parameters of different methods and standards for calculating geared speed reducers. The calculation process has been automated, in order to allow for application on a larger number of reducers. By giving a comparative analysis, based on dimensional criteria, the best calculation for a specific case can be determined. Choosing the adequate calculation method a smaller length, width, height or volume of a gearbox can be achieved, resulting in the best possible gearbox applicable in practice.

2. PROBLEM DEFINITION

Designing a gearbox presents a complex task due to the large number of parameters which influence its operation. Design solutions can be achieved analytically or numerically. For the purposes of this research analytical processes based on ISO standard [9], Petruševič, GOST standard [10] and Kudrijavcec [11] have been automated. Testing criteria is based on dimensions of a gearbox. Length, width, height, and volume are used for a comparative analysis of calculation results.

2.1 Conditions and constraints of calculations

Input/output values for calculating gearboxes are singular, in order to be comparable. Values for input/output are given in Table 1.

Table 1. Input parameters and working conditions

Denotation	Value
Input power, P_i (kW)	25
Material	34CrAlNi7
Input speed n_i (rpm)	2800
Total gear ratio u_r	12.5
Usage	Electricity motor
Available modules (mm)	1, 1.125, 1.25, 1.375, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 8, 9, 10, 11, 12, 14, 18, 20, 22, 25, 28, 30, 32, 36, 40

In order for the gearbox to properly function and to ensure adequate lubrication, certain clearances must be created. There must be clearances between gears and bearings, between the largest gear diameters and the housing, as well as between the gears themselves. These values also go into the calculation of the total length, width, height, and volume of the gearbox. Technical clearances are adopted according to suggestions, and are used for the purposes of this research as is shown in Table 2.

Table 2. Technical clearances

Denotation	Label	Value
Distance between gear face and bearing	c_1	15 mm
Distance between outside gear diameter and gearbox housing	c_2	15 mm
Distance between outside diameter of the biggest gear and gearbox housing bottom	c_3	50 mm
Distance between gears	c_5	15 mm

Values and positions of technical clearances are illustrated in Figure 1. The figure also shows the length (L), width (B), and height (H) which are the output values for comparing calculation results. These values are the basic criteria for comparing gearboxes.

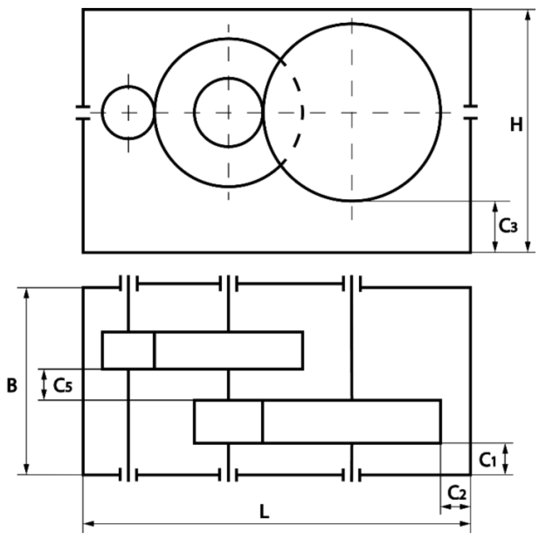

Figure 1. *Gearbox dimensions*

For the minimal safety factor against pitting and brakeage SHmin = SFmin = 1.2. Testing for the safety factors against pitting and brakeage was done in Autodesk Inventor, in order to verify the analytically calculated results.

3. AUTOMATED ANALYTICAL CALCULATION

The conducted research requires a large number of extensive calculations which is why it has been automated. Aside from this, in order to allow for application on a larger number of problems it is necessary to automate the process so that the invested time and effort of calculating would not be too large in comparison to the resulting effects. Automating the previous calculation is conducted in Microsoft Excel and covers the following segments:

- Input of values (material characteristics, input/output of the gearbox, clearances between elements)
- Database of standard modules and constraints of specific values (i.e. integers for number of gear teeth)
- Calculations according to the used suggestions (ISO, Petrusevic, GOST, Kudrijavcev)
- Visualization and result processing (comparative tables, calculation of length, width, height, and volume).

Values from table 1 are plugged in as input values for calculation in the Excel file and all calculation types are done based on identical input values. The calculation is automated in such a way as to require manual input of technical clearance values between the gearbox elements, and is thereby taken into account in the final dimension results of the gearbox. Technical clearances for this specific case have the same values as are given in table 2. Once these values are entered, the final results which are used for the analysis are obtained. As output values length, width, height, and volume are set as the basis for comparing the resulting gearboxes.

Based on defined input values the analytical calculation was automatically done, according to different suggestions. Stiffness was tested in AD Inventor, and the calculated values were also automatically compared to each other based on length, width, height and volume criteria. Based on these results an adequate design concept can be adopted which would be suitable for practical application on real-world problems.

4. RESULTS

According to calculations based on the various suggestions, parameter values are obtained for the gearboxes. In values shown in Table 3 these gearboxes are completely defined and can be used. These values show various dimensions, which mean various length, width, height, and volume, therefore it is possible to analyse which calculation should be used, and when it shouldn't.

Table 3. Gearbox comparison for all design solutions

Denotation	ISO	Petrusevic	GOST	Kudrijavcev
1st Stage				
Normal module, m_{n1st} (mm)	1.75	1.75	1.75	2
Gear ratio, u_{12}	4.309	4.488	3.15	2.5
Number of teeth on pinion, z_1	24	24	24	24
Number of teeth on wheel, z_2	103	108	76	60
Face width, b_{12} (mm)	38	38	38	43
2nd Stage				
Normal module, m_{n2st} (mm)	3.75	3.75	3.25	3
Gear ratio, u_{34}	2.901	2.785	4	5
Number of teeth on pinion, z_3	18	18	18	19
Number of teeth on wheel, z_4	52	50	72	95
Face width, b_{34} (mm)	61	61	53	51

Based on values from Table 3 the length, width, height, and volume of each gearbox is derived. This approach is important, as it is not always explicitly required that volume is minimized, but a specific dimension depending on available space. Therefore it is often more important to adopt a design with a specific value minimized, rather than the volume. This approach leads to designs of various dimensions and volumes based on the previous calculations. Calculated lengths are shown in Figure 2 for all calculation cases. The range of values for all the different designs is from 387.75 (Petrusevic) to 451.5 mm (Kudrijavcev). According to this criteria the best concept is the design according to Petrusevic's calculations.

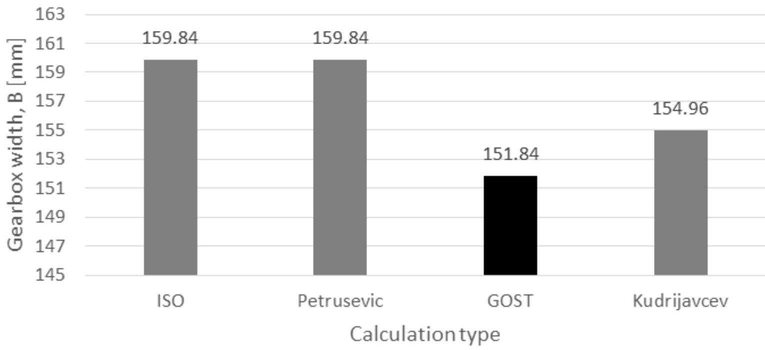

Figure 3. Gearbox widths

According to height criteria values corresponding to each design solution are given in Figure 4. The range of values is from 252.6 (Petrusevic) to 350 mm (Kudrijavcev). According to this criteria the most favourable solution is according to Petrusevic.

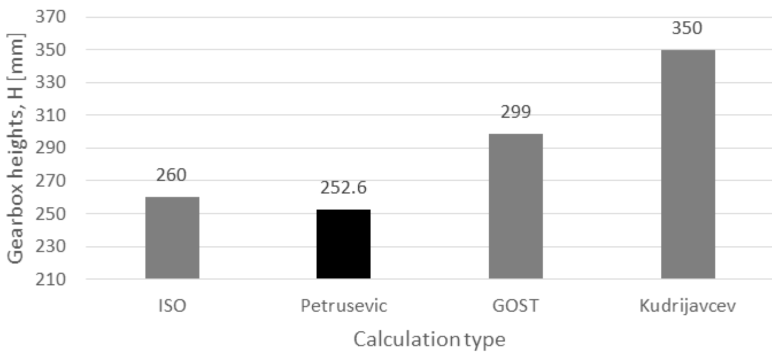

Figure 4. Gearbox heights

According to the criteria of overall volume of the gearbox each design solution value is given in Figure 5. The range of values is from 15.65 (Petrusevic) to 24.49 mm3 (Kudrijavcev). According to this criteria the most favourable solution is according to Petrusevic.

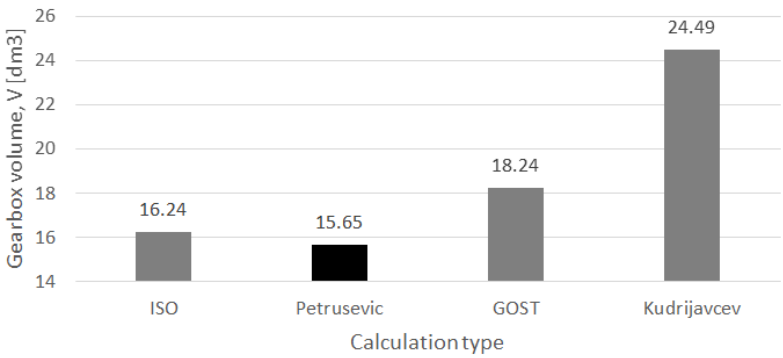

Figure 5. Gearbox volumes

All calculated values take into account technical clearances. For practical application of gearboxes it is possible to determine the type of calculation which gives desired results, while all calculated design concepts are practically applicable.

5. CONCLUSIONS

For this research an approach to the choice of concept of gearbox was developed based on criteria of length, width, height, and volume. Gearboxes were designed based on different suggestions for calculation. An automated process of calculating was developed, which based on input parameters achieves final dimension values. The calculations take into account clearances between elements of the gearbox, standard modules, as well as other realistic constraints. A validation of gear stiffness was conducted in AD Inventor. This approach gives practical results and based on specific situations, an engineer can choose the most suitable calculation for their application.

The calculated values vary greatly, which indicates the large influence of the calculation type on final gearbox design dimensions. The most suitable value according to length criteria is achieved using Petrusevic's suggested calculation (387.75 mm). Compared to the ISO standard the length is greater by 1% which is negligible. The difference for the GOST standard is around 3.6%, while the difference from Kudrijavcev's calculation is 16.5%.

According to width criteria, the best value is achieved according to GOST standard (151.84 mm). For ISO and Petrusevica calculations give larger widths than the GOST for around 5.3%, while Kudrijavcec's calculations give around 2% larger width.

According to the criteria of height, the best values are achieved using Petrusevica's calculation (252.5 mm). For ISO calculation the height is around 3% larger, the GOST standard around 18.4% larger, while the values according to Kudrijavcec are larger by abour 38.6%.

In terms of volume criteria the best solution is using Petrusevic's calculations (15.65 dm3), followed by ISO standard (16.24 dm3), then GOST standard (18.24 dm3), and lastly using Kudrijavcev's calculations achieving (24.49 dm3). Compared to the lowest value, ISO standard volume is 3.8% greater, 16.6% greater using GOST standard and using Kudrijavcev's calculations is around 56.5%.

The smallest difference is achieved in terms of volume criteria, then by length, while the greatest difference can be made in the height of the gearbox. The most common criteria for choice of gearbox concept is volume, however it is not compulsory. Using the here proposed approach, an alternative is created for engineers to choose adequate designs depending on the type of chosen calculation. Further research in this field should include a comparative analysis of achieved values to those achieved through optimization according to defined criteria.

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EXAMINATION OF SENSITIVITY OF TRACTOR TIRE FILTERING BEHAVIOR TO CONTACT LENGTH CHANGE

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RESEARCH ARTICLE

ABSTRACT: Vibrations of agricultural tractors and other off-road vehicles are mainly excited through uneven ground encountered by such vehicles. Thereby tire acts as geometrical filter that transforms short-wavelength road undulations into effective excitation profile of milder geometry. Being geometrically conditioned, this filtering behaviour depends on tyre radial deflection i.e. contacts length. In this paper examination of sensitivity of filtering behaviour to contact length change is described and results are presented.

KEY WORDS: tractor tire, vibration, effective road profile

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ISPITIVANJE OSETLJIVOSTI FILTRIRAJUĆEG PONAŠANJA TRAKTORSKOG PNEUMATIKA NA PROMENU DUŽINE KONTAKTA

REZIME: Vibracije poljoprivrednih traktora i drugih terenskih vozila uglavnom su izazvane neravninama terena po kojima se kreću ova vozila. Zbog toga se pneumatik ponaša kao geometrijski filter koji transformiše neravnine podloge kratkih talasnih dužina u efektivan profil pobude blaže geometrije. Budući da je geometrijski uslovljeno, ovo filtrirajuće ponašanje zavisi od radijalne deformacije pneumatika tj. dužine kontakta. U ovom radu je ispitivana je osetljivost filtrirajućeg ponašanja pneumatika na promenu dužine kontakta i dobijeni rezultati su prikazani.

KLJUČNE REČI: traktorski pneumatik, vibracije, efektivan profil puta

EXAMINATION OF SENSITIVITY OF TRACTOR TIRE FILTERING BEHAVIOR TO CONTACT LENGTH CHANGE

Boris Stojić, Aleksandar Poznić, Nebojša Nikolić

1. INTRODUCTION

If tyre rolls over uneven ground whose irregularities have wavelength of the order of magnitude similar to tyre contact length, wheel centre will not follow exact ground geometry (as would be the case when using point-contact rigid follower instead of elastic tyre), but will travel along the path of different shape. If tyre motion happens in quasistatic manner, than tyre response (in view of the wheel centre trajectory shape) will have greater length and lower height compared to single road irregularity causing this response. This is the result of both tyre geometry and elasticity, and can be described as geometric low-pass filtering of the original road profile. Wheel centre trajectory is thereby considered effective road profile, since this motion represents real vehicle vibration excitation. This mechanism is depicted in Figure 1. This aspect of the tyre behaviour is referred to as „enveloping behaviour“, since the tyre virtually envelopes i.e. wraps around ground irregularity of the short wavelength. Choosing quasistatic mode, it is possible to focus analysis purely on tyre enveloping behaviour, not taking into account tyre internal dynamics and vibration properties.

By using different combinations of tyre load and pressure, it is possible to obtain the same value of the length of contact area of the tyre with even ground. Furthermore, unambiguous relationship exists between contact length and radial tyre deflection [3, 4]. If values of these parameters change, the way of establishing contact between tyre footprint and road irregularities encountered by the tyre during motion also alters. This further leads to alteration of tyre enveloping behaviour i.e. geometric filtering properties. This phenomenon leads to conclusion that tyre contact length can be used as parameter of the tyre enveloping model. Such approach has already been used previously, e.g. [6, 7], though for road vehicle tyres.

Tractor tyre is characterized by significant differences in some aspects of its behaviour when compared to road tyres, above all due to different tyre structure and different relation between this physical structure and pneumatic contribution to tyre behaviour. In [1], results of examination have been published that shown that, although not completely accurate, approach of using tyre contact length as unique parameter of enveloping behaviour can be used as satisfying approximation, providing that tyre operational parameters are within usual range. Attaining higher level of model simplification additionally justifies adoption of this approximation. Primary topic of this paper is to obtain numerical quantification and qualitative assessment of the level and nature of contact length impact on tyre enveloping behaviour.

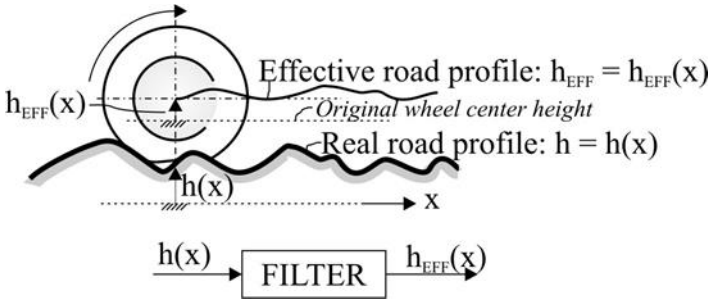

Figure 1. Concept of effective road profile: h(x) - ground profile shape, hEFF(x) - wheel centre trajectory based on h(x) and transformed by tyre filtering mechanism, x - direction of motion

2. EXPERIMENTAL SETUP AND METHOD

Tyre enveloping behaviour has been studied by measuring horizontal and vertical displacement of the wheel rolling very slowly over the singular road obstacle, in nearly quasistatic conditions (i.e. such that all kinds of dynamic excitation of the tyre structure can be considered negligible). Experimental facility used in these investigations is shown schematically in the Figure 2. It was described in more details in [2] and [5].

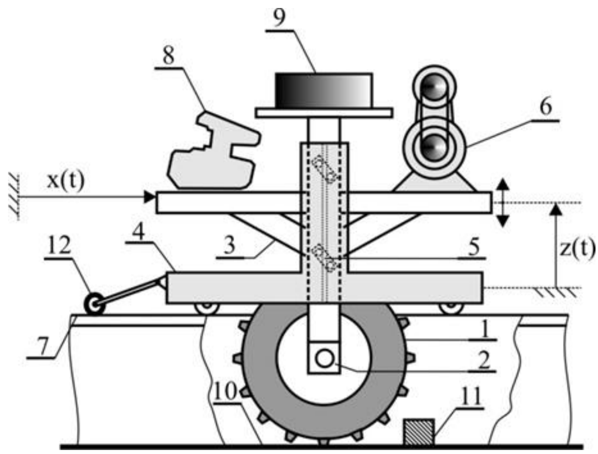

Figure 2. Composition of the test facility: 1-tested wheel, 3-wheel mounting frame, 4-wheel guiding cart, 11-road irregularity

Experimental measurements were made with the tyre of the size 12.4R28. Shape and dimensions of the road obstacle used for investigations are shown in the Figure 3.

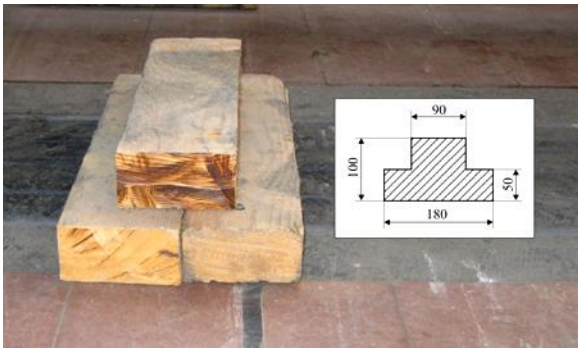

Figure 3. Shape and dimensions of the road obstacle used for investigations

Different levels of contact length were obtained by using constant tyre load of 960 daN and by varying tyre pressure. Four levels of contact length were used: 30, 35, 40 and 45 cm. Significant level of result fluctuations was observed, so in order to compensate for this, every measurement was carried out 10 times. Results were averaged and smoothed subsequently, so as to obtain representative response curves for each case.

Contact length was determined by measuring the distance between two tin plates placed along both front end rear edges of the tyre contact area, Figure 4. This method was described in more details in [3].

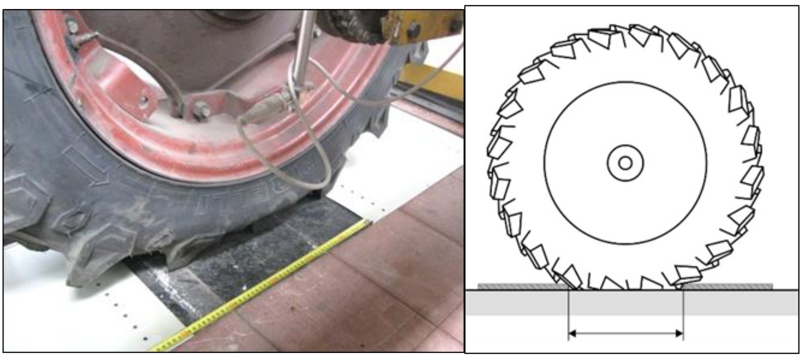

Figure 4. Measuring tyre contact length

3. RESULTS AND DISCUSSION

In order to quantify impact of contact length change on tyre filtering i.e. enveloping properties, measurements of tyre response curves have been made for different values of contact length. Geometric and spectral properties of response curves in different conditions were compared to each other.

In Figure 5, measurement results i.e. enveloping curves obtained are directly compared to each other. Vertical shift between the curves originates from the different levels of tyre centre due to different values of tyre deflection, at the same time enabling better visual overview of this comparison. Two main properties that can be clearly seen from the Figure 5 are:

1. Completely different shapes of individual curves
2. Significant difference in maximum values of response amplitudes.

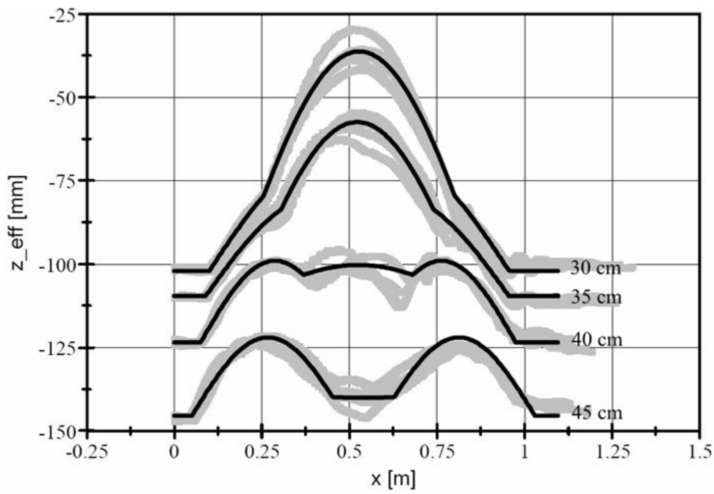

Figure 5. Enveloping curves obtained for different values of the contact length (values next to curves

In the Figure 6, zoomed area from the Figure 5 close to the origin is shown. In this figure it can be noticed that for greater value of contact length (corresponding to smaller level of radial deflection of the tyre) response curves start earlier, due to earlier contact with the obstacle. This also leads to the difference of the overall response curve length.

Conclusion that can be made on the basis of these results, corresponding to intuitive comprehension of tyre behavior, is that the effect of tyre low-pass filtering will be more pronounced for larger contact length. Therefore under such conditions amplitude response tends to decrease, while response length grows.

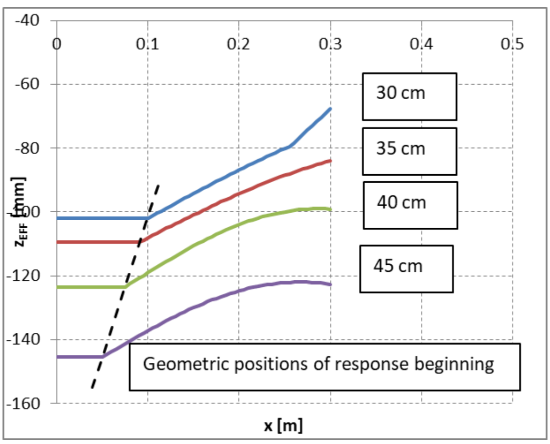

Figure 6. View of response curve beginning point (i.e. therefore overall length) change with the change of the contact length

Another view of investigation results is shown in Figure 7. In this view all response curves are shifted to the same referent ground level. For better visibility, only parts of curves left to the vertical symmetry axis are shown. This view shows properties noticed according to the previous figures, regarding main differences in tyre response for different contact lengths, more clearly.

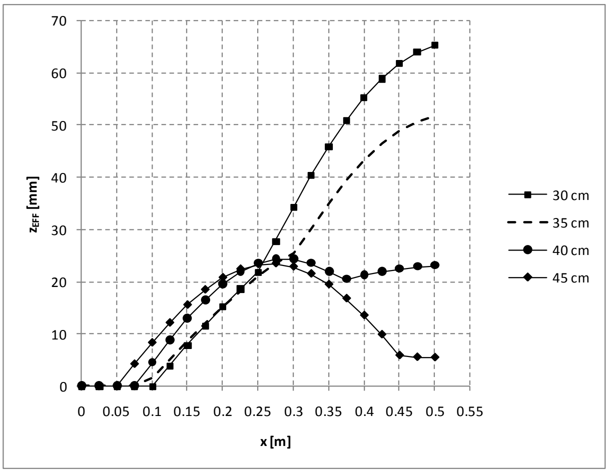

Figure 7. Response curves shifted to the same referent ground level

Finally, analysis of response curves spectral content is carried out in term of power spectral density. PSD curve of ground profile excitation is also shown for comparison. Results are shown in Figure 8. Change of response frequency content, which is indicator of filtering properties alteration, can be notified from the figure. Curves show that with increasing contact length, spectral content of the response curves decreases. It can also be seen that this change in tyre filtering behaviour is especially abrupt in transition of contact length values between 35 and 40 cm.

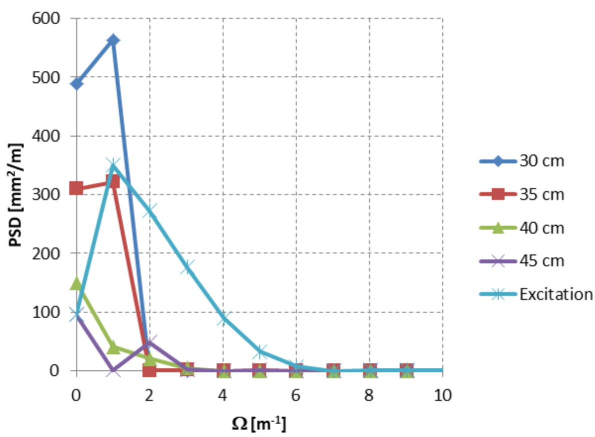

Figure 8. Spectral content of response curves and excitation

4. CONCLUSIONS

In order to quantify impact of contact length change on tyre filtering i.e. enveloping properties, measurements of tyre response curves have been made for different values of contact length. Geometric and spectral properties of response curves in different conditions were compared to each other.

Results of investigation have shown clearly that contact length change lead to significant variation of tyre enveloping behaviour, in a way that larger contact length means more pronounced low-pass filtering. Analysis of frequency content of response curves for different values of contact length, which can be regarded as the most appropriate indicator of tyre filtering properties, suggests that alteration of enveloping behaviour does not happen evenly with the change of contact length, but that it will be much more significant in certain regions of contact length gradient.

In this paper tyre contact length was mainly treated as suggested parameter of tyre enveloping model. Further task that has to be carried out within this scope is to assess level of dynamic fluctuations of tyre contact length, which is effect of deflection change due to dynamic wheel load. In that way it will be possible to conclude if it is necessary to include variable contact length into tyre enveloping model. Should it be possible to leave out this part of modelling approach, it would contribute significantly to the model simplification and therefore improvement of numerical efficiency.

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GUIDELINES FOR CERTIFICATION AND INSPECTION OF VEHICLES ON NATURAL GAS IN THE REPUBLIC OF SERBIA AND ISSUING OF CERTIFICATE

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RESEARCH ARTICLE

ABSTRACT: Natural gas and liquefied petroleum gas represent the most practical, realistic and easiest way to reduce pollution coming from road transportation. In practice, natural gas vehicles are as safe as any other vehicles (gasoline, diesel, liquefied petroleum gas, etc.) operating on the roads. However, safety incidents sometimes occur where a natural gas system, primarily storage cylinders, have failed. Recent incidents involving natural gas vehicles have shown that cylinders may explode through compliant with current UN ECE 110R regulation. In the paper are systematized regulations and technical requirements relating to the installation of devices and equipment on vehicles powered by natural gas. The main objective of the research is to present a good practice related to inspection of motor vehicles on natural gas. It was also shown the several options for the reconstruction of vehicles to drive on gas fuel, as well as logistics.

KEY WORDS: logistics, motor vehicles, natural gas, regulations

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UPUTSTVO ZA SERTIFIKACIJU I PREGLED VOZILA NA PRIRODNI GAS U REPUBLICI SRBIJI I IZDAVANJE SERTIFIKATA

REZIME: Prirodni gas i tečni naftni gas predstavljaju najpraktičniji, najrealniji i najlakši način da se smanji zagađenje koje potiče od drumskog transporta. U praksi, vozila pogonjena prirodnim gasom su sigurna kao i sva druga vozila (benzin, dizel, tečni naftni gas, itd.) koja se kreću na putevima. Međutim, bezbedonosni incidenti se ponekad dešavaju kada sistem za snabdevanje prirodnim gasom, pre svega rezervoari, otkažu. Nedavni incidenti sa vozilima sa pogonom na prirodni gas pokazali su da cilindri mogu eksplodirati iako su usklađeni sa aktuelnom regulativom UN ECE 110R. U radu su sistematizovani propisi i tehnički uslovi koji se odnose na ugradnju uređaja i opreme na vozila na prirodni gas. Glavni cilj istraživanja je predstaviti primere dobre prakse u vezi sa kontrolom motornih vozila na prirodni gas. Takođe, prikazano je nekoliko mogućnosti za rekonstrukciju vozila za pogon na gasno gorivo, kao i logistika.

KLJUČNE REČI: logistika, motorna vozila, prirodni gas, propisi

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1. INTRODUCTION

In energy plan, oil as a conventional fuel is still a very important energy resource. On the other hand, constant increase in consumption of conventional energy generating products opens the door for all potential substitutes for oil.

Natural gas is a high-quality fuel for motor vehicles. Above all, available reserves equal the known oil reserves; negative influence upon environment is less than with fuels derived from oil, as well as the price. Due to that, natural gas as a motor fuel has been having a growing application in motor vehicles, which is further proved by the fact that there are over 26 million vehicles in the world powered by natural gas (1.86 million in Europe). As an example, we could mention the city of Porto whose budget for the current year includes the funds for purchasing 173 new buses powered by natural gas. Currently, in the Republic of Serbia, there are in traffic on the roads 878 natural gas vehicles (792 passenger and light duty vehicles, 58 buses and 28 medium and heavy duty trucks) [1].

The growing number of vehicles powered by natural gas has required in parallel new regulations and rulebooks regulating this field to be adopted. Thus, environmental requirements for vehicles fueled by natural gas have been prescribed by ECE rulebooks 49 and 83; whereas the requirements related to the aspect of safety and functionality of installation of gas devices and equipment have been defined under regulations UN ECE 110R and UN ECE 115R. Laws and bylaws applicable in the Republic of Serbia for natural gas vehicles are: Road traffic safety law, Rulebook on the Classification of Motor Vehicles and Trailers and Technical Conditions for Vehicles in Road Traffic and vehicle testing rulebook on [2–6].

For the purpose of managing the process of logistic affairs, from production to periodical checks and maintenance of vehicles powered by natural gas, it is necessary to systemize the above mentioned regulations and rulebooks. That would also provide an answer to the question of how safe the vehicles powered by natural gas actually are.

2. NATURAL GAS AS FUEL FOR DRIVING AND MOBILE SYSTEMS

All gases are good fuels for Otto engines: the mixture is of high-quality and ready for full combustion, engine operation is economical, pollution is less, oil and engine life is longer etc. In terms of engine related criteria, natural gas may be used as the sole fuel for Otto or diesel engines (with certain engine reconstruction). In addition to that, it may be used in mixture with every kind of oil or proved alternative fuel (lower or higher alcohols, biogas, and other) [7].

In normal ambient conditions, natural gas has a low density of energy per unit of volume. Due to that, in case of application of natural gas as a motor fuel, it is necessary to have a certain treatment of natural gas in order to have a higher concentration of energy by unit of volume. Given that it is expected to have a wider radius of vehicle movement with one fuel tank topping, it is necessary to have operating pressures of around 200 bar which is the limit that standard bottles for technical gases may endure. The simplest way is to compress natural gas in high-pressure tanks (CNG–compressed natural gas). The second alternative for increasing the density of energy of natural gas inside tanks on vehicles is its extreme cooling down to (−162 °C), i.e. conversion to liquefied state (LNG−liquefied natural gas) and storing in cryogenic tanks.

Optimistic studies about natural gas are based on pure methane. Unfortunately, pure methane is nowhere to be found in nature. It is always in mixture with other impurities in concentration of various percentages. In order to use natural gas as fuel, it is necessary to filter it until it reaches more or less the established composition and quality. There are some national standards that regulate quality of natural gas as engine fuel: SAE J1616, DIN 51624 and 13 CCR § 2292.5 (California regulations). In parallel, there is an international standard ISO 15403, accepted also by the Republic of Serbia. The purpose of this standard is for producers, vehicle users, filling station operators and other logistics participants in the industry of (CNG) vehicles to get informed about quality of fuel for natural gas vehicles [7].

Natural gas has the following characteristics:

- It is non-toxic, non-carcinogenic, non-corrosive, however, it is suffocating, colorless and odorless due to which it is necessary to add certain odorizes and foul smells
- Natural gas is lighter than air (density of methane is 0.68 $kg \cdot m^{-3}$ at 15 °C), and when leaking it leaks upwards, whereas for example propane (1.87 $kg \cdot m^{-3}$) and butane (2.44 $kg \cdot m^{-3}$) are heavier and leak downwards
- Auto flammability temperature of (CNG) is in the scope of 480−650 °C, whereas in case of (LPG−liquefied petroleum gas) it is in the scope of 480−495 °C (methane 595 °C, propane 495 °C, butane 480 °C, gasoline 260−430 °C, whereas in diesel it is less than 260 °C)
- Flammability scope in volume percent of methane with air is 4.4–15%, in case of propane it is 2.4–9.3%, butane 1.8–8.8%, (gasoline 1.4–7.6% and diesel 0.6–7.5%)
- Natural gas is converted to liquid at ambient pressure at temperature of (−162 °C); and
- Critical point of methane is defined by temperature of (–82.7 °C), and pressure of 45.96 bar.

3. EXAMPLES OF SOLUTIONS FOR NATURAL GAS VEHICLE DESIGN

Natural gas as fuel of vehicle drive systems in road transport is applied in new vehicles with original natural gas engines or by converting existing engines so as to use gaseous fuels. In practice, there are the following options for conversion of vehicles so as to use (CNG), [8,9]:

- Modification of gasoline engines so as to use CNG (Eng. dedicated fuel)
- Modification of gasoline engines so as to use CNG or gasoline (Eng. bi−fuel)
- Modification of diesel engines so as to use CNG (Eng. dedicated), spark plug ignition and
- Conversion of diesel engines so as to have parallel function with CNG and diesel fuel (Eng. dual fuel).

The concept of vehicles with original factory produced engines designed for use of natural gas as fuel is the only one that can use all the natural advantages of this fuel [8, 9]. Modifications of old carburettor engines so as to use natural gas as fuel with use of cheap systems, such as those with injectors, do not contribute to reduction of emissions and improvement of safety, but quite the contrary, result in their increase and deterioration respectively.

Figure 1 shows the scheme of universal installation for CNG with sequential injection.

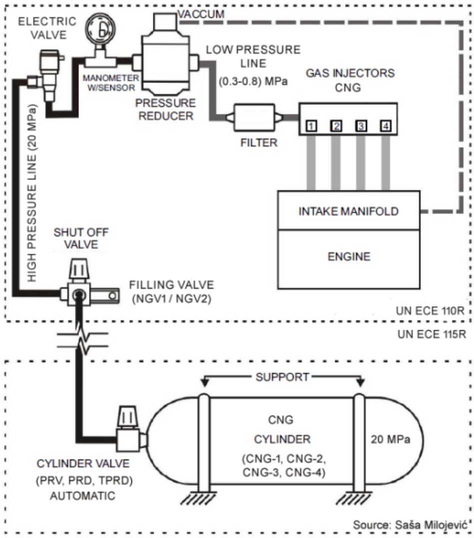


Figure 1. Parts of system for sequential injection of CNG to engine

Figure 2 shows position of the installed devices and equipment on the vehicle Volvo S80, with propulsion system on natural gas or biogas.

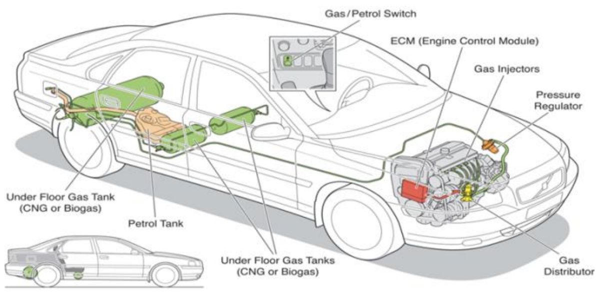


Figure 2. Bi–fuel systems (CNG or biogas) on passenger vehicle Volvo S80

Figure 3 shows parts of gas installation of a city low-floor bus on CNG. Bus propulsion system has been equipped with original, factory produced gas engine for CNG or LNG. The concept of engine that works on the principle of combustion of lean mixture meets the Euro IV regulation. With application of engines whose operation has been based on combustion of stoichiometric mixture of natural gas and air with recirculation of cooled combustion products and three-component catalyst, the reached level of toxic and hazardous combustion products from vehicle is within the limits prescribed by Euro VI [9-11].

According to author's experiences, the best option for reconstruction of existing city buses is the using of completely new propulsion system with dedicated (CNG) combustion. In the bus, need to be integrated modern automatic fire protection system [12]. Similar conditions apply if Hydrogen is used as a fuel [13].

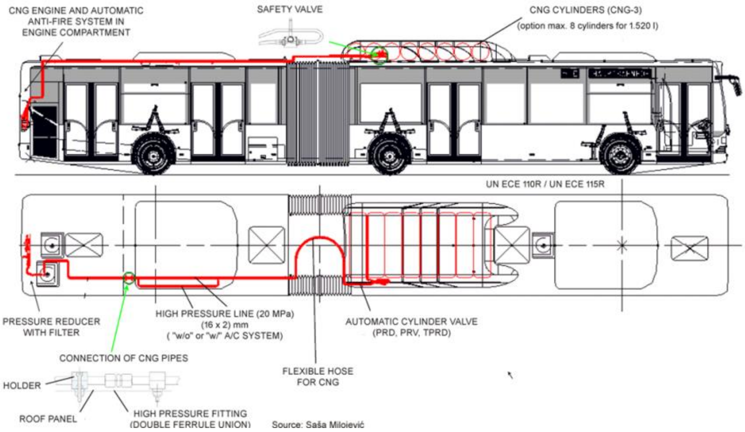


Figure 3. CNG installations on city low-floor bus

4. REGULATIONS REGULATING THE ISSUES RELATED TO VEHICLES POWERED BY NATURAL GAS

4.1 International regulations

Environmental requirements that should be met by CNG vehicles have been defined within ECE Rulebook no. 49 for freight carrying vehicles and buses, and within ECE Rulebook no. 83 for passenger vehicles.

From the aspect of safety and proper installation of gas equipment, the requirements to be met by CNG vehicles have been prescribed within two ECE regulations [5, 6]:

- UN ECE 110R – uniform homologation regulations:
  - Specific equipment of motor vehicles powered by CNG; and
  - Vehicles equipped with specific equipment for CNG in terms of installation of such equipment.
- UN ECE 115R – uniform homologation regulations:
  - Vehicles, previously homologated for basic fuel and subsequently equipped with specific equipment for LPG drive, in terms of installation of such equipment; and
  - Vehicles previously homologated for basic fuel and subsequently equipped with specific equipment for CNG drive, in terms of installation of such equipment.

4.2 National regulations

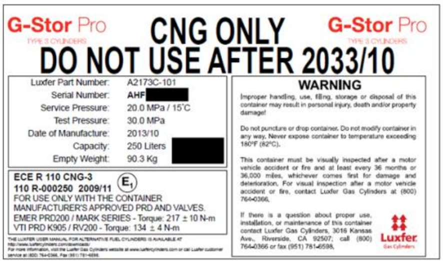
The following laws and by-laws apply to the vehicles in the Republic of Serbia [2-4]:

- Law on road traffic safety
- Rulebook on the Classification of Motor Vehicles and Trailers and Technical Conditions for Vehicles in Road Traffic and
- Vehicle testing regulations.

5. TECHNICAL REQUIREMENTS FOR INSTALLATION OF DEVICES AND EQUIPMENT OF NATURAL GAS VEHICLES

Cylinders for CNG must have the following data permanently inscribed in accordance with provisions of Rulebook UN ECE 110R, Figure 4:

- Name of manufacturer
- Factory number
- Month and year of production (inspection)
- Volume of empty cylinder in liters (l)
- Max. allowable pressure of cylinder filling (MPa/bar)
- Mark of gas to fill the cylinder – "CNG ONLY" and
- Imprint of cylinder expiry date – "DO NOT USE AFTER XX/XXXX" where XX/XXXX indicates the month and year.



a) b)

Figure 4. a) Cylinder identification and labels; b) Photography of sticker for CNG cylinder

The cylinders must be fitted to the basic vehicle structure according to the instructions of the manufacturer, i.e. technical requirements and must not be in direct contact with other metal parts, except in case of cylinders with special supports designed to be fitted to the metal structure. The technical requirements for cylinder fitting according to ECE Rulebook no. 115 annex 5 point 1.3 are listed in the table below 1 [6]:

Table 1. Technical requirements for cylinder fitting

Tank volume, l	Minimum dimensions of washers, mm	Minimum dimensions of fixing metal straps, mm	Minimum dimensions of screws, mm
Up to 85	30x1.5 or 25x2,5	20x3 or 30x1.5	8
85 – 100	30x1,5 or 25x2.5	30x3 or 20x3*	10 or 8*
100 – 150	50x2 or 30x3	50x6 or 50x3**	12 or 10**

Cylindrical tanks are fixed with at least to insulated straps, except in the following cases:

- in this case, three straps are necessary for fixing and
- in this case four straps are necessary for fixing.

In case of cylinders installed below the vehicle floor, the cylinder must be fixed with at least three suitable straps. The screws used must be at least in the class 8.8.

As for the cylinders of volume over 150 l, it applies that the requirements of UN ECE 110R must be met. Rulebook UN ECE 110R prescribes that (CNG) cylinders must be fixed in appropriate way, so that they can (when full) endure deceleration in the moving direction of vehicle and in direction perpendicular to vehicle moving direction, depending on the vehicle category, as per Table 2. It also requires a certain resistance (absence of any deformation) of cylinder supports and also of the part of vehicle structure to which the cylinders have been fixed, which could also be proven by the following calculation [5, 10].

Table 2. Prescribed deceleration as per UN ECE 110R

CATEGORY OF VEHICLES	M1 or N1	M2 or N2	M3 or N3
Deceleration – in vehicle moving direction	20·g	10·g	6.6·g
Acceleration – in horizontal plane, perpendicular to vehicle moving direction	8·g		5·g

According to UN ECE 110R, the cylinder for (CNG) must be approved and equipped with the following components at the least which could be separate or combined [5]:

- Hand valve
- Automatic valve of cylinder
- Pressure relief device (PRD) or temperature activated pressure relief device (TPRD) and
- Excess flow valve (EFV).

The cylinder and valves may also be equipped with gas-tight housing with ventilation, if necessary. It is necessary to protect them from direct sun rays.

High-pressure gas pipes must not be soldered nor welded and instead have to be joined by fixing elements made of steel. High-pressure gas pipelines must be laid so as not to vibrate, not to have friction among parts especially in places where the pipes go through openings. The distance between two places of fixing, in case of high-pressure gas pipes below vehicles, may be at most 500 mm, whereas radiuses of pipe bending must be adjusted to material and dimensions of pipes.

Gas pipelines are installed in the driver and passenger's compartment, including the trunk, only if protected in a special way (impermeable housings, pipe-in-pipe etc.) provided that the protection must be resistant to mechanical damage, and its openings must be located on the external side of vehicles for ventilation purposes.

Before being connecting to the device (gas valve, pressure reducer, filter, manometer and other), gas pipe must have a compensation coil that enables expansion. The high-pressure gas pipelines must not have visible damage and the pipes that have fractures or have undergone mechanical damage due to corrosion process and other must be replaced immediately.

Low-pressure gas pipelines connecting the pressure reducer with device generating the mixture of fuel and air for engine must not be in contact with warmed up parts of exhaust system, i.e. with engine, but only with device for fuel supply to engine. Rubber lines must not be damaged nor cracked. Low-pressure gas lines are joined by collars. The junctures must be impermeable, collars must be self-blocking, and so there could be no uncontrolled loosening of joints.

Gas pressure reducer is bracket fixed on the interior part of car body, outside of driver and passenger's compartment, including the trunk and it must not be fixed to the parts of vehicle that get warmed up and must be distanced in a proper way from the parts of exhaust system and vehicle engine.

6. INSPECTION OF VEHICLES WITH INSTALLED DEVICES AND EQUIPMENT FOR NATURAL GAS POWERED VEHICLES

6.1 Necessary checks

Checking the compliance of devices and equipment with the approval type

Devices and equipment installed in the vehicles fueled by (CNG) must be type approved (homologated) according to UN ECE 110R, which is to be determined during this check-up.

Checking if meeting the requirements related to compliance of devices and equipment with the manner of combustable mixture preparation and technical implementation of installation

Checking if meeting the requirements related to compliance of devices and equipment with the manner of combustible mixture preparation

Devices and equipment must be installed in compliance with the instruction manual for installation made by the manufacturer of devices and equipment for natural gas vehicles, and if there is no such instruction; the minimum requirements of compliance are as follows:

- Devices and equipment with vacuum regulation system could be applied only in intake carburetor engines and
- Engines with a plastic intake manifold and engines with multi point injection system (MPI) in vehicles produced after January 1st 2001 must have equipment with sequential injection of gas.

Checking if meeting the requirements in terms of technical implementation of installation

Devices and equipment of natural gas vehicles must be installed so as to be within limits of vehicles overall dimensions, not to reduce possibility, to be protected from mechanical damage that may occur in exploitation, and to be accessible for the purpose of checking their functionality and impermeability, and checking their identification marks. At the same time, it is mandatory that installation requirements have been met, as defined under regulation UN ECE 110R, which is to be determined during this inspection.

The following is to be checked:

- Meeting of requirements for installation of cylinder and its equipment
- Meeting of requirements for gas lines (high-pressure and low-pressure lines)
- Meeting of requirements for gas pressure reducer and
- Meeting of requirements for other devices (valves, fuel fill connector, manometers and pressure indicators, electrical installations, gas dosing devices etc.).

Inspection of tightness of gas installation is done by using a detector sensitive to methane, where each leak of gas to atmosphere is the reason for making a conclusion that the vehicle is not safe for further exploitation.

Inspection of vehicle mass

Installation of devices and equipment for natural gas fuels changes the vehicle mass, thus requiring during inspection to determine the mass of vehicle with installed device and equipment. Vehicle mass may be determined by calculation if you have available information about exact mass of basic vehicle, mass of installed device and equipment and mass of gas with tank filled by maximum allowed operating pressure in the tank. If the authorized organization, having checked the relevant technical documentation or in any other way, has any doubt about accuracy of these data, the mass must be measured. The calculation, i.e. data on grounds of which the mass of modified vehicle has been determined, must be indicated in the report on testing/inspection of vehicle. In case of testing a freight vehicle for the purpose of determining the value of increased mass of vehicle ready for driving, it is necessary to reduce the load bearing capacity of vehicle. In case of buses, if necessary, the total number of places for standing and seated passengers should be determined by calculation. For that purpose, depending on the bus body form, you should use the instructions defined by regulations UN ECE 36R and UN ECE 52R.

6.2 Periodical inspection

Cylinders are designed and manufactured for a limited design life, which is indicated on the cylinder label. Always check the label first to ensure that the cylinder has not exceeded its expiration date.

Regulation UN ECE 110R prescribes the time schedule of periodical inspections of CNG cylinders every 48 months, from starting the servicing. In doing so, it is visually checked if there are mechanical, abrasive or chemical damages. This regulation recommends checking during technical inspection if there is a gas leak [5].

In the Republic of Serbia, periodical inspections of vehicles with CNG devices and equipment are done every four years.

Periodical inspection of CNG cylinders

Inspection of CNG cylinders is done in accordance with procedure defined by standard ISO 19078, and/or in accordance with the national standards of the state in which the vehicle and CNG equipment have been exploited. If using during a cylinder periodical inspection the hydraulic pressure test, it is mandatory to use specially treated water (with inhibitors, without chlorine etc.). Also, it is recommended to have the cylinders exposed to inspection as little as possible in terms of time, and never to have the cylinders with regular water (but to treated water instead). The reason for that is in the corrosive effect of water to material out of which the cylinders are made (mostly aluminium alloy).

Periodical inspections are a safety measure for timely detection of damages of cylinders and cylinder supports. Inspections must be conducted with use of special tools (measuring tools for measuring length and debt of cracks, battery lamps and other). There are two types of inspections: general inspection and, as already indicated in the previous section, inspection by an authorized organization in which case there is also a suitable certificate issued, Table 3.

Table 3. Overview of procedures for periodical inspections of CNG cylinders and equipment

TYPE OF INSPECTION	DESCRIPTION OF INSPECTION	PERIOD
General inspection	Inspection is conducted by a driver, a mechanic or a technician working in a workshop. It includes visual inspection of condition of cylinder and its supports, as well as of pipelines for the purpose of determining if they are in good condition and properly fixed.	Recommended to have it every three months (recommendation of manufacturers of CNG cylinders and equipment)
Inspection by authorized institutions and issuing of Certificates (Certificate and /or attestation of correct installation of CNG device and equipment)	Inspection is conducted by a professional/expert with authorization of the relevant institution.	Every four years from starting its service life in accordance with the national regulations.

6.3 Marking of CNG fueled vehicles

The vehicles of M2 and M3 class fueled by (CNG) must have stickers as a visible indication that they use this type of natural gas fuel. The form and dimension of stickers have been defined by standard UN ECE 110R. Stickers are to be place in the front, rear and on the door exterior on the right side of vehicle.

7. SAFETY MEASURES DURING CHECK□UP AND TECHNICAL INSPECTION OF CNG VEHICLES

Flammability limits of fuel and air mixture are often called explosiveness limits so as to warn about severity of possible incidents. Below the flammability limits, the mixture is too lean and over it too rich for combustion. The flammability limits are often called lower and upper limit of flammability/explosiveness.

Gas leaking from the system installed on a vehicle during the check-up and technical inspection of vehicle may create an explosive mixture in work environment due to which it is necessary to provide the following:

- Take the measures for the purpose of prevention of gas leaking from vehicle system,
- Keep the flame sources far from the place where there is a chance of forming a flammable mixture,
- Surface of heating elements inside the facility must not have the temperature over 400 °C, it is forbidden to use open flame, electrical or gas heaters; and
- It is necessary to adopt and regularly practice the measures of safety at work and fire protection of facilities, as well as professional training of staff, etc.

Given that in case of leaking from vehicle system, (CNG) leaks upwards it should be observed that explosive mixture is created in upper zones of the room. On the other hand, the position of the area with explosive concentration highly depends on the type of the roof structure of facility. In case of no flat roof, the increased concentration is usually in the highest parts). The position of setting the probes of gas automatic detection and alarm system also depends on the type of roof structure.

On grounds of applicable U.S. regulations for example ventilation systems in workshops for maintenance of CNG buses should enable 5–6 air changes per hour in the room. Also, it requires the air change dynamics of 425 $l \cdot min^{-1}$ per $1 \cdot m^2$ for the ventilated areas. Given that the requirements for workshops are similar in case of diesel buses (must have ventilation system with 4–6 air changes per hour), it is conclusive that it is not necessary to change the ventilation system, in case of adaptation of existing facility so as to be used to work with CNG vehicles as well, thus there are no additional costs of maintenance. The relevant regulations also recommend to equip such facilities with so called roller doors that open faster than the standard ones so that in case of accidental gas leak it enables additional ventilation of facility in a natural way [14].

Electric equipment of facility for servicing CNG vehicles, such as switches, sockets, lighting devices, motors, should have a certain degree of explosion protection.

Contrary to the previously given instructions, e.g. when doing the LPG vehicle check-up and technical inspection, the facilities should be provided with as good as possible ventilation in the floor area of facility, especially in the zones where pits for repair or inspection of vehicles are, etc.

In general, the basic warnings which apply in cases of gas leakage accidents from vehicles and basic requirements and safety measures for facility are briefly listed in the Table 4 below.

Table 4. Warnings in case of gas leakage and preventive measures

TYPE OF GAS – FUEL	CNG	LPG
Warnings in case of gas leakage	Gas concentration is up!!	Gas concentration is down!!
Basic requirements and preventive safety measures for facility	Good ventilation of ceiling-roof zone Elimination of flame source above vehicle Staff safety training for working with CNG vehicles	Good ventilation of floor-pit zone Elimination of flame source near floor Staff safety training for working with LPG vehicles

7.1 General conditions and recommendations for working with cylinders and equipment for CNG

When handling the cylinders and equipment on vehicles fueled by CNG it is necessary to adhere to the following measures and instructions for the purpose of improving safety.

1. Ensure that all mounting blocks, brackets and other components are in good condition and properly secured. If any mountings are loose, re-tightened them by procedures specified by the fuel system manufacturer. If a mounting is damaged, need to be conducting a re-certification inspection.

2. Use suitable tools:

- Use the tool recommended by manufacturer, if possible and
- Provide the relevant technical documentation of manufacturer before intervention.

3. Fuel system inspection includes checking all attached components, such as valves, tubing, end plugs, fittings and pressure-relief devices. During inspection, make sure that each device is securely attached. If any is loose, tighten it in accordance with the fuel system manufacturer's instructions:

- Only trained staff may repair and inspect the cylinders and equipment for CNG and
- It is necessary to be familiar with functionality of parts of system for CNG on vehicles.

4. Eliminate potential flame sources:

- No open flame or other heat sources and
- Disconnect electrical supply on vehicle; provide good grounding of facility for the purpose of preventing sparks and similar.

5. Never forget that parts of CNG system are under pressure:

- Loosen the joints slowly due to discharge of gas under pressure, it is mandatory to tighten the joints with suitable torques according to recommendation of manufacturer (the torques are not the same for nuts when tightening the pipeline for the first time and in case when tightening the joint that was previously loosened).

6. Precautionary measures for potentially flammable mixture of natural gas and air:

- Natural gas is flammable in air when the concentration is 4,4–15%,
- It is forbidden to have service interventions, storing and transport of cylinders and equipment with potentially flammable mixture. Discharging of gas from cylinder is to be done according to instructions and technical documentation of manufacturer through a special connector; and

It is forbidden to connect to electric voltage any parts of device and equipment for CNG in which there is a potentially flammable mixture.

8. CONCLUSIONS

The issue that primarily refers to emission of particles resulted in reduced use of diesel buses and freight vehicles in downtown zones of cities in developed countries. It brought about intensive substituting of vehicles of public utility companies with vehicles powered by natural gas. As a consequence, there are over 26 million vehicles fueled by natural gas in the world today.

The growth of the number of vehicles fueled by natural gas has been followed in parallel by adopting new Regulations and Rulebooks regulating the issues in this field. From the aspect of safety and proper installation of natural gas equipment, the requirements to be met by vehicles fueled by CNG have been prescribed by two regulations: UN ECE 110R and UN ECE 115R. Thus, devices and equipment for vehicles fueled by gas must be installed in vehicles in accordance with requirements of applicable national and international regulations.

International and national regulations foresee periodical inspections of devices and equipment for vehicles fueled by natural gas. In the Republic of Serbia, there is a control check prescribed for the vehicles fueled by CNG that has to be conducted by an authorized institution every four years followed by a certificate being issued.

During checkups, technical inspections and servicing of CNG vehicles, the facilities should be provided with better ventilation in the zone of ceiling and roof, and it is mandatory to adhere to measures of safety at work for staff and fire protection for facilities.

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